Situation Awareness in equestrian polo: insights into experience, methods, and training

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Abstract

The equestrian sport of polo has been played for almost 2500 years and is characterised by high speeds, physicality, and visuo-cognitive complexities similar to team ball sports and driving. Given its dynamic characteristics, it is an ideal sport to investigate Situation Awareness (SA) and the cognitive skills that underly it. The aims of the thesis were to investigate the objective methods of SA assessment in polo, explore the role of experience in SA skills and the potential transfer of SA across sports, to explore some of the components behind SA skill, and to investigate a polo SA training for those with no experience in the sport. The first phase of the thesis investigated the validity of a static image 'Spot the Ball' (STB) Level I SA (perception) assessment tool for polo and soccer, explored the role of visual cues on perception in sports, and investigated if perceptual skills could transfer between similar sports. It was found that the STB tool discriminated sports experience, and that gaze cueing was a strong predictor of perception performance. No transfer effects were evident between polo and soccer. The second phase investigated the validity of a dynamic 'What Happens Next?' (WHN) SA assessment tool and the role of situational context on anticipation. An interaction effect of sport experience by type of situation presented in the video clips showed discrimination of sports experience (those with some polo playing experience) when provided with situational context about the plays, and it was found that polo players benefitted more than controls (those with no polo or sport experience) from additional situational context during the task. Lastly, the third phase developed two programmes aimed at training polo SA in participants with no polo experience. The WHN tool was used as a SA assessment and eye movements were used a measure of attentional allocation. The training programmes showed no evidence of improving polo SA, and eye movement behaviours indicated that novices primarily fixated on the ball and did not conduct wider searches indicative of higher order cognition, suggesting SA training

may need a more scaffolded approach. The results of the thesis provide insights into equestrian polo SA, how sports experience drives SA, the validity of SA methodologies, and the practicality of training SA. It also furthers the understanding of SA within general sports settings, which is currently lacking.

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Preface

The sport of polo has been around for almost 2500 years (Chehabi & Guttman, 2010; Watson, 1989), and many sports can trace their roots to the ancient game (Dale, 2015). However, in a modern context, the sport is still shoehorned into an elitist box (Gilbert & Gillett, 2013) despite valiant efforts in recruiting new members (Oliver et al., 2017). Today, polo is played by a fraction of those who play other sports, such as soccer (Darroux, 2016), and it is neither an Olympic sport nor a sport heavily televised, which understandably is not conducive towards improving its exposure on a global scale. One drawback potentially stemming from such small participant numbers and minimal exposure is the lack of academic research into the world of polo. Compared to the numerous studies sanctioned for sports such as soccer, basketball, and hockey in areas such as psychology, biomechanics, and so forth, equestrian polo studies are few and far between. The polo studies that do appear in a targeted search predominately pertain to injury epidemiology (for both humans and horses) (Clark et al., 2002, Costa-Paz et al., 1999, Desta et al., 2011, Granville-Chapman, 2020; Inness & Morgan, 2015a, 2015b; Milne, 2011; Pfau et al., 2016; Winge & Phadke, 1996; Wollenman et al., 2003), biomechanics (Brittain & Oliver, 2018; Oliver, 2017, 2018a, 2018b, 2019), and physiological performance characteristics (for both humans and horses) (Araujo et al., 2014; Bello et al., 2012; Best, 2020; Best & Standing, 2019a, 2019b, 2019c, 2019d; Craig et al., 1985; Dale et al., 2017; Ferraz et al., 2010; Giraudet, 2011; Gondin et al., 2013; Marlin & Allen, 1999; Noleto et al., 2016; Pritchard et al., 2017; Standing & Best, 2019; Williams & Fiander, 2014; Wright & Peters, 2008; Zobba et al., 2011). Importantly, there is no research at the time of this writing that delves into the psychological and cognitive skills that are necessary to play the sport.

So how does the research presented in this thesis ultimately benefit the sport of polo, its exposure, its players, and its ponies? The short answer is that it provides the first set of laboratory studies investigating the SA of polo players and how to train such skills. Laboratory studies are important in the first stages of research, particularly in the realm of cognitive psychology where it is often difficult to isolate and study one singular skill (for instance, anticipation) out in 'the real world', so that skill must instead be isolated in a laboratory setting (Foulsham et al., 2011). The studies in this thesis provide a base or 'backbone' for other polo cognitive skills studies—even perhaps *in situ* studies—to build upon. Additionally, the methods presented in this thesis are easily replicable (the STB and WHN tasks, but not so much the eye movements which require expensive laboratory equipment) and can be implemented almost anywhere with computer access. Polo clubs, coaches, players, and umpires may take advantage of these methods—especially the WHN task—to test or potentially improve SA in a real-world setting, such as during strategy sessions—colloquially known as 'chalk-talks' in the industry—where teams and coaches discuss strategies for an upcoming game/tournament, go over set plays, and identify strengths and weaknesses of the team and their opponents. The USPA, HPA, and many individual polo clubs already require players to pass a rules test before they may obtain a handicap and play in sanctioned events, such as tournaments ("HPA Rules & Regulations for Polo 2019," 2019; USPA, 2020), much like drivers must pass a road rules test, a vehicle operation test (Curry et al., 2013; Watson-Brown et al., 2020), and in some places, a Hazard Perception test (Crundall, 2016) before they are granted a license. In both situations, this is to ensure that the sport (or road) is kept as safe as possible. It is, therefore, not a far-fetched idea to begin incorporating WHN exercises into the USPA and HPA rules test to assess the SA abilities of polo players, particularly those new to sport.

A quick note about the impact of Covid-19 on the completion of this thesis

The announcement of nation-wide Covid-19 social-distancing measures in the UK, including the national lockdown, were announced soon after this project was approved. Polo clubs across the country closed under directions of the UK government and the Hurlingham Polo Association (HPA). At the time, there were huge uncertainties regarding reopening due to inconsistent government advice (indeed, sports clubs ultimately did not re-open until late summer of 2020). Therefore, there was no way of filming live sporting events and no access to the planned sample of polo players to measure their sporting behaviours. It was clear that this project would need to be redeveloped in its entirety. As such, and given that national Covid-19 measures came into effect at around the same time as project approval, the initial and typical months (~5 months) spent on project generation and approval procedures were lost. From April 2020, a new PhD programme, including contingency plans, was generated. The first contingency plan was to ensure this PhD programme would be able to be conducted online. The second was to acquire pre-filmed appropriate polo-stimuli from a professional video company. During the waiting period for a second project approval, polo stimuli was curated using open-source online photography websites (static images; Chapter 3: Studies 1.1 and 1.2) and a renowned polo video company, Global Polo TV (dynamic video; Chapter 4: Studies 2.1 and 2.2, Chapter 5: Study 3). The stimuli were then edited and inserted into online studies, which are discussed more in-depth below and in their respective experimental chapters.

Chapter 1 General Literature Review

This chapter will provide an overall review of the literature surrounding the topics of equestrian polo and Situation Awareness. It will first describe the sport of polo and the concept of field awareness when playing. The polo-specific concept of field awareness will then be related to the more general Situation Awareness (SA). The literature of SA within sporting contexts will be reviewed. The types of SA frameworks used in sports will be described, followed by the direct methods of assessing SA in sports, and lastly ending with the cognitive skills directly associated with SA in sports. This chapter will also outline the thesis with brief explanations of the three distinct phases and their individual aims and rationales. Much of this chapter has been published, although not verbatim, under the citation:

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1.1 Introduction

Polo is a team equestrian sport dating back around 2500 years to ancient Persia as a cavalry training exercise (Price & Kauffman, 1989). Today, it is a modern sport in which two teams on horseback compete to score the most goals by hitting a small ball into a goal. It is an open-style strategic sport with elements similar to soccer and ice hockey (Dale, 2015) and is played either outdoors or in an arena. Outdoor (grass) polo is played on the largest pitch in sports measuring 300 by 200 yards with teams of four (Price & Kauffman, 1989). Meanwhile, arena polo is played in an enclosed arena of 100 by 50 yards with teams of three ("HPA Rules & Regulations for Polo 2019," 2019; USPA, 2020). For the purpose of this thesis, only the outdoor version of the game will be discussed as this is the most commonly played version (Darroux, 2016).

Today, polo is played by over 24,000 people in 1100 clubs in over 90 countries worldwide (Darroux, 2016). The "Big Three" countries in polo are Argentina, the United States, and the United Kingdom and make up 58.6% of players and 55.3% of clubs (Darroux, 2016). While these numbers are small compared to participation in other sports—soccer, for instance, has approximately 265 million players across the globe (Kruschewsky, 2014), the sport of polo is growing. From 2008 – 2018, the United States Polo Association (USPA) saw an increase in players by 44% (Oliver et al., 2017). This increase is largely attributed to clubs extending membership to people of varying ages and socio-economic backgrounds. Women, who until the early 1900s were traditionally neglected on the polo scene, have now become some of the most passionate participants today (Gilbert & Gillett, 2013). Children are also being encouraged to pick up the sport, and there are several high-profile tournaments (*e.g.*, the National Youth Tournament Series in the United States) specifically for children and teens (Oliver et al., 2017). Lastly, schools and universities have provided young adults with the opportunity to play polo. The popularity of school programs such as the Intercollegiate/Interscholastic (I/I) teams in the United States and the Schools and University Polo Association (SUPA) in Great Britain has skyrocketed in the last decade (Oliver et al., 2017).

New participants allow the sport to continue to grow and thrive. However, new players require a safe and effective way of learning the game. Polo is a dangerous game that combines the inherent risks of general equestrian activities with a full-contact ball sport. The rules of the game—designed to protect the safety of the players and ponies—can also be confusing to beginners. Innocent deviation from the rules and the flow of the game can easily place players in dangerous situations and risk injury to themselves and others (Goodspeed, 2005). Therefore, it is important to study polo and disseminate important information to participants to keep the players and ponies safe. Polo is not as widely studied as other equestrian sports such as racing, show jumping, dressage, and cross-country eventing. Of the academic studies published, a majority pertain to the physiological demands of the ponies (Araujo et al., 2014; Ferraz et al., 2010; Gondin et al., 2013; Marlin & Allen, 1999; Noleto et al., 2016; Williams & Fiander, 2014; Zobba et al., 2011), while only a few examine the sport from a player's perspective (Costa-Paz et al., 1999; Inness & Morgan, 2015a; Wright & Peters, 2008). With the increasing popularity (Oliver et al., 2017), there is a need for polo participants to have access to peer-reviewed information about all facets of the sport, from the physiological demands to the psychological skills needed for successful performance. One such area that should be considered within polo research is providing information and learning opportunities for new players off the horse. New players are particularly vulnerable to injuries and accidents when learning the sport (Inness & Morgan, 2015a), thus it would be beneficial to introduce new players to rules, techniques, and strategies in a safe environment off a horse. Academic researchers should therefore widen the scope of information available by conducting research in similar manners and methods as other sports. This section will briefly describe the academic literature of polo while also making a case for incorporating Situation Awareness (SA) into the game for performance and safety.

1.2 The rules of polo, performance characteristics, inherent risks, and the case for incorporating cognitive skills into play

To fully understand why SA, knowing what is going on in an environment and anticipating the future state of the environment, is needed in polo, the gameplay must be described. The two main rules of polo are the Line of the Ball (LOB) and the Right of Way (ROW). The LOB and ROW dictate the overall flow of the game and provide guidance on who can make a play on the ball without endangering other players (Goodspeed, 2005). The LOB is created when a player hits the ball or the ball redirects off the boards or another horse. An invisible "line" extends from the ball and acts as a lane divider that is constantly changing (Goodspeed, 2005; Grace, 1991). Players may not cross over the LOB unless there is ample room to do so without interfering with another player's trajectory. Crossing the LOB is one of the most common fouls called during the game, and for good reason. When a player crosses the LOB, he risks unintended collisions with other players which can cause accidents, falls, and injuries (Goodspeed, 2005). The ROW determines which player has precedence when hitting the ball, and it constantly changes with the LOB (Grace, 1991). Unfortunately, many players fall into the trap of thinking that just because they see the ball, they can hit the ball. Often, the LOB changes with a hit or redirection, and the last person to hit the ball no longer has the ROW. Players that violate the ROW can impede the flow of the game and create dangerous situations for the players and ponies (Goodspeed, 2005). The LOB and ROW require players to be continuously alert and forward-thinking; players must remember where the ball was hit from, who hit the ball last, where the ball is going, and who has the legal hit (Goodspeed, 2005). For this reason, polo is just as much—if not more—mental than physical.

Physically, polo is a dangerous sport for a multitude of reasons, but notably because it is an equestrian sport played at high speeds with full contact. It is widely accepted that equestrian sports in general (*e.g.,* racing, show jumping, dressage, cross-country eventing, and even hacking) come with inherent risks to participants, as evidenced by numerous injury epidemiological studies (Carmichael et al., 2014; Davidson et al., 2015; Jauch et al., 2015; Meyers & Sterling, 2000; Milne, 2011; Papachristos et al., 2014; Zuckerman et al., 2015). Interestingly, equestrian sports are more dangerous than motorcycle riding (Davidson et al., 2015), with motorcyclists presenting a serious accident rate of 1 per 7000 hours of riding (Silver, 2002). In comparison, equestrians experience a serious injury rate of 1 per 350 hours of activity (Milne, 2011). Notably, polo is one of the more dangerous equestrian sports due to the high speeds and physicality it is played at, along with its frequent changes in speed and direction (Inness & Morgan, 2015a, 2015b; Milne, 2011; van Tuyl et al., 1943). During a high-level (termed 'high-goal') game, the ponies can reach speeds of up to 40 miles per hour and the hard plastic ball can travel up to 100 miles per hour (Price & Kauffman, 1989), thus characterising the outdoor game as fast-paced and high-intensity. Therefore, polo players must endure the risks associated with general equestrian activities plus the dangers associated with a traditional ball sport. Polo also includes horse-to-horse and rider-to-rider contact, often at high speeds (Milne, 2011), which can be dangerous. The sheer forces from collisions are enough to cause deep bruising and more severe wounds in some cases. Severe injuries can occur due to falls, broken equipment (saddles or stirrups), collisions, and hits from mallets and/or balls (Costa-Paz et al., 1999).

As mentioned previously, polo players must rely on their mental processes as well as physical abilities to perform at their best. Cognitive skills such as visual search behaviours, anticipation, and decision-making have been argued as an important factor in athlete's performances (Hadlow et al., 2018), and experience/expertise has been identified as a predictor of such skills. For instance, Abernethy et al. (1990) showed in a seminal piece that expert squash players extracted and processed information from early visual cues more accurately than novice players. Similarly, elite athletes have been shown to search their surroundings more efficiently using fewer fixations of longer duration in interceptive sports like tennis (Murray & Hunfalvay, 2017) and employ frequent scanning in open-style sports like soccer (Jordet et al., 2020), thus suggesting that visual behaviours are linked to skill level and style of play. Research has also shown that expert athletes make quicker and better decisions than near-experts and non-expert athletes (Raab & Johnson, 2007), and elite athletes are better able to anticipate the moves of their opponents (Wu et al., 2013) which allows them to make better decisions on how to invade or intercept their opponents. Owing to the nature of the sport, polo players likely require cognitive skills similar to other athletes; polo is, after all, described as "hockey on horseback" (Price & Kauffman, 1989).

Polo players' cognitive skills and visual behaviours have not been studied extensively (if, at all) at the time of writing this thesis. However, visual cognitive skills have been explored in other equestrian disciplines, such as show jumping (Hall et al., 2009, 2014; Laurent et al., 1989). Hall et al. (2009) examined the relationship between visual memory and show jumping experience with the aim of providing evidence that more experienced riders display better visual memory towards appropriate areas of the jump upon approach, thus improving the success rate of their course (fewer faults in a shorter amount of time). Photographs of show jumps of varying heights (*Range* = 0 – 110cm; *M* = 61.82cm) were taken by an experimenter on horseback as they would approach the jump. An expert competitive rider pre-selected two points of focus. Focus 1 was the relevant point of focus when riding towards the fence (central portions of the fence) and Focus 2 was an irrelevant alternative (taken from anywhere within the scene). Riders of varying levels (non-rider, novice rider, intermediate rider, advanced rider) were shown a series of images of fences (jump cross-rails and wings) commonly seen in a show jumping course. A multiple-choice test was developed that showed four similar sections (one of which was from the original photograph). Twenty-two photographs (11 Focus 1 and 11 Focus 2) were shown to participants. Each photograph was shown for four seconds, and then participants completed a multiple-choice visual-recall test associated with the image they had just seen. The test images were split into four sections (labelled A, B, C, and D), where one section was from the previous image (either Focus 1 or Focus 2) while the other sections were from different, yet similar, images. Each test image was presented for 10 seconds, and participants were asked to identify the section that was from the previous image. The visual-recall memory test was scored as a total of correct responses and whether those responses related to Focus 1 or Focus 2. While the rider expertise did not affect the overall performance in the visual memory task, expert riders were more accurate in identifying the relevant images (Focus 1) when compared to lower-skilled riders. Hall et al. (2009) also found a positive correlation between rider expertise and number of correct Focus 1 questions. The authors concluded that the level of expertise in show jumpers influenced their visual recall in a simulated task. Show jumpers, when approaching a fence, display visual skills that direct them to the point of the fence that allows them to clear it successfully (Laurent et al., 1989). Lastly, the authors suggested that visual perception and memory skills of show jumpers may be important to ridden performance, and training such skills could potentially improve performance and reduce accidents attributed to rider error (Hall et al., 2009). Ultimately, this study demonstrates that cognitive skills are important in equestrian sports and serves as a rationale for conducting experiments related to the cognitive skills—and SA—of equestrian polo players.

Eye tracking technology has been used to assess visual search behaviours in equestrian sports. Hall et al. (2014) recorded the gaze behaviour of 10 female competitive show jumpers with the aim of measuring the position of gaze (POG) and fixation timing, frequency, and durations as the riders approached a jump. Each rider performed a short course of 3 fences 0.725m in height and 4m across. A mobile eye tracker recorded the rider's POG every 33.33ms. The location of the POG was recorded as jump, ground, other, or no eye. The authors reported the POG was located on the jump 0 – 63.89% (mean 19.78 +/- 12.69%) during the overall approach, and slightly higher during the last 5 strides of the approach (0 – 77.07%; mean 23.29 +/- 16.02%). There was no correlation between the rider level and the percentage of time the POG was located on the jump, ground, or other. However, the riders spent approximately 40% of the time fixating on the ground, potentially scanning for an appropriate take-off point. Additionally, more frequent fixations of the jump during the approach led to an earlier fixation during take-off. This study suggested that there are several factors that influence the gaze behaviours of riders as they approach a jump. Riders must direct their gaze for planning on how to successfully clear the jump. Rider error can cause knocked rails (faults) or refusals, thus affecting the rider's overall performance (time and scoring). The authors concluded that visual skills in equestrian sports are similar to those found in other sports, and that there may be a relationship between expertise and visual skills (Hall et al., 2014).

The identification and assessment of cognitive skills in other equestrian sports is important because it provides evidence that equestrian performance requires both physical and cognitive skills, just as in other sports. Additionally, it may be possible to train those skills in equestrian athletes in manners similar to other sports athletes. However, to date, there have been no studies on the cognitive requirements of polo players, despite the sport being similar in nature to open, strategic sports such as soccer and ice hockey. With the high physical demand and risk levels associated with polo (Costa-Paz et al., 1999; Inness & Morgan, 2015a), it is surprising that the cognitive skills of players have not been identified. Thus, this thesis aims to begin the investigation into the cognitive skills, in particular Situation Awareness (SA), of polo players.

1.2.1 Field Awareness in polo: a framework for equestrian polo performance.

Polo players and coaches have created a polo-specific cognitive approach to safety and performance, known as field awareness (FA); this approach aims to understand the role of perception, anticipation, and decision-making in the prevention of accidents. FA has been defined as "…the knowledge of the positioning of the players and umpires, along with the current line of the ball and associated right-of-way to the line" (Goodspeed, 2005, para 1). The associated right-of-way (ROW) has three dimensions: the current line of the ball (LOB), the previous LOB, and the future LOB. Field Awareness (FA) is undoubtedly one of the most important components to a player's safety (Goodspeed, 2005), and a fundamental aspect of FA is to look before you perform any manoeuvre (Goodspeed, 2006). This includes changing speed, changing direction, and entering and exiting the flow of the game. The flow of the game is the overall pattern of plays and is highly dependent on the level of players. A low-goal (novice) game flow will be clustered and choppy, whereas a high-goal (elite) game will be fast and open (Goodspeed, 2018). Players must recognise and respect the flow, the LOB, and the ROW in order to have good FA (Goodspeed, 2005).

While FA is an important framework for polo player performance and safety, it has not been studied empirically. However, FA can be related to the cognitive framework of Situation Awareness (SA) which has been described in aviation, transportation, medicine, sports, and other dynamic environments (Salmon et al., 2009). Generally, SA is thought of as 'knowing what is going on around you', or more formally, the perception of environmental elements, the comprehension of those element’s meanings and significance, and the projection of the elements in the environment in the near future (Endsley, 1995b). Goodspeed's (2005) definition of FA is comparable to Endsley's (1995) definition SA; a player must perceive the players and umpires, the LOB and associated ROW and comprehend the significance of these elements. A player must then project or anticipate the future movement of the players and future LOB and ROW. Both the FA and SA frameworks involve cognitive skills such as visual search, anticipation, and decision-making. However, there is a significant lack of information regarding the visual and cognitive skills required by polo players, despite these abilities being shown to influence performance in other sports sectors (Hadlow et al., 2018). While there is no research into the cognitive skills, such as SA, employed by polo players, there is literature on SA in sports. The following section will give a detailed overview of the SA in sports literature, which will be used as the underlying theoretical framework for the development of the studies that make up this thesis.

1.3 Situation Awareness in sports: a scoping review

This section is adapted from a review published by the thesis author entitled ‘Situation Awareness in sports: A scoping review’ published in Psychology of Sport and Exercise by Huffman et al. (2022). A review of the SA in sports literature was conducted using a systematic PRISMA approach, outlined in Appendix 1. Firstly, this review section will identify the different types of frameworks labelled as SA used in sporting contexts. Secondly, the methods used to directly assess SA in sporting contexts will be discussed. Finally, this section will describe the cognitive skills linked to a SA framework in a sporting context.

Researchers have investigated how cognitive skills such as visual search (Loffing et al., 2015a; McGuckian et al., 2020; Sors et al., 2017) or anticipation (Smeeton & Huys, 2011) contribute to sporting performance. While isolating and assessing cognitive skills is important in sports research, it is also necessary to explore how cognitive skills are combined to influence overall awareness of the sporting environment; awareness that may aid in sporting performance. Situation Awareness (SA) is a popular construct that arguably captures these elements holistically during complex dynamic tasks (Hulme et al., 2019). Endsley (1995b) describes SA as "the perception of the elements in the environment […], the comprehension of their meaning, and the projection of their status in the near future" (pp. 36). SA has been studied in a variety of highly dynamic environments including aviation (Muehlethaler & Knecht, 2016), transportation (Jackson et al., 2009; Underwood et al., 2011), and medicine (Chapman et al., 2020; Dishman et al., 2020; Hunter et al., 2020; Mackenzie et al., 2023). Within a sports setting, some researchers have argued that SA is necessary for an athlete to achieve high-level performance (Hadlow et al., 2018), yet few studies have examined the role of SA in sports (Ng et al., 2013). This is interesting considering the cognitive skills associated with SA are widely studied in sports (Hadlow et al., 2018). This section aims to therefore provide a reconnaissance of information related to SA in sport and focus on identifying the frameworks labelled as SA in a sporting context, the methods used to assess SA in sports, and the cognitive skills directly associated with it.

While many researchers agree that SA is important for safety and performance in dynamic environments (Salmon & Stanton, 2013), there is no universally accepted framework or definition of SA (Salmon et al., 2009). Endsley (1995b) makes an important distinction where SA as a whole is considered a state of knowledge—or product (Salmon et al., 2009)—and the cognitive skills, individual and task factors, decisions, and performance are *processes* towards which SA is acquired. This classification of SA as a product is disputed by other researchers, who have referred to the construct of SA as a process (Frack, 1991) or externally directed consciousness (Smith & Hancock, 1995). Bell & Lyon (2000) have even proposed that SA is more appropriately a measure of working memory knowledge. Thus, the construct of SA and its associated frameworks can be contentious, but Endsley's three-level framework is perhaps the most cited and validated amongst researchers (Salmon et al., 2009). In this framework, perception (Level I SA) is the detection of surrounding elements and provides the base for an individual's overall SA. Comprehension (Level II SA) is identifying the importance and understanding the meaning of the perceived elements, and projection (Level III SA) involves predicting what may happen in the near future (Jackson et al., 2009). It is important to recognize that SA is not decision-making nor is decision-making encompassed within the three-level framework. SA will influence, in part, decision-making where good SA can subsequently contribute to better decision-making. However, SA does not always guarantee good performance as there are many factors which influence performance, and SA is just one of those factors (Endsley, 1995b).

1.3.1 Situation Awareness frameworks in sports.

Because SA is not universally defined (Salmon et al., 2009), researchers have posited different types of frameworks that measure different components. Therefore, it is important to identify which SA frameworks are used in sporting contexts and how these frameworks attempt to capture the varied elements across sports (*e.g.,* individual vs team). The following sections outline the frameworks applied to SA in sports, including the three-level framework (Endsley, 1995b), Distributed Situation Awareness (Stanton, 2006), and Shared Situation Awareness (Salas et al, 1994).

1.3.1.1 Three-level framework.

Endsley's (1995b) three-level framework was described in four papers investigating SA in cyclists (Knez & Ham, 2006), tennis players (Caserta & Singer, 2007), basketball players, (Ng et al., 2013), and squash players (Murray et al., 2018). While these papers mentioned the three-level framework of SA, their main objective related to the other research aims more closely and, as such, will all be discussed individually in subsequent sections. Still, however, it is important to discuss the facets of the three-level framework because of its heavy use in the research presented in this thesis. See Fig. 1.1 for a diagram of the three-level SA framework as developed by Endsley (1995b).

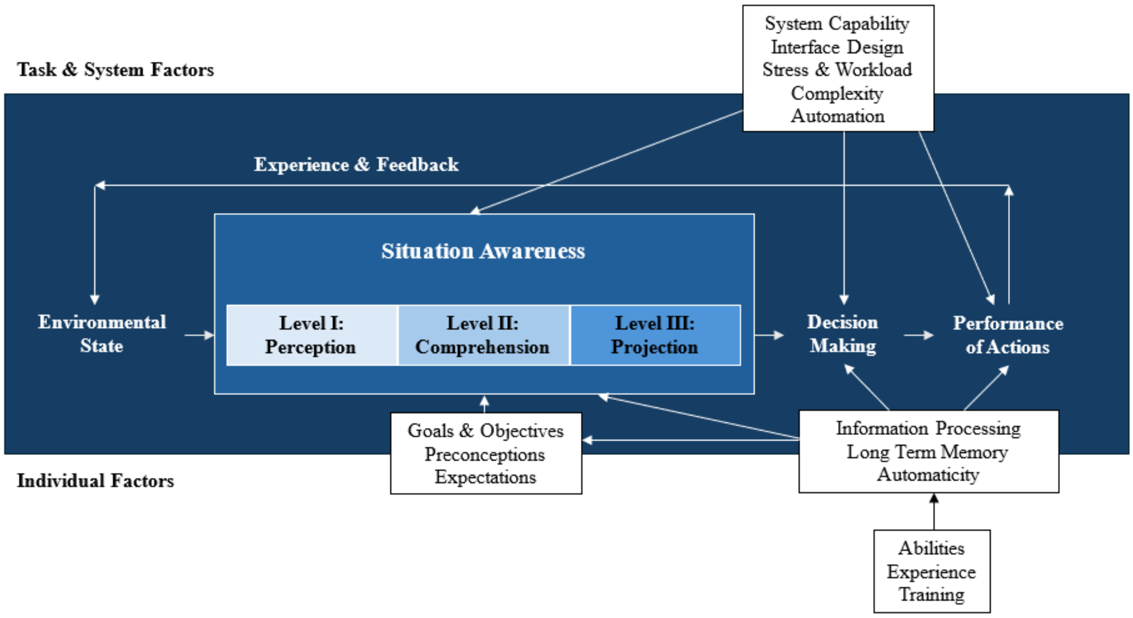

Figure 1.1 *Diagram of Endsley's (1995b) three-level framework of Situation Awareness showing the individual levels (perception, comprehension, and projection) with a larger feedback loop that includes the state of the environment, additional cognitive skills, individual and task/systems factors, and actions that influence SA as a whole.*

The three-level framework describes a holistic construct containing the hierarchical progression of 'levels' towards which overall SA is obtained; each level is important for acquiring and maintaining SA using different cognitive skills and processes. These levels then feed into a larger feedback loop containing separate skills such as decision-making and performance of actions. Throughout the acquisition and maintenance of SA, a multitude of cognitive skills (perception, attention, memory, anticipation, decision-making) and individual and task factors interact to form a complete picture of the environment and aid in SA and performance. These will be discussed in detail below. Within the three hierarchal levels, Level I SA refers to the *perception* of elements within the environment. In this level, individuals must perceive elements (defined as things specific to the environment and system) using the senses: vision, auditory, tactile, olfactory, *etc*. (Endsley, 1995b). In sports, perception of elements may refer to athletes seeing the ball, teammates, opponents, umpires (Goodspeed, 2005) or hand signals (Novitaria & Subarkah, 2018). It may also refer to athletes hearing verbal communications (Blaser & Seiler, 2019), the strike of a ball (Sors et al., 2017), or even crowd noise (Otte et al., 2021). Once the environmental elements are perceived, these elements and current situation must be understood. Level II SA refers to the *comprehension* of the significance and meaning of the elements which are perceived. During this level, patterns and a holistic picture of the situation is created within the mind, and mental models are recruited to match the situation and aid in SA acquisition and maintenance (Endsley, 1995b). Comprehension would occur in instances when an athlete recognises the colour of the players' jerseys (*i.e.*, teammate or opponent), the direction of the ball (towards or away from the goal), the communication (visual or verbal) meaning, *etc*. This comprehension relies on mental models previously stored in the long-term memory (LTM) (Endsley, 1995b), and it will influence the final level of SA. Once the athlete has comprehended the situation, they may then predict what will happen next in the environment. Level III SA is the *projection* of the future state of the environment; this is considered the highest level of SA and is achieved based on the knowledge gained from Levels I and II (Endsley, 1995b). The projection of the future state of the environment is often equated to anticipatory skills and is thought to be a sign of expertise in a domain (Jackson et al., 2009). In sports, projection can be seen when athletes anticipate the location of a shot (Huys et al., 2009), an opponent's deceptive movements (Loffing et al., 2014), or intercept and hitting a fast-moving ball (Mann et al., 2013).

As an example of this three-level framework in a polo context, a player may perceive another player running with the ball (Level I SA). The player must now comprehend (Level II SA) if the player with the ball is a teammate or opponent, and then they must understand what their role is (*e.g.,* they are an opponent running towards goal). The polo player then combines their perception of the elements (a player running with the ball) with the comprehension of the elements (the player is an opponent running towards goal) and may now make a prediction (Level III SA) on what the perceived player intends to do; will the opposing player shoot to goal, or will they pass—and if so, to whom? This SA will then allow the player to make a decision on how to defend against their opponent and then make a subsequent performance action, such as hooking their opponent.

1.3.1.1.1 Cognitive processes associated with the three-level framework.

Importantly, Endsley's (1995b) three-level framework does not solely include the individual levels (perception, comprehension, and projection), but instead encompasses additional cognitive skills, individual and task factors, and actions. Decision-making and performance of actions are notably separate from the three levels but are influenced by the information provided in each prior level. Individual (internal) factors, such as goals, expectations, information stores (previous knowledge), long-term memory, automaticity, and anxiety—all of which are influenced by individual abilities, experiences, and training—in addition to task (external) factors, such as system capability, interface design, stress, workload, and complexity, also interact to achieve SA (Endsley, 1995b).

This framework highlights that SA is ever-changing, modelled using a feedback loop where the three levels lead to subsequent decision-making, which then leads to performance of actions, which will then feedback into the three levels through the new state of the environment, thus creating one 'rotation' of the cycle. After the 'completion' of the three levels, decision-making and performance of actions work together to create experience; this experience is then used to create mental models which are then used to acquire SA in a new environmental state (Endsley, 1995b). Experience and its role in SA will be discussed in greater detail in below.

Within the feedback loop, there are cognitive skills and processes recruited for acquiring and maintaining SA. Notably, the three levels have been argued to be cognitive processes themselves (Salmon et al., 2008), but Endsley (1995b) distinguishes the processes separately from the overall product of SA. The first set of cognitive skills pertain to how individuals process information from their environment. When searching the environment, elements may be processed in one of two ways: bottom-up, in which elements are attended to based on their saliency, or top-down, in which elements are attended to based on preconceived goals or expectations (Kinchla & Wolfe, 1979; Eysenck, 1998). During bottom-up, or stimulus-driven processing, external stimuli are identified by saliency and, in the case of a visual search of the environment, image features; on the other hand, with top-down, or knowledge-driven processing, stimuli are attended to using guides from memory stores in a goal-directed visual search (Shea, 2015).

Working memory (WM) and long-term memory (LTM) have been identified as two memory stores important for SA acquisition and maintenance (Endsley, 1995b). WM stores environmental information used for immediate processing (Baddeley & Hitch, 1974), and also serves as the site where new and pre-existing information are combined to create a holistic picture of the environment (*i.e.*, Level II SA); additionally, projections and subsequent decision-making also occur within the WM (Endsley, 1995b). Importantly, as the WM is a finite resource, heavy loads are placed on the WM when individuals move through the three levels (Wickens, 1984), thus resulting in potential bottlenecks in SA, particularly in novices who rely solely on WM stores (Fracker, 1987). To work around the limitations of the WM, LTM stores information about previous experiences in similar environments that can be retrieved and used for top-down processing, thus relieving the workload on the WM when gathering information about the environment (Endsley, 1995b). Naturally, though, such LTM resources are only available to those with previous experience in a domain.

Within the LTM, mental models are stored and retrieved when acquiring SA. Salmon et al. (2008) states that a key process in achieving SA is the creation and utilisation of mental models. As an individual moves through the hierarchal levels, mental models are chosen based on the specifics of a situation (Endsley, 1995b), and those mental models then aid in the selection and application of action approaches (Collins & Gentner, 1987)—or more simply, they aid in the decision-making process (Chermack, 2003). Importantly, good SA does not guarantee good decision-making skills; individual differences stemming from a lack of proper training, poor strategies, or incorrect mental models may hinder the decision-making process despite having ‘good’ SA (Endsley, 1995b).

Perception, the basis for acquiring SA, is guided by the information contained in both the WM and LTM, the latter of which supplies mental models to facilitate an individual’s perception of environmental elements (Endsley, 1995b). During the perception process, an individual selectively attends to certain items—the relevancy of which may be determined by how the item was perceived (*i.e.*, was the item perceived using a bottom-up or top-down approach?) (Kinchla & Wolfe, 1979). Endsley (1995b) described the importance of direct attention on relevant elements during each of the three levels, but also during the decision-making process and the performance of actions. Attention, like the WM, is limited (Lavie et al., 2004); it is simply not possible to attend to every single element for one hundred percent of the time. Thus, it is imperative that individuals determine which elements are task-relevant and disregard those that are irrelevant; this works to keep cognitive load to a minimum (Lavie et al., 2004), thereby freeing up cognitive resources for developing SA and executing subsequent actions. Top-down processing allows an individual's goals to direct their attention (Kinchla & Wolfe, 1979; Eysenck, 1998), perception, and ultimately SA (Endsley, 1995b).

1.3.1.1.2 Individual factors associated with the three-level framework.

In addition to the unique cognitive processes underlying SA, there are also many individual factors described in the three-level framework (Endsley, 1995b; Sarter & Woods, 1991). Such individual factors may influence how well a person may acquire SA (Endsley, 1995b), particularly where memory and information processing skills are concerned (Hunt et al., 1973). For instance, storage of information may be one person's strength, but they may struggle with processing that information—another person might have opposite aptitudes (Cowan et al., 2005). However, an individual's goals or expectations may play an even larger role when acquiring SA. The construct of SA itself—when referring to Endsley's (1995b) framework—is inherently goal-driven. An individual within an environment typically has some sort of goal they are trying to achieve. In polo, it may be as broad as scoring a goal or hooking an opponent, or it may be more complex and involve multiple goals (*e.g.*, a player must hook an opponent in order to steal the ball, find an open teammate, then execute a pass).

The confidence levels, stress (physical, social), and anxiety of an individual may also affect their SA. Oftentimes, environments in which SA is developed are complex, dynamic, and potentially dangerous, which can increase stress and anxiety in individuals, particularly those who are less familiar with the environment (Endsley, 1995; Knez & Ham, 2006; Tseng et al., 2022). While there will always be some level of uncertainty with anticipating future events, confidence in the information supplied by the environment and mental models may ultimately affect the decision-making process (Norman, 1983; Endsley, 1995b). Confidence levels within individual abilities also has the potential to increase performance efforts despite the uncertainty (Eysenck, 1982; Hardy & Callow, 1999). While some level of stress and anxiety can be beneficial (see the inverted U-hypothesis developed by Yerkes & Dodson, 1908 where there is an optimal level of arousal for optimal performance), typically stress and anxiety negatively affects performance in sports (Arent & Landers, 2003; Bali, 2015; Ford et al., 2017). The detriment to performance can be explained by landmark hypotheses within the field of cognitive psychology. For instance, the cue utilisation hypothesis (Easterbrooks, 1959) suggests that higher than optimum arousal (such as in high-stress or high-anxiety situations) lead to a narrowing in an individual's focus, thus causing important elements and details in the environment to be missed, therefore decreasing performance (Knez & Ham, 2006). This may look like an American football player being 'blind-sided' because he was directing his attention at his receiver and did not perceive an approaching defenseman. A similar explanation for anxiety-related performance differences comes from the processing efficiency theory, where anxiety and worrying can either cause individuals to deplete cognitive resources and leave them with a limited capacity for the task or cause an individual to devote more effort to the task, thus improving performance (Eysenck & Calvo, 1992). It has also been suggested that stress may cause a decrease in WM function (Hockey, 1986), which, as discussed above, is a key factor in acquiring SA.

1.3.1.1.2.1 Experience as a driver of Situation Awareness.

Experience in a domain is believed to be a strong driver of SA (Endsley, 1995b; Macquet & Fleurance, 2007), with experienced individuals exhibiting higher levels of performance across a range of contexts including general aviation tasks (Garland, 1991; Muehlethaler & Knecht, 2016; Wickens, 2002), fighter pilot simulated missions (Endsley, 1988b), air traffic control tasks (Bacon & Strybel, 2013; Durso et al., 1999; Endsley et al., 2000), driving and transportation hazard perception tests (Gugerty, 2011; Gugliotta et al., 2017; Horswill & McKenna, 2004; Jannat et al., 2018; Kaber et al., 2016; Underwood et al., 2013; Walker et al., 2008, 2013), and medical simulations (Chapman et al., 2020; Crozier et al., 2015; Fioratou et al., 2010; Gillespie et al., 2013; Lavoie et al., 2016; Mackenzie et al., 2023) to name a few. In sports-specific tasks, skilled or experienced athletes typically show superior sport-specific visual search strategies (Abernethy, 1990; Murray & Hunfalvay, 2017; Roca et al., 2018; Savelsbergh et al., 2002, 2005; Singer et al., 1996; Vaeyens et al., 2007; Williams et al., 2004), anticipation (Li & Feng, 2020; Mori & Shimada, 2013; Rowe et al., 2009; Runswick et al., 2020; Savelsbergh et al., 2002, 2005; Singer et al., 1996; Wright et al., 2011), and decision-making skills (del Campo et al., 2011; Hancock & Ste-Marie, 2013; Kaya, 2014; Macquet & Fleurance, 2007; Roca et al., 2018; Travassos et al., 2013; Vaeyens et al., 2007).

Importantly, though, is recognising the relation between SA and experience—in other words, understanding how experience is acquired in a domain and how experience drives SA and performance. The exploration into experience and SA in polo is an important facet in this thesis that will be empirically tested across three experimental chapters. It should be noted that experience and expertise are not one in the same but have been frequently used interchangeably within several domains (Swann et al., 2015). Experience simply refers to having some level of familiarity with an area, such as a sport; expertise, however, relates more to the performance of an individual. An expert athlete who has achieved peak performance may thus also be termed ‘elite’ (Bourne Jr. et al., 2014). There are many factors that make an individual an expert (or elite), and experience is one such factor (Swann et al., 2015), but experience alone does not make an elite athlete (Ericsson et al., 2003). So, whilst it may be tempting to equate a person with many years of sports experience to an elite athlete, that is not always the case. In the case of the research presented in this thesis, sports *experience*—not expertise—will be used as a predictor of SA performance.

Experience (and expertise) in a domain can be acquired in many ways, but perhaps one of the foundational theories amongst sport performance is Ericsson & Lehmann’s (1996) theory of deliberate practice (DP), which states that expert performance comes as a result of training using specific drills aligned with their desired field in combination with longitudinal experience. DP differs from simple experience because it requires immense effort, is driven by a need to improve, and focuses on specific areas for improvement (Baker et al., 2020). Simply put, an athlete such as a polo player would achieve expert-level performance by playing the sport for a long period of time (suggested to be at least 10 years to reach the ‘international-level’ in sports; Ericsson et al., 2003) in addition to practicing polo-specific drills depending on what he wants to improve. Polo drills, such as hitting, mallet control, ride-offs/bumping, and play tactics would be considered specific, while horsemanship drills (seat and leg cues, riding at speed, rein usage) would be more general, although still important.

The progression of skills within a domain sees individuals initially start out as novices who are new to the sport with minimal knowledge (Baker et al., 2015) and require specific instruction; as they improve and gain experience, they will begin to perform on their own with the same results as they had with instructions. Finally, after years of experience, they will become experts who can perform under immense time pressures with a high level of accuracy (Ericsson, 2008). Research into DP in sports has focused on different approaches to measure DP and its outcomes. The first approach had researchers explore the amount of time athletes spent on different types of practice. The second approach aimed to investigate the athlete's personal activities in conjunction with their practice techniques to identify how their development changed over time. Lastly, the third approach looked at athletes' perceptions of practice and sport in relation to everyday activities (Baker et al., 2020). A review of DP in sports conducted by Baker et al. (2020) showed that across a majority of studies, athletes' skill levels were discriminated by high-quality training (DP).

While it is promising that DP and experience have been shown to lead to higher-level sports skills, there is still a question of how such experience influences SA. Gabbett & Abernethy (2013) proposed that sports perceptual-cognitive skills develop with DP, and Runswick et al. (2020) have suggested that high-level performance comes from the ability to quickly and appropriately pick-up environmental and sensory information and combine that information with contextual information about the scene. One could make the connection that Gabbett & Abernethy (2013) and Runswick et al. (2020) are broadly describing SA—the perceptual-cognitive skills could equate to Level I SA whilst the utilisation of information about the environment could be considered Level II SA. Therefore, whilst the theory of DP is promising in that it shows how experience and expertise are obtained through domain-specific tasks, it is a generalised concept that does not really target what is differing between experienced and non-experienced, high and low-level performers: SA. Experience and DP ultimately develop SA skills, which allows athletes to perform at a high level and achieve expert (or elite) status.

As an important note, the terms ‘expert’, ‘non-expert’, ‘experienced’, ‘inexperienced’, ‘elite’, and ‘novice’ are frequently used throughout the sporting literature to describe groups of participants, however, there are large variations in the definitions of these terms (Swann et al., 2015). For example, Abernethy (1990) considered ‘expert’ squash players to be those who were ranked worldwide, whilst ‘novice’ players were those who did not participate in squash; del Campo et al. (2011) similarly described youth ‘expert’ soccer players as having at least one year of experience, whereas ‘novice’ players were those with no formal training or competition experience. Conversely, del Villar et al. (2007) classified high-ranking tennis players as ‘expert’ and players with grade school experience as ‘novice’, and MacPherson (1999) used a similar scheme for classifying tennis players, with ‘experts’ being Division I players and ‘novices’ as recreational players. Interestingly, Buszard et al. (2013) named AFL (Australian Football League) players as ‘experienced’ if they participated in more than 20 AFL games; ‘less-experienced’ players participated in less than 20 AFL games, but still had high-level AFL training. However, Ferrari et al. (2018) sampled participants with no prior handball experience and termed them as ‘inexperienced.’ Given the discrepancies with the terminologies used in traditional expert-novice paradigm, there are inevitable inconsistencies with how results are reported and interpreted (Swann et al., 2015). If one study’s novice cohort has no experience in a sport whilst another study’s novice cohort has experience, it is difficult to make inferences about the behaviours and skills possessed by ‘novices’. In the same grain, if one study classifies highly ranked or professional players as experts and another study classifies players with a few years of formal training as experts, there will more than likely be different conclusions drawn about ‘experts’ sports. Thus, clarification and consistency of terms is important when considering using any sort of expert-novice paradigm. One such way to achieve consistency is to use an ‘absolute’ versus ‘relative’ approach. An absolute approach typically samples small groups of undeniably elite athletes (i.e., Olympic or world medallists, record-holders) whilst a relative approach will still use an expert versus novice paradigm, but the groups are defined only in relation to each other (Chi, 2006). Another method for assessing sport experience was developed by Ballantine & Mackenzie (in press), which used Likert scales to numerically assign experience levels. Participants were asked to report the number of years they participated in a specific sport, the level of sport they currently played at (scored 1—10), and how many times a week they played the sport (scored 0—7). Sport-specific domain knowledge was then assessed using a multiple-choice test regarding rules and concepts. The scores for the Likert scales and multiple-choice test were added to produce a numeric value of sport experience. For the purpose of this thesis, a relative approach will be taken in regards to defining the participants' groups. A binary categorisation of experience versus no-experience will be used for the experimental studies, with the experienced group having some level of playing experience/expertise compared to the no-experience (control) group who have no level of playing experience/expertise.

1.3.1.1.3 Task factors associated with the three-level framework.

Aside from individual factors, task factors associated with the external environment also have the potential to influence an individual's ability to acquire and maintain SA. While some factors, in particular, system design, interface design, and the automation of systems, are more associated with socio-technical systems (*i.e.*, airplane cockpit), workload and the complexity of the environment can be applied to sports settings. Workload, or the amount of information receive or tasks one must perform in a given amount of time, can be considered a stressor, and thus operates in the same manner as physical or mental stress (as discussed above). An ideal workload would be such that an individual has a high level of SA with a low workload, where information is easily seen and processed (Endsley, 1995b). Complexity in an environment refers to the number of components, their interactions, and how often they move or change (Endsley, 1995b). Increasing the complexity of the environment or tasks undoubtedly increases the mental and physical workload and stress, potentially leading to a decrease in SA as previously discussed.

Lastly, while it is not shown in the framework's model, space and time are important factors in the three-level model (Endsley, 1995b). Spatial components of the environment may include where others are positioned or where they are moving (Endsley, 1995b), and Endsley & Garland (2000) discuss that both the temporal aspects (how slow/fast events develop in a system) and how individuals perceive time can influence SA. Spatial-temporal factors can ultimately constrain an individual's SA and performance (Endsley, 1995b; Endsley & Garland, 2000), particularly in sports where decisions and actions must occur in a matter of seconds or even milliseconds (Loffing & Cañal-Bruland, 2017).

1.3.1.1.4 Criticisms of the three-level framework.

There has been criticism of the three-level framework and SA as a construct (Salmon et al., 2008), which has arisen from disagreements about what SA actually represents—in other words, is it a product (Endsley, 1995b), a process (Fracker, 1991), or some sort of combination of the two (Smith & Hancock, 1995)? Wickens (1992) stated that SA is the ability to access information within the working memory, Crane (1992) equated SA with expert performance, and Smith & Hancock (1995) argued that SA was "adapted, externally directed consciousness" (pp. 138). Endsley's (1995b) definition of SA ("…the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future") (pp. 36), of which the three-level framework is based upon, is perhaps the most widely used (Salmon et al., 2008), however it still faces critique. Additionally, the psychological approaches underpinning the construct of SA have been the subject of debates amongst researchers, with one prominent viewpoint being that it is a cognitive theory using an information-processing approach (Endsley, 1995b) and another viewpoint being that it is an ecological approach developed using the perceptual cycle model (Smith & Hancock, 1995); see Salmon et al., (2008) for an in-depth analysis of different SA frameworks and models.

In critiquing the three-level framework, Salmon et al. (2008) argued that while a clear distinction was made between SA being a product achieved through multiple processes, the three levels themselves could be considered cognitive processes which would contradict the framework's definition. Endsley (2015a) rebuked this assertion by stating that the three-level framework addresses both the product and the processes used for acquiring SA. Uhlarik & Comerford (2002) also found issues with the lack of dynamics in the three-level framework, however the feedback loop modelled by Endsley (1995b) clearly shows the dynamic and cyclical nature of the framework.

The reliance of the three-level framework on poorly understood cognitive processes, such as mental models, attention, and schemata, has come under scrutiny. Smith & Hancock (1995) faulted the three-level model for using mental models as a major component, given that mental models are not well understood or defined. Similarly, Uhlarik & Comerford (2002) also critiqued the use of attention and schemata in the three-level framework, suggesting that including processes that are not well-defined or thoroughly researched ultimately hinders the framework's usefulness for explaining SA, and it compounds the confusion surrounding an already heavily debated topic (Uhlarik & Comerford, 2002; Salmon et al., 2008).

The similarity of the three-level framework to other constructs has caused some concern as well (Salmon et al., 2008). For instance, Smith & Hancock (1995) stated that the three levels of SA are akin to the three stages of information processing (Newell & Simon, 1972), and Salmon et al. (2008) compared it to the construct of working memory and thus may not even be warranted as a new construct. However, it can be rebutted that Endsley's (1995b) three-level framework is an adaptation of Newell & Simon's (1972) information processing model which underlies the holistic framework; importantly, the three-level framework does not consist solely of those three levels but instead encompasses several processes, such as working memory and actions that lead to experience—experience which, ultimately, drives the acquisition of SA in future events. This SA-performance-experience feedback loop is, perhaps, the main theoretical foundation for the studies presented in this thesis, and therefore, should not be ignored or understated.

The three-level framework has also faced criticism for its focus on individual SA rather than SA in a team, which, especially in a sports-setting, is a limitation of the model (Stanton et al., 2015). Whilst the framework was initially developed for individuals, the framework (and its partnered assessment tool, Situation Awareness Global Assessment Technique—see Section 1.3.2.1) has been successfully employed in team settings. Crozier et al. (2015) developed a team SA assessment tool based on SAGAT (Team Situation Awareness Global Assessment Technique—TSAGAT) which showed experience differences when analysing trauma team resuscitation, thus suggesting validity within the tool. Coolen et al. (2019) stated that measuring team SA using the three-level framework gave valuable insight into paediatric care team member SA differences which could be used to train and enhance health care. Additionally, Hultin et al. (2019) found high both individual and team SA could be reliably measured using both SAGAT and TSAGAT in medical simulations. Thus, it can be concluded that the three-level framework can be appropriately applied to both individual and team settings.

Lastly, Salmon et al. (2008) stated that a major concern of any SA framework was the lack of empirical evidence. In other words, how do we know that these frameworks are actually describing SA and not some other construct? Notably, this criticism was written in 2008 when SA, “the buzzword of the ‘90s” (Weiner, 1993, pp.4), was only a couple of decades old. Today, there is substantially more empirical data on SA and its various measurements applied across multiple domains. The three-level framework and SAGAT tool have been developed and applied in medicine (Crozier et al., 2015; Coolen et al., 2019; Hultin et al., 2019; Mackenzie et al., 2023), aviation (Nguyen et al., 2019), driving (Horswill & McKenna, 2004; Kass et al., 2007), and more (Endsley, 2021). Therefore, the initial criticism levelled by Salmon et al. (2008) for the framework lacking empirical evidence may be considered outdated.

1.3.1.1.5 The three-level framework in sports.

Of the sports papers that cite the three-level framework, only one actively assessed the SA as a whole and for each individual level. Ng et al. (2013) measured the SA of teenage basketball players using the Situation Awareness Global Assessment Technique (SAGAT; described in detail in Section 1.3.2.1) developed by Endsley (1995a) to directly assess the three-level SA framework (Endsley, 1995b). The basketball players were awarded an overall SA score, as well as individual scores for their perception, comprehension, and projection (Levels I – III). The players’ basketball knowledge, competitive anxiety, memory, short-term spatial awareness, and physical fitness were also measured. The authors reported that SA was not a significant predictor of basketball performance, but it can be argued that there were certain limitations of the study which should be rectified in further sports SA studies, which is further discussed in Section 1.3.2.1.

Interestingly, the Ng et al (2013) study is the only one (at the time of writing) which employs a direct, objective measurement of the three-level framework in a sport setting, despite the success of the framework (and SAGAT method) in other domains. For instance, in transportation, the three-level framework served as a foundation for Hazard Perception (HP) (Horswill & McKenna, 2004), which is widely used to assess driver competence and prediction abilities (Crundall, 2016). SA has even made the jump into the medical field (Crozier et al., 2015; Gillespie et al., 2013; Mackenzie et al., 2023; Schulz et al., 2013), with the overall aim of investigating and improving medical professionals' performance, and thus, patient care. This thesis will use the three-level framework as its foundation, given its applicability and validity across several domains (Crozier et al., 2015; Dishman et al., 2020; Endsley, 2000a; Endsley et al., 2000; Endsley, 2021a; Horswill & McKenna, 2004; Hunter et al., 2020; Mackenzie et al., 2023; Schulz et al., 2013; Walker et al., 2009). Importantly, the cognitive skills (*i.e.,* attention, perception, memory, anticipation, decision-making) which underly this framework (or are a product of the framework, in the case of decision-making) are ones frequently identified and isolated by sports researchers, making this a logical framework for use in sports SA research. This framework, additionally, is the only one that provides objective, empirical data that can be compared across different studies and trials (Endsley, 1995b, 1995a), which is perhaps what the sports SA domain needs (further discussed in Section 1.3.4.3).

1.3.1.2 Distributed Situation Awareness.

The construct of SA has historically been debated by researchers, particularly around the controversies of modelling individual and team SA. Individual SA is easy enough to understand (modelling it, however, has been contentious): it is the SA of one person within an environment. Conversely, identifying, modelling, and measuring SA within and across a team becomes more complicated. Teams, by nature, are comprised of multiple individuals but act as its own singular entity with its own set of goals and functions, often to be completed in a short amount of time (Kaber & Endsley, 1998). Individual sports, such as swimming, tennis, golf, track and field, *etc*., only have one athlete competing for a goal, whereas, in team sports such as polo, football, basketball, soccer, rugby, *etc*., individual athletes collaborate to achieve a unified goal. Of course, this is an overly simplistic explanation which does not account for the 'behind-the-scenes' team members, such as coaches or trainers, who, while not actively competing, may still influence an athlete's performance. When investigating the SA of a team, it is necessary to determine the individual roles and responsibilities of each member in the team, acknowledge any similarities (overlaps) and differences in roles, and identify the level of SA for each member to create a 'sum' of SA for the team (Endsley, 1995b; Endsley & Roberts, 2000). Endsley (1995b) models team SA as overlapping circles, much like a multi-faceted Venn diagram where each team member has their own SA elements, and where the circles overlap represents SA that is shared across members; this overlap in SA is made possible by coordination and information-sharing between members (Endsley, 1995b). Not surprisingly, understanding how information and SA is shared across team members can become complicated. One such proposal for identifying the collaborative efforts between team members and their overall environment is Distributed Situation Awareness (DSA).

Distributed Situation Awareness (DSA) (Stanton, 2016; Stanton et al., 2006) suggests SA is applied across systems or environments and describes how SA is obtained via the interaction between human and non-human agents. It argues that SA is within both the individual and the context of the environment, including a team of individuals (Macquet & Stanton, 2014). With DSA, researchers and practitioners may describe how interactions within a system determine the overall performance (Neville & Salmon, 2016). DSA therefore describes what unique SA information is necessary for each individual agent within a system. Once the unique SA information is identified, agents can exchange that information when and where it is required. Within DSA, SA is a combination of the individuals' and technical agents' (*e.g.,* sports equipment, communication tools, digital technology) SA models. However, the actions of each individual are still based on their own understanding of their SA. DSA has been suggested to be a more accurate representation of a team's SA (Stanton, 2016) and has been described in many environments such as military control, healthcare, transportation, and sports (Neville & Salmon, 2016). DSA has been argued as an appropriate method for describing SA within sports because of the cooperative nature of sports with multiple individuals each with different relationships and tasks (Macquet & Stanton, 2014; Neville et al., 2016). Many sports create an environment in which individuals and teams of people compete for the same goal, so while a sport may be labelled as "individual", there is still a team of coaches, trainers, and other athletes that influence training, competition, and ultimately SA.

1.3.1.2.1 Distributed Situation Awareness in sports.

Salmon et al. (2017) used a DSA approach to examine the SA networks in elite women's cycling. In elite cycling, athletes form a "peloton" or pack of cyclists. In these pelotons, athletes must remain aware of their teammates' and opponents' movements in order to successfully strategize how to win as well as to avoid collisions. There is also substantial communication during a race between teammates and coaches. In their research, Salmon et al. (2017) video-recorded a cycling race, recorded the verbal communications during team race planning meetings, conducted post-race Critical Decision Method (CDM) interviews, and audio recorded post-race team debriefs. Following the interviews, each participant completed a social network analysis diagram to show who and what they interacted with during the race. The interviews were transcribed verbatim and categorized into three networks based on the Event Analysis of Systematic Teamwork (EAST). This is a framework designed for analysing behaviour of sociotechnical systems (a system with both human and digital agents). The three thematically identified networks were the: 1) Task, 2) Social, and 3) SA networks. The Task Network revealed there was a range of subtasks involved - both at an individual and team-level. The relationship between each subtask can be used to identify which are important to team success. The Social Network showed that the "protected rider" (the leader of the peloton) and "domestique rider 2" (support rider in the peloton) were the most connected with incoming/outgoing communications. These two riders also had more frequent communications with other agents. Importantly for this research, the network analysis revealed, with the SA Network, that SA was distributed across the team, peloton system, and between human and non-human agents. As an example, information presented on the bike-mounted computer and handlebar screen was used in conjunction with verbal transactions within the peloton and was important to inform decisions; for example, when to attack. This research was exploratory in nature and, like much of the DSA research, simply offered a description of the elements that may be related to situation awareness or performance.

The athlete is not the only performer in a sports context. The coach is also an important member of the team in many ways. The coaching process is composed of training, competition, and organization, which is highly cognitive in nature (Debanne & Chauvin, 2014). They must have an awareness of how their team and the opposition are performing to make quick decisions. Coaches often have different vantage points of the situation in comparison to the athlete, therefore they may interpret the situation differently (Macquet & Stanton, 2014). Macquet & Stanton (2014) used a DSA approach to determine if the athletes' and coaches' SA matched each other. Six elite athletes (two male and two female hammer throwers, and one male and one female rower) and three coaches (one hammer throwing and two rowing) were observed and recorded during training sessions. Video recordings of the athletes' behaviour, athletes' and coaches' communication, and verbalizations from post-training interviews were analysed for behavioural and contextual data. Participants watched their videos during interviews with the researchers and described their activity and thoughts during a course of action. The data identified what the authors called "meaningful units", which were verbalizations relating to or that described the athlete's behaviour, focus, feelings, and the situation (Macquet & Stanton, 2014). It was suggested that if the content of the units described by the player and coach matched or were "compatible", then this would aid performance. The authors then thematically organized the content of the meaningful units into broader categories. They identified that the content of the meaningful units could be themed as relating to "Technical Elements", "Athlete's Psychological States", "Organization and Safety", "Performance", and "Athlete's Experience". They report that the meaningful units themed within Technical Elements were reported to have the highest number of compatible matches. Meaningful units themed within the Athlete's Experience were reported to having the least number of compatible matches. What the authors suggest then, is that coaches and athletes often have compatible SA about certain performance elements but can differ in their overall perspective. How this relates to performance, however, is unclear.

Officials are a vital part of all sports and can be classified as interactors (*e.g.,* basketball referees), reactors (*e.g.,* line judges), or monitors (*e.g.,* gymnastics judges) (Neville & Salmon, 2016). Officials are required to have significant awareness of the unfolding play and make rapid decisions that may be influenced by a variety of factors (Burnett et al., 2017). Therefore, it can be argued that officials must have SA during competitions to ensure correct and fair calls or judging. Neville et al. (2016) applied a DSA framework to officials in sport (OiS). Game video recordings and audio commentaries between referees were provided by the Australian Football League (AFL). Each game was transcribed and coded for DSA using the EAST method. The authors described how SA is distributed within an OiS sociotechnical system with six tenets (Neville et al., 2016), where the OiS sociotechnical system is defined by the network of both human referees and non-human technical agents (*e.g.*, video review and goal-line technology). Tenet 1 described that the OiS SA is held by both human and non-human agents. Video review systems and goal-line technologies facilitated the SA held by officials. Tenet 2 stated that the agents have different perspectives on the game due to positions and roles, and these different views are combined to make an appropriate decision. The authors report that the system could not function if the officials' SA are not compatible with each other, or in other words do not align towards a similar goal or decision. Tenet 3 described the overlapping of SA between agents and suggests that overlapping of SA occurs and is only important when the goals of the agents are similar or the same. Tenet 4 stated communication between agents could be verbal and non-verbal. The use of hand signals and flags were used by officials as non-verbal SA transactions in the OiS system. Tenet 5 described how SA holds loosely coupled systems together, but also that coupling can shift dynamically throughout the duration of a game. The officials interacted with the game differently depending on play situation. Officials were more loosely coupled during general play, and field umpires did not interact as much with boundary and goal umpires. However, during set shot for goal and out of bounds situations, the umpires interacted much more with each other. Lastly, Tenet 6 described that one agent may compensate for the degradation of SA in another. For example, video review for uncertain plays and goals compensates for an on-field official's initial ruling. Overall, Neville et al. (2016) suggested that SA in officials is activated and updated through transactions in the system either through verbal or non-verbal communication. They also argued that DSA can contribute to the understanding and enhancement of complex sociotechnical systems performance.

While DSA has been described as appropriate for assessing SA in sports (Macquet & Stanton, 2014; Neville et al., 2016; Neville & Salmon, 2016; Salmon et al., 2017), this method merely describes the thoughts and actions of the performers and identifies relevant knowledge that other actors have. Ultimately, DSA appears vague and unquantifiable. It offers no obvious way of creating a standardized test that can be compared across studies, trials, and sports. There is also no discernible in-depth measurement of performance with DSA that states whether or not a performer has good or adequate SA required for their tasks, nor does DSA allow one to identify where mistakes were made during a performance or how to correct those mistakes. One could propose that DSA is simply a way to describe that the overall SA model is an outcome of the combination of all others' SA models. Related, but perhaps not a limitation given the nature of DSA, DSA does not provide insight into the importance of an individual's SA – particularly in sports where communication between coaches during gameplay is minimal (*e.g.,* racquet sports). Even in team sports, one still operates at an individual level, and as such it would still be useful to explore individual SA in team sports. It should be noted, however, that DSA is still in its infancy and has not been extensively studied and applied as other measures of SA (Stanton, 2016).

1.3.1.3 Shared Situation Awareness.

Shared Situation Awareness (SSA) promotes the idea that team performance will be optimal if players on the same team have a shared understanding of the environment, the agents within the environment, and how to execute the current task (Jonker et al., 2010; Salas et al., 1994). SSA appears to be very similar in nature to DSA (both in terms of construct and measures of) and has been defined as a shared understanding of a situation (Kurapati et al., 2012). It is argued that each team member has their own pre-existing knowledge and experience that differs from the other members. However, the members often must have good SA of their specific components as well as those shared by the team (Gillespie et al., 2013). Success of a task depends on the members' shared strategic knowledge and mental models which allows the team to have common definitions of tasks, assessments of the situation, and expectations of the task requirements (Salas et al., 1994). Communication amongst team members is argued to be the most important aspect of SSA as it affects the flow of information and ultimately the decision making of the team (Seppänen et al., 2013). Researchers believe that through SSA, teams become coordinated, and members are able to anticipate the actions of the other members (Salas et al., 1994), which is important for sports teams (Loffing & Cañal-Bruland, 2017).

Schei & Giske (2020) examined the SSA between soccer players and their coaches to determine if athletes and coaches are coordinated in their views of the game. Ten elite soccer players and their coach watched 12 videos of a soccer match in which the players participated, and they were interviewed following each video. Participants were asked to "describe what you perceive in this video" along with follow-up questions. Each interview was transcribed and analysed to determine similarities and differences amongst the players and coach. Situational descriptions, such as the theme, terminology, positions, and pitch area, as well as the situational solutions were used to evaluate the similarities and differences in statements. The authors revealed that in seven of the game situations, the players and coach shared coordinated views, but in five of the situations, they had contradictory views. The contradictory views would arguably have a negative effect on SSA, and therefore team coordination (Schei & Giske, 2020). The authors suggested that SSA requires players (and coaches) to continuously update their views of the situation for the team to be cohesive. They also argued that SSA in a team is a collective endeavour, and that teams should watch game footage to express their opinions to improve their shared knowledge skills, and thus SSA (Schei & Giske, 2020).

While SSA does address the communication and coordinated information required for successful teams, it arguably fails to explain how the individuals obtained their information, whether that information gave them "good" or "bad" SA, or how to improve their overall SA, which is often the goal of researchers (Patrick & Morgan, 2010). Therefore, it appears the major shortcomings of SSA and DSA are that these frameworks are only descriptive in nature, do not provide an in-depth measurement of SA, and lack the ability to be empirically tested.

1.3.2 Direct methods of assessing Situation Awareness in sports.

There have been several methods employed by other domains which assess an individual's SA. For instance, offline freeze-probes such as the Situation Awareness Global Assessment Technique (Endsley, 1995a) and What Happens Next (WHN) (Jackson et al., 2009) involve simulations or freeze-frame video techniques, and participants must answer queries that target their SA (Endsley, 1995a). These techniques have been used in aviation (Endsley, 1995a, 2000b), air traffic control (Endsley, 2000a), driving (Jackson et al., 2009), medicine (Dishman et al., 2020; Wright, 2005), and sports (Ng et al., 2013). Real-time online probes such as the Situation Present Assessment Method (SPAM) (Durso & Gronlund, 1999) presents queries during a simulation, and participants may choose when to answer the queries based on their workload (Salmon et al., 2009). This has been used in air traffic control (Bacon & Strybel, 2013) and submarine track management (Loft et al., 2013). For a recent review that compares the SAGAT and SPAM methods see Endsley (2021). Lastly, subjective rating tools such as Situation Awareness Rating Technique (SART) (Taylor, 1990) measure an individual's perceived SA through a series of post-simulation questionnaires (Salmon et al., 2009), and has been used in aviation (Endsley, 1988a), air traffic control (Durso et al., 1999), and military planning (Salmon et al., 2009). Because there are a variety of methods that directly assess SA in other domains, the aim of this section is to identify which SA methods are used in a sporting context. Within the sports SA literature search, only two studies employed direct methods of assessing SA. Ng et al. (2013) used a SAGAT approach for assessing SA in teenage basketball players, and Knez & Ham (2006) used a subjective Cognition Self-Assessment Tool (CSAT) and objective Random Number Cognition Test (RANCT) for SA in cyclists. These studies and their SA assessment methods will be discussed below.

1.3.2.1 Situation Awareness Global Assessment Technique (SAGAT).

Perhaps the most popular and validated objective method is the Situation Awareness Global Assessment Technique (SAGAT) (de Winter et al., 2019; Endsley, 1995a, 2021a). The SAGAT method was designed alongside the three-level framework of SA proposed by Endsley (1995b), and it targets the three levels of SA (perception, comprehension, projection) independently. It is an offline, freeze-probe, objective measurement taken during a task that queries participants' knowledge of task-specific elements and how they are likely to act in the future (Orique & Despins, 2018). The questions target a participant's perception, comprehension, and projection of the situation (Dishman et al., 2020), with SAGAT scores equating to the quality of SA. During a SAGAT task, once the participant answers the questions, the simulation or video resumes. SAGAT questions may be scored binarily as "correct" or "incorrect" (Endsley, 1995a) or the response time may be used to assess SA (Bacon & Strybel, 2013). Upon the completion of the simulation or video, the points are summed to give an SA score (Endsley, 1995a). The higher the score or lower the response time, the better the participant's SA.

SAGAT queries are created using a goal-directed task analysis (GDTA) which defines the goals, subgoals, and decisions an operator must make. These are then formatted into questions which focus on relevant areas of SA following a pause in the simulation or task (Endsley, 1995a). Importantly, these questions are phrased so they are similar to how an individual would assess the situation—no extra decisions should have to be made during the queries that would confound the initial purpose of the query (Endsley, 2000). A polo-specific GDTA for winning a game is shown below in Table 1.1 with examples of queries that would target the individual levels. It is important to note that the examples provided are not an exhaustive list of the goals or decisions that must be made during a polo game.

Table 1.1 *Example of a Goal-Directed Task Analysis (GDTA) and SAGAT queries (SA Requirements) for winning a polo game.*

Major Goal Win Polo Game		
Subgoal Score Goals	**Subgoal** Prevent Opponent Scoring	**Subgoal** Commit Minimal Fouling
Critical Decisions Who is the best teammate to pass the ball/receive a pass? Where is the best open area on the field to run with the ball? What shot is the best to take when aiming at the goal?	**Critical Decisions** Which opponent is the strongest player? Which teammate should mark which opponent? What defensive manoeuvre is the best at preventing the opponent from scoring?	**Critical Decisions** How to best play the ball without crossing the LOB or impeding the ROW?
SA Requirements	**SA Requirements**	**SA Requirements**
Perception	*Perception*	*Perception*
Locate players on the field. Locate the ball. Locate the goal posts. Identify the LOB and ROW.	Locate players on the field. Locate the ball. Locate the goal posts. Identify the LOB and ROW.	Locate players on the field. Locate the ball. Locate the goal posts. Identify the LOB and ROW.
Comprehension	*Comprehension*	*Comprehension*
Which players are teammates/opponents? Which team is in possession of the ball? Which direction is the ball traveling in relation to team possession? Which goal belongs to which team?	Which players are teammates/opponents? Which team is in possession of the ball? Which direction is the ball traveling relation to team possession? Which goal belongs to which team?	Which player has the ROW based on the current LOB?
Projection	*Projection*	*Projection*
How will the positions of the players change? Will the ball handler shoot or pass? Who will receive a pass? What shot will be taken?	How will the positions of the players change? Will the opponent shoot or pass? Who will receive a pass? What shot will be taken?	How will the LOB and ROW change? Who will have the future ROW?

Note. This is not an exhaustive list of the individual goals, subgoals, and decisions to be made during a polo game, but only an example of broad tasks in a polo game.

One advantage of the SAGAT method is that it allows researchers and practitioners to infer the level of SA objectively and determine where there may be a breakdown in SA by assessing the queries and responses (Endsley, 2021). For example, if a participant scores well on the Level I queries but falls short on the Level II queries, it can be inferred that a breakdown in SA occurred during the comprehension stage; with that information, training or instruction can be applied to remedy those skills. The SAGAT method's objectivity is another advantage because it allows researchers to have an unbiased viewpoint of the data, whereas subjective methods have the potential to fall victim to participant bias and memory issues (Endsley, 1995a; 2021).

The SAGAT method has been shown to be a reliable method for measuring an individual's SA in a variety of environments (Crozier et al., 2015; Dishman et al., 2020; Endsley, 2000a; Ikuma et al., 2014; Jannat et al., 2018; Joffe & Wiggins, 2020; Kaber et al., 2016; Lavoie et al., 2016). Additionally, SAGAT results have been shown to indicate higher SAGAT scores corresponding to better performance (Endsley, 2000). The statistical reliability of the SAGAT method has also been explored. Endsley & Bolstad (1994) reported high reliability with test-retest SAGAT scores in fighter pilots, and high reliability scores were also shown in driving recall events (Gugerty, 1997). Importantly though, the SAGAT method has not been extensively utilised within sports, and as such, it has not been empirically evaluated for its reliability for a sport setting. It has, however, been used in a basketball SA study (see below; Ng et a., 2013), and more recently with rugby by Ballantine & Mackenzie (in press).

The SAGAT method has been critiqued much in the same way as Endsley's (1995b) three-level framework. One of the main criticisms is its disruption of the task or simulation to answer a query, thus potentially taking a participant out of the 'flow' of the simulation. Sarter & Woods (1991) and Salmon et al. (2009) criticised the issue of intrusiveness during the stoppage of the task, as well as its difficulty to use during live, 'real-world' situations. Endsley (2000), however, has shown that SAGAT queries do not impact performance during a simulation of fighter pilots, whereas other methods (such as SPAM) may cause higher workloads in participants (Endsley, 2015b). Salmon et al. (2009) also questioned the method's validity, or more specifically its ability to measure SA versus memory. This criticism, though, likely stems from the debate over whether the three-level framework is too similar to the constructs of working memory.

Additionally, Chiappe et al. (2015) noted that the SAGAT method, because its probes target internal representations, is only applicable when measuring internal consciousness, or the knowledge the individual holds in their mind. When attempting to measure how an individual's SA interacts with the environment (such as when an operator stores information in a computer to access at a later time), SAGAT would not be an appropriate tool. Likewise, it has been argued the SAGAT tool does not include technical elements where SA may be stored but not immediately accessed by individuals, thus classifying the operator as being unaware (Sorensen et al., 2010; Salmon et al., 2012). However, as mentioned previously, the three-level model and accompanying SAGAT tool accounts for technical factors such as system capability, interface design, and automation of the systems (Endsley, 2015a). Salmon et al. (2012) also criticised the SAGAT method for its linear approach where individuals cannot achieve a high level of SA without first going through the lower levels. Endsley (2015a) rebutted this claim as a misconception; she stated the three levels were not 'linear' but were 'ascending' where an operator who understands the situation in its entirety (Level III) has better SA than someone who only perceives things in the environment (Level I) but does not understand their meaning (Level II). Therefore, it does not necessarily mean that a person must move from Level I to Level II to Level III to have good SA.

Walker et al. (2009) also stated that SAGAT does not acknowledge that SA as a whole may be better than its individual parts, and Salmon et al. (2012) argued that the SAGAT tool does not measure the links between the elements, but Endsley (2015a) stated that Level II, comprehension, is how elements are linked, and the SAGAT method is capable of targeting that comprehension ability. Ultimately, these criticisms are largely borne from the contentious nature of defining SA itself—different definitions and schools of thoughts will undoubtedly lead to clashing ideologies and researchers vying for a universal framework. Overall, despite its proposed shortcomings, the SAGAT method has been shown to be a robust, validated measure of SA when compared to other tools like SPAM (Endsley, 2021) or SART (Salmon et al., 2009).

As mentioned, only one study reviewed used the SAGAT tool to measure SA in a sport setting. To assess how cognitive skills and SA influence basketball performance, Ng et al. (2013) tested teenage (14 – 16 years) basketball player's level of anxiety, short-term memory, and SA. They also tested the players' knowledge of basketball rules and concepts, their ability to learn and set plays, and their physical fitness level. Twenty-five basketball players completed a SAGAT test and several other cognitive tests in conjunction. The SAGAT and cognitive tests were taken twice during the study—once at the beginning of the season before the first game and once at the end of the season following the last game. In the SAGAT test, players were shown a 5 – 7-minute professional basketball video that was paused three times. At each pause, the players answered 4 – 5 multiple choice questions that targeted their perception, comprehension, and anticipation abilities. Alongside the SAGAT test, the basketball players completed a Competitive State Anxiety Inventory-2 (CSAI-2) test to measure cognitive and somatic anxiety plus self-confidence. They completed a Corsi block-tapping task to measure short-term spatial memory, in which participants were shown a pattern of randomized block taps and were required to replicate the pattern, with the patterns increasing in length for each trial. Participants also completed a multiple-choice basketball knowledge test, a basketball recall-and-recognize learning video task, and a standardized physical fitness test. The authors compared scores of the SAGAT, cognitive tests, and fitness test with the players' performance results in the basketball games. Ng et al. (2013) reported that the fitness test score can best explain the variance in basketball performance, followed by basketball learning ability, basketball knowledge, short-term spatial memory, competitive anxiety, and lastly SA, which was not a significant predictor. Within the cognitive skills tests (Corsi block-tapping and CSAI-2), the short-term spatial memory (Corsi block-tapping test) had the largest coefficient for predicting basketball performance, which the authors suggested was indicative of players' abilities to find open spaces on the basketball court to score points.

SA, measured through the SAGAT test, was not a significant predictor of the variance in performance scores across the players (Ng et al., 2013). Players averaged 54.2% on the perception questions, 33.3% on the comprehension questions, and 46.9% on the anticipation questions. However, the players were least consistent when responding to the anticipation questions, with scores ranging from 0 – 100%. The authors argued SA may not explain basketball performance as well as the other skills because basketball performance is often influenced by other players. They reasoned that a player may have good SA and pass the ball to a teammate, but if that teammate does not have the same SA and catch the ball, the performance is ultimately affected. Herein lies one of the cruxes of the SA construct debate, mainly the differentiation of individual versus team SA. In this specific instance, when reasoning why a pass between two players could not be completed, it is not enough to simply examine one player's SA; the SA of *both* players must be measured in addition to their team SA. Currently, there is a lack of studies explicitly looking at team SA in sports, particularly using the SAGAT method; this is clearly a limitation, but also an opportunity for future areas of research.

The inability to execute a correct pass to a teammate may also not solely be a result of SA either; if a player has poor physical skills (such as passing target inaccuracy or muscle weakness where the pass would come up short), it would be difficult to complete the pass regardless of SA. Therefore, it is important to reiterate that SA does not equal performance—it is a precursor which may allow an individual to perform well, but there are many reasons why good SA may not necessarily equate to good performance (Endsley, 1995b). Ng et al. (2013) also explained that performance statistics are also often dependent on the opposing team, wherein a stronger team might negatively affect the performance scores—and thus perceived SA—of the team studied. This is, undoubtedly, where experience and/or expertise may play a role in SA; therefore, as has been stated throughout the review of the literature, one of the main goals of the research in this thesis is to explore the role of experience on SA so that a clearer picture of the relation between experience and SA may be formed. One of the important takeaways from this piece of research therefore is that SA does not equal performance. Simply stated, SA is not performance itself, but a mental awareness that may aid in performance, and good SA cannot guarantee good performance. Where this distinction is likely to be most salient is in the execution of technical motor skills. Whilst an individual may have a good level of SA, and then subsequently make the correct decision, they may, for example, be inaccurate in their pass.

Some limitations remain in the Ng et al. (2013) study, particularly with regards the attempt to relate SA and performance. This research did not consider the importance of measuring different experience levels of players, which, as discussed previously, plays a large role in SA acquisition through the honing of perceptual-cognitive skills (Gabbett & Abernethy, 2013). The players sampled in the study were all similar ages (14 – 16 years) and played on the same team, so it is possible the variability of SAGAT scores and basketball performance was small due to the similarities of the players. It would be beneficial to sample players of differing experience (*i.e.*, experts and novices) to provide a greater variability in SA performance measures. This is often seen in driving SA studies where experts and novices are compared (Kroll et al., 2020). It is also worth noting that the low SAGAT scores in all three levels suggest that the questions were perhaps too difficult for the level of the players, or that the questions focused on elements that the players did not consider relevant to their next move.

It should also be noted that Ng et al. (2013) only averaged the SAGAT scores of the players and did not look at the individual scores themselves. It would be beneficial to see if individuals with higher SAGAT scores had better basketball performance scores. This would potentially show a link between better SA and better performance, often seen in other domains such as driving (Crundall, 2016; Kroll et al., 2020). Ultimately, whilst SA may not explain all the variance in performance, further studies better targeting this relationship using the SAGAT method are warranted.

1.3.2.2 Cognition Self-Assessment Tool (CSAT) and Random Number Cognition Test (RANCT).

Knez & Ham (2006) examined the effects of fatigue on elite cyclists' subjective and objective SA during a Time Trial 30km (TT_{30}) cycling race as physical factors such as fatigue and psychological factors such as boredom, anxiety, and pressure have been known to affect SA in individuals (Endsley, 1995b; Sneddon et al., 2013). The measures identified to assess SA were 1) the Cognition Self-Assessment Tool (CSAT) and 2) the Random Number Cognition Test (RANCT). The CSAT is a subjective self-report measure that asks questions related to the degree to which participants would be able to carry out specific cognitive tasks. Tasks such as the ability to plan race lines, develop race strategy, judge distance, *etc.* The RANCT is a common measure for visual search and detection performance. In this study participants were presented with a 6 x 6 grid containing numbers 1 – 36 and were asked to sequentially score out the numbers. Whilst the CSAT may seem somewhat related to assessing SA, it is more difficult to connect performance in the RANCT with overall SA. At best, perhaps it might relate to Level I of the three-level framework (perception), but it is unclear how it might relate to a general awareness where one is able to make predictions or make decisions.

The authors reported that the maximal physical effort during a TT_{30} race resulted in a significant increase in performance in the RANCT, suggesting that high-exertion exercise benefits visual search/detection. In contrast, it was reported that high exertion also resulted in greater perceived difficulty to maintain SA during the race, which were reflected in the scores of the CSAT.

Knez & Ham (2006) suggested that CSAT and RANCT have a high reliability to give consistent measures of visual perception and detection skills, as well as measures of cognitive function. The authors also suggested these tools may be used to help manage an athlete's perception of fatigue and arousal levels, the contributing factors to fatigue and arousal, and their own SA abilities (*i.e.,* recognising key elements and making correct and timely decisions). While Knez & Ham (2006) noted the increase in perception of difficulty through the CSAT was inconsistent with the 'objective' measurement of SA through the RANCT, they suggested athletes perhaps underestimate their level of SA. Self-reported SA assessments have been criticised as being unable to accurately report SA (Salmon et al., 2009) because they are thought to be influenced by an individual's performance or memory and not on a participant's actual SA (Endsley, 1995b). However, it is still important for athletes to know if they are over- or underestimating their SA abilities as this knowledge may allow them to alter their behaviour to better suit their environment and performance (Knez & Ham, 2006).

1.3.3 Cognitive skills associated with Situation Awareness in sports.

Endsley's (1995b) three-level hierarchal framework, for example, necessitates certain cognitive skills such as attention, visual search skills, and auditory processing (*i.e.*, for Level I SA), memory (*i.e.*, for Level II) and anticipation (*i.e.,* for Level III SA) (de Winter et al., 2019; Endsley, 1995b; Salmon et al., 2009). Of course, as has been discussed in Section 1.3.1.1 when describing the three-level framework (Endsley, 1995b), there are several cognitive skills and processes which interact to allow an individual to acquire and maintain SA. These skills, such as perception, attention, memory, anticipation, and decision-making, are all important, and therefore, it is necessary to investigate which cognitive skills have been *directly* associated with SA or mentioned in relation to SA within a sports context. As a reminder, whilst a plethora of sporting research will investigate and report on these elements, only those that specifically discuss these in relation to SA were included in the section (this point is addressed later). For examples of reviews targeting certain cognitive skills in sport more generally, see McGuckian et al. (2018) for visual search, Furley and Wood (2016) for working memory, and Loffing & Cañal-Bruland (2017) for anticipation. As such, the literature search identified three separate cognitive skills directly associated with SA in sports: perception, anticipation, and decision-making. Also of importance, there were no cognitive skills directly associated with Level II SA (comprehension) identified within the sports SA literature. This is yet another example of the underdeveloped nature of the research into SA in sports contexts.

1.3.3.1 Visual search behaviours.

Perception—the first level in Endsley's (1995b) framework of SA—is heavily influenced by an individual's ability to efficiently and effectively use vision to monitor their environments. Perception (Level I SA) errors are notably the most common amongst SA errors, particularly due to the failure to recognize or see important environmental elements (Mason, 2020). Therefore, visual behaviours are important in acquiring SA. Each athlete has different perceptions and roles in their environment based on their past experiences, coaching, and positions played (Richards et al., 2009). Playing positions, offense or defence, positions on the pitch, and the flow of the game can all impact an athlete's visual perception and ultimately SA.

McGuckian et al. (2020) examined how SA and decision-making (DM) via visual search behaviours is affected based on an athlete's pitch position, role on the team, and phase of play. Twenty-two teenage Australian National Premier League youth players competed in two separate 11 v 11 training matches. The players' head movements and pitch position were recorded. The authors examined data regarding pitch zone, ball possession, phase of play, head turn frequency, and head turn excursion for each player. McGuckian et al. (2020) reported the ball possession, phase of play, location on the pitch, and playing role constrained the way players visually explored their environment. They found players explored more extensively when they were in possession of the ball in comparison to when they were not. The authors suggested players were not searching as much prior to ball possession and thus compensated and searched more when they received possession. In a defensive or attacking area on the pitch, players explored more than they did in central or neutral areas despite being surrounded by teammates and opponents in the central areas which offered an abundance of visual information. McGuckian et al. (2020) proposed that players should develop their visual searches in the central pitch areas. The players also searched more when their team had possession of the ball compared to when the opposing team had possession and transition phases when there was no clear possession. McGuckian et al. (2020) suggested there may be less searching in transition phases due to the uncertainty of the situation and the increased task demands. The authors also reported that players were only in possession roughly 2% of the playing time, and they argued that players should develop their searching abilities outside of ball possession. McGuckian et al. (2020) suggested that perception—and the visual behaviours that underly it—forms the base of a person's SA, therefore it is important that players are able to increase their searching abilities in times outside of possession to increase their SA.

Yet, despite this mention, this study did not measure the relationship between visual search behaviours and SA explicitly. Because perception (Level I SA) is the foundation for good SA (Endsley, 1995b), sports studies investigating SA should ideally explore the relationship between visual behaviours. Other domains, such as driving, have identified visual search strategies and their effect on SA (Haupt et al., 2015; Scott et al., 2013; Underwood et al., 2003). Generally, more experienced drivers exhibit more effective and wider search strategies and also have better driving performance and SA (Konstantopoulos et al., 2010; Mackenzie & Harris, 2015). This is theorised to be because experienced drivers have a better developed mental model gained from experience and are thus better equipped to search their surroundings for hazards (Underwood et al., 2002). Additionally, it is possible that experienced drivers exhibit a wider search due to their automation of controlling the vehicle, which frees up cognitive resources to devote towards visual searches (Mackenzie & Harris, 2017). Novices, on the other hand, must divide those resources between controlling the vehicle and conducting a visual search, so therefore, their visual search may be contracted as they struggle to maintain the vehicle and scan the roadway for hazards (Underwood, 2007). In sports, many studies have examined gaze behaviours (Binsch et al., 2009, 2010; Panchuk & Vickers, 2006; Panchuk et al., 2017; Vickers, 1996), but few have related those behaviours to SA explicitly. Therefore, it is important to examine how sports participants use perception and visual behaviours to achieve SA within a sporting domain.

1.3.3.2 Anticipation.

Anticipation has long been investigated within sporting contexts (Loffing & Cañal-Bruland, 2017; Williams & Jackson, 2019). Projection (Level III SA) is often seen as the ability to anticipate or predict what may happen next in the environment (Jackson et al., 2009). Therefore, it can be argued that anticipation and SA are highly related. Information from athletes' bodies, kinematics, and equipment is often used to anticipate shot direction (Cañal-

Bruland, Zhu, et al., 2011), movement (Loffing et al., 2015a), and deceptive actions (Wood et al., 2017), which affect sports performance.

Caserta & Singer (2007) investigated how anticipation and SA training in tennis influenced performance on a tennis-related video task (identify where to position oneself to return a shot). Training was instruction-based and, depending on the experimental condition, informed participants about: the most important cues to attend to (visual), the meaning of those cues (understanding), how to use this information to anticipate shots (anticipation) and how to respond effectively (decision-making). After training, each participant viewed several tennis video clips and were required to choose a location to return a shot by manually pressing buttons that represented areas of a tennis court. The results were that, overall, the training groups responded faster than the control group (no instructional training) but there was no difference in accuracy (Caserta & Singer, 2007). The training had perhaps enhanced the awareness of strategies, court positioning, and shot tendencies and thus allowed the training groups to make faster decisions (Caserta & Singer, 2007). The authors proposed that athlete performance can be improved with training SA, anticipation, and decision-making (DM) skills rather than years of developing physical skills. Importantly, Caserta & Singer (2007) argued that training perceptual skills should go beyond isolating anticipation and DM and should instead combine the skills associated with SA to provide athletes with a complete set of perceptual tools. The results of Caserta & Singer (2007) lend credence to the idea that SA is important in dynamic sports contexts, and that training SA and anticipation skills may be effective in assisting athletes' DM processes.

1.3.3.3 Decision-making.

The decision-making (DM) abilities of athletes have long been explored by researchers and practitioners. Researchers generally accept that SA is an important foundation for DM and ultimately performance (Mason, 2020). Many also agree that DM in complex environments, such as sports competitions, requires extensive domain expertise that is acquired through many hours and years of practice and experience (Hutton & Klein, 1999; Macquet & Fleurance, 2007). In a SA context, DM is influenced by an individual's ability to take in all relevant sources of environmental information, combine that information using knowledge from past experiences, and physically respond to that information (Murray et al., 2018). Researchers also argue that SA is an important precursor to DM (Endsley, 1995b), meaning that better SA may lead to better decisions.

Murray et al. (2018) investigated how SA influenced the decision of which shot to play in expert squash players. Over 40 squash matches were recorded, and player shot type, player position and movement, and ball position were tracked using squash game tracker technology. Based on these quantifiable aspects of play, the authors conducted a cluster analysis to identify categories of shot-outcome. The analysis revealed six, what the authors termed, "SA clusters" that related to the shot the player decided to play. For example, an "attempted winner", was revealed as a cluster that often resulted from when the player identified the opponent was out of position and the player was facing low pressure (*i.e.,* more time to play the shot). Conversely, a "defensive" cluster was identified, and this was a shot outcome that would result from when the player was facing high pressure (*i.e.,* where the distance they would have to travel to make the shot was large or the time they had to make the shot was short). The authors suggested this method and the results allowed for a fine-grained analysis into the reasons for differences in behaviour and decision making within expert-level players. And this is an important addition to the field, where much of the research into differences in behaviours within sports addresses the differences between expert groupings (novice/amateur/professional).

The terminology of “SA cluster” is somewhat misleading, however, as it seems these clusters are categorized as decision-making outcomes rather than SA itself. SA is arguably more related to the analysed components that fed into the corresponding cluster (*i.e.,* having awareness of an opponent’s position or awareness of how long one has to make a shot). The authors make an inference that the players had SA related to these parameters that then may have influenced the decision of which shot to play, but there was no measure of SA per se. Successful decision-making is likely, at least in part, a result of successful SA (Endsley, 1995b) but is not the same as SA. This distinction is not made particularly clear in the research by Murray et al. (2018).

1.3.4 A summary of Situation Awareness in sports.

This scoping literature search examined SA in sports, focusing on three research aims: Within sports, identifying the different types of frameworks labelled as SA, discussing the methods used to directly assess SA, and describing the cognitive skills that have been explicitly linked to an SA framework. Findings confirmed there is a paucity of sources that report studies of SA within sporting contexts. In the following sections, the key findings, implications, present suggestions for future studies of SA in sports and how these principles are important in equestrian polo and for this current thesis will be discussed.

1.3.4.1 Issues with descriptions in Situation Awareness frameworks used in sporting contexts.

Perhaps one of the more surprising findings in this review is the scarcity of using the more tangible three-level SA framework in a sporting context. It has been investigated in other domains such as aviation and driving and is able to provide quantifiable insights into the nature of SA and how it might link to sporting performance. As such, one would argue this is an appropriate starting point for investigating SA in sports. Yet, in much of the research described, analyses relating to SA frameworks have been somewhat retroactive. That is, games have been recorded and then researchers make inferences based on the behaviour observed (Knez & Ham, 2006; Murray et al., 2018). Whilst this approach has benefits such as being able to analyse naturalistic behaviour, it often results in very descriptive research; research that appears to provide only surface level observations of what information a human or digital agent may hold. From the literature search, there was ultimately a lack of testability and replicability in SA frameworks used in sports, namely with the Distributed Situation Awareness (DSA) and Shared Situation Awareness (SSA) frameworks. The descriptive nature of these frameworks makes it difficult to compare results across the studies and draw conclusions on the importance of SA in sports. While DSA and SSA acknowledge the importance of team communications and technological agents in SA, they do not provide a reliable and/or valid method of measurement. Nor do they provide an in-depth measure of performance or decision-making or indicate the sufficiency of SA. There is no discernible component to DSA and SSA which allows one to conclude if a person's SA is good or bad, and there are no performance measures described to correlate with the SA. Consequently, the implications for training and assessment become limited, which are aspects that are often targeted in sports cognition (Caserta & Singer, 2007; McGuckian et al., 2020; Patrick & Morgan, 2010). If SA in sports is to be trained as a means to aid performance, as it has been in other domains (Mason, 2020; Salehi et al., 2018), including driving (Horswill et al., 2013; Wetton et al., 2013; Young et al., 2017), and aviation (Muehlethaler & Knecht, 2016), arguably quantifiable measures of assessment in SA frameworks are needed. This need is then addressed in the empirical chapters of this thesis in which SA assessment methods are validated within a sports setting, providing valuable empirical data to this domain.

1.3.4.2 Underdeveloped methods of assessing Situation Awareness in sporting contexts.

Providing individual assessment of SA in sports is hugely important as 1) many sports are individual based (*e.g.,* squash) and 2) even in team sports, team performance is (usually) a culmination of individual performances. As demonstrated in other domains, Endsley's (1995a) SAGAT method appears reliable for assessing individual SA (Crozier et al., 2015; Dishman et al., 2020; Endsley, 2000a; Ikuma et al., 2014; Jannat et al., 2018; Joffe & Wiggins, 2020; Kaber et al., 2016; Lavoie et al., 2016) given its link to the three-level framework. As such, this is likely again a good starting point in assessing SA in sport. Other methods identified as providing assessment (or claiming to) for individual SA included the Cognition Self-Assessment Tool (CSAT) and Random Number Cognition Test (RANCT) (Knez & Ham, 2006). There were issues relating to the validity of SA measurements in sport which was most salient with the RANCT which appeared to assess visual search/identification and not SA. Beyond this, no research had demonstrated a level of validity in their tool (including SAGAT) by comparing performance between, for example, novices and experienced, 'more expert' sports players, or even winning and losing teams. One could argue that identifying performance differences across these groups would identify expertise effects suggesting a level of validity in the tool (if, of course, the more experienced or expert players perform better than novices). This type of comparison is commonly seen in What Happens Next? (WHN) tools in driving;

for example, Kroll et al. (2020) have shown that emergency response drivers outperformed control drivers in a WHN task based on the SAGAT. The WHN paradigm will be described and employed in Chapters 4 and 5 of this thesis. The WHN paradigm, which is largely based on the SAGAT methodology, was chosen ultimately for its ease of use. Instead of developing complicated GDTAs and queries for each scenario, the only question asked is, "What happens next?". This question specifically targets the Level III SA (projection) and has been shown to successfully infer a person's overall SA (Jackson et al., 2009).

The reviewed studies also gave conflicting results regarding the relationship between physical performance and SA, with Ng et al. (2013) stating no relationship between actual performance and SA, and Knez & Ham (2006) stating the opposite. Given the scarcity of research, it is difficult to make any claims here linking 'adequacy of SA' and sporting performance. Developing more quantifiable and sensitive measures of SA would benefit the field whereby one might be better able to identify the link between SA and sporting performance. These measures might also identify the possible disconnect between level of SA and sporting performance where, for example, an avid soccer viewer has high level of SA but is physically unable to perform. For this thesis, however, the performance measurements used will be the outdoor polo handicap, a number between -2 – 10 'goals', awarded by the player's country's governing body (*e.g.,* United States Polo Association [USA], Hurlingham Polo Association [UK], Asociación de Argentina de Polo [Argentina]). Handicaps are awarded based on a player's experience, level of play, horsemanship, ball-handling abilities, and game sense (Dale, 2015; Darroux, 2016). A higher handicap number generally denotes better playing performance (USPA, 2020). The handicapping system is not a perfectly objective system (see Chapter 2, Section 2.7.2); however, it is the best measure given the absence of actual game-play performance data and statistics from each polo player.

1.3.4.3 Cognitive skills, Situation Awareness, general limitations, and concluding remarks.

The cognitive skills directly linked to SA in sports were visual behaviours, anticipation, and decision-making (Caserta & Singer, 2007; McGuckian et al., 2020; Murray et al., 2018). Notably, the SA in sports literature did not identify any cognitive skills associated with Level II SA (comprehension). The three-level framework of SA acknowledges that these cognitive skills contribute to SA or, in the case of decision-making, is a potential product of SA (Endsley, 1995b). Many sports studies have alluded to the importance of SA, but either only isolate a particular cognitive skill to study (Macquet & Fleurance, 2007; Macquet, 2009), or in the case of McGuckian et al. (2020), do not demonstrate how the cognitive skill (visual search) relates to SA. Owing to the vague descriptive nature of the Distributed Situation Awareness (DSA) and Shared Situation Awareness (SSA) frameworks one might question if the role of cognitive skills is supported by or indeed relevant to DSA/SSA. The role of cognitive skills in acquiring DSA/SSA is currently unclear rather than them not being important. Thus, one of the advantages of the three-level framework is the potential to identify how SA can be acquired by means of the individual, yet interacting, components including the cognitive skills. Research into the possible cognitive skills that would be related to DSA/SSA would also be warranted. Where, for example, in the case of DSA, visual search would likely be very important for sports officials in aiding in the decision of the legality of a play.

However, there is one, potentially of the greatest importance, aspect to sports SA research that is missing from the literature. How is SA acquired in the first place? Endsley's (1995b) three-level framework lists perception as the lowest level of SA, but this does not answer the question of how athletes go about perceiving their environment. What are their scan paths? What visual cues are important in SA acquisition? Are these visual cues sport specific, or is there transfer between sports? How does prior knowledge and experience factor into the equation? Plenty of researchers have alluded to visual cues (*i.e.*, postural cues, kinematic cues) that may aid in anticipation abilities (Jackson & Morgan, 2007; Loffing & Cañal-Bruland, 2017; Smeeton & Huys, 2011; Wright et al., 2011), but few at the time of writing directly link those visual cues to SA (see Caserta & Singer, 2007). What is arguably missing here in sports SA research is 1) a body of research that better links cognitive skills to SA and 2) a body of research that investigates the interaction between these cognitive skills and their relation to SA, and finally, 3) a body of research which explores how SA is acquired and maintained during sports. This thesis, in the experimental chapters, aims to validate different SA assessment methods while investigating the roles of cognitive skills and visual cues in sports (in particular, equestrian polo) SA abilities. Lastly, or perhaps, most importantly, this thesis aims to explore the importance of sport experience that may aid in the acquisition of SA.

The purpose of this review chapter was to identify the different types of frameworks labelled as SA, discuss the methods used to directly assess SA, and describe the cognitive skills in an SA framework. A scoping review was conducted on the current literature of SA in sporting environments. It was found that Endsley's (1995b) three-level framework and Distributed Situation Awareness (DSA) were the most mentioned frameworks of SA in sports, while the methods used to directly assess SA in sports varied across studies and sports. Lastly, the cognitive skills of visual behaviours, anticipation, and decision-making were directly linked with SA in sports. Ultimately, to advance the field of SA in sports, researchers might find advantage in grounding their research within the three-level framework (at least initially), identify quantifiable ways to assess individual and team SA, identify how significant SA or the elements of SA are in relation to performance in naturalistic contexts, and explore the roles of visual cues in acquiring SA in sports.

1.4 Thesis overview

The literature reviewed provided an in-depth look into the previous work done in the fields of equestrian polo and SA in sports. It has highlighted that, to date, there has been no research into the cognitive skills of polo players. Additionally, and perhaps of more importance, it has also highlighted that the literature of SA in sports—and overall—is underdeveloped, with discrepancies in frameworks, a lack of empirical studies, and missing links and interactions between isolated cognitive skills, such as visual search behaviours, anticipation, and decision making, and SA as a holistic framework. This ultimately gives the thesis its overarching aim: to investigate the SA abilities of polo players using objective methods resulting in empirical data. The thesis, more importantly, delves into the validity of static and dynamic assessments of SA, investigates the role of sports experience on SA, and explores SA training interventions developed from the methods and cognitive skills presented in this review. This thesis is segmented into three phases: Phase I—exploring the validity of a static-image Level I SA (perception) assessment and investigating the importance of visual cues in perception; Phase II—validating a dynamic task which investigates the role of prediction in SA; and Phase III—exploring prediction training and the visual search behaviours associated with SA in a sports task.

Phase I (Chapter 3: Studies 1.1 and 1.2) uses a static image 'Spot the Ball' (STB) method, where participants (polo players, soccer players, and controls) are asked to locate a missing ball on a series of images with different sports, gaze, and grouping conditions. The overall aim of the STB studies is to investigate the validity of a novel static-image Level I SA (perception) assessment method in a sports setting, as well as exploring the role of experience and visual cues in sports perception tasks. Visual cues, such as gaze, body positioning, and field grouping, can provide beneficial information that athletes may use when anticipating shot direction (Smeeton & Huys, 2011), therefore, this phase aims to understand which visual cues are the most important in polo—and soccer—perception tasks.

Phase II (Chapter 4: Studies 2.1 and 2.2) uses a dynamic video 'What Happens Next?' (WHN) method, where participants (polo players, athletes, controls) are asked to watch short polo video clips and predict what may happen next following an occlusion. The overall aim of the WHN studies is to validate a dynamic SA assessment for use in sports and to investigate the role of anticipation and decision-making in sports SA. The WHN paradigm is commonly used in driving to assess a driver's ability to anticipate hazards and other road occurrences but has never before been used in a sport setting where a player must anticipate a pass to a teammate or defensive manoeuvre. Additionally, this phase aims to segregate offensive and defensive plays. In sports, offensive and defensive athletes typically have differing roles and positions on the field, and this phase will investigate the role of play type on prediction as well.

Phase III (Chapter 5: Study 3) uses visual cueing and expert commentary cueing over video clips to train polo SA in participants with no prior polo experience. It was chosen to train individuals with no experience, rather than train those who have had previous experience and would potentially—based on the findings of sports (Wimshurst et al., 2012) and transportation training literature (Castro et al., 2016; Horswill et al., 2013)—show a larger training effect, in order to develop and validate an off-horse polo training package. Polo is, as has been discussed previously in Section 1.2, a highly dangerous sport, particularly to new players. Thus, developing a training method to introduce new players to the sport in a safe environment is warranted. Though, it is important to acknowledge that a more robust scientific venture would be to first explore the visual behaviours of polo players (likely, more expert) polo players prior. This would provide a more empirically-driven set of findings with which to develop the training programme.

In this study, participants' eye movements (fixation counts, durations, and dispersions) are measured in WHN tests before and after training. The training packages include cues (visual and commentary) based on the findings of the previous experimental chapters to train participants to direct their attention to locations off the ball. The overall aim of the training study is to tie in the results from the STB and WHN studies and develop a SA training method, while also exploring the role of visual search and eye movement behaviours in a sports SA task. While transportation research has shown positive SA training effects on novice drivers (Wetton et al., 2013), and sports have successfully improved athletes' SA with a brief training package (Caserta & Singer, 2007), there have been no such studies examining sports SA training using a WHN paradigm on participants with no prior experience. Therefore, this phase aims to investigate if training SA by guiding attention to relevant locations is sufficient at improving SA in complete novices.

The General Methods chapter (Chapter 2) provides an overview of methods, apparatus, and stimuli used for each study. Each experimental chapter (Chapters 3, 4, and 5) discusses the individual studies' designs and results and provides a discussion with limitations and future directions. Finally, the General Discussion chapter (Chapter 6) summarises the experimental results and further considers the theoretical and methodological limitations, practical applications, and future directions of the research of SA in polo, and in sports as a whole.

Chapter 2 General Methods

This chapter will provide an overview of the general methods, the stimuli and their creation, and the apparatus used throughout the entire thesis. It will discuss the effects from the Covid-19 pandemic on data collection, the advantages and disadvantages of conducting research online, the apparatus and methods for editing stimuli, and finally the statistical tests used during data analyses, including linear mixed effects modelling and binary logistic mixed effects modelling. Each experimental chapter (Chapters 3, 4, and 5) will describe the individual methods (*i.e.,* design, stimuli, and procedure) in more detail.

2.1 Introduction and Covid-19 statement

The methods used for each study in this thesis were largely shaped to fit the constrictions that arose from the Covid-19 pandemic, however, there was theoretical rationale and literature to support these methods. Originally designed as an *in-situ* thesis using in-person data collection, the methods were forcibly adapted to fit the requirements of government-mandated social distancing. The original PhD proposal involved measuring polo players' behaviour across a three-phase study programme. Specifically, and imperatively, this involved the filming of polo games across the projects to generate appropriate stimuli. This would have included general filming of live polo games via drone capture in the first phase, head-mounted camera capture in the second phase, and real-time eye movement capture (using eye tracking glasses) in the third phase. This programme was approved 20 March 2020. Please see the Covid-19 statement at the beginning of the thesis for details on how the programme was altered to adhere to government guidelines. Given the guidelines at the time restricting face-to-face experimentation, the methods were changed to online data collection methods. The following chapter details the general methods used in the thesis.

2.2 Covid-19 and the advantages and disadvantages of online research

Because the pandemic and government advice prevented face-to-face data collection for the bulk of 2020—2022, the studies that comprise this PhD project were largely conducted online with the exception of the final study (Chapter 5: Study 3), which was conducted in a laboratory setting. What was originally planned to be a thesis of laboratory-heavy studies in eye movement behaviours turned into a thesis of mostly online studies assessing Situation Awareness (SA) in polo through image and video tasks. Of course, this thesis is not the only evidence of a growing movement in online research. Many researchers and institutions have conducted more and more research online (Andrade, 2020; Janssens & Kraft, 2012; Wright, 2005), particularly with the current global pandemic causing intermittent disruptions to in-person meetings. As with any method, however, there are advantages and disadvantages to conducting research online which should be discussed. This section will provide an overview of the advantages and limitations of online research and how they relate to this PhD thesis.

The main advantage of conducting research online is its ability to circumvent the need for face-to-face data collection, particularly during a pandemic when social distancing was mandatory or highly suggested (Andrade, 2020). This allowed for a safer means to collecting data for both the participant and experimenter. Additionally, the experiments were disseminated to a much larger sample population than face-to-face data collection would have allowed (Andrade, 2020; Lefever et al., 2007). Indeed, online research has been shown to produce larger sample sizes with higher statistical power than in-person data collection (Sassenberg & Ditrich, 2019). Through the help of the United States Polo Association (USPA) and Hurlingham Polo Association (HPA), the links for the online experiments were distributed to United States and United Kingdom polo players, resulting in a possible reach of 8000 players (5300 in the United States and 2700 in the United Kingdom) (Darroux, 2016). Reaching such a wide participation pool in a short amount of time would not have been possible with in-person data collection. Similarly, with the studies circulated online, participants were free to partake in the studies at their leisure. They were not required to make an appointment with the researcher and travel to the lab for a quick experiment but could instead complete it in the comfort of their own home. Overall, posting the studies online made collecting data more efficient.

The platforms used for creating the experiments (in this research programme: Qualtrics and Gorilla Experiment Builder) created another advantage for conducting online research. These platforms are generally cost-effective if accessing them through a university license

(Andrade, 2020), easy to use for researchers, even those without extensive programming expertise (Wright, 2005), and easy for participants to respond to and partake in the study. Both Qualtrics and Gorilla Experiment Builder (discussed below) are advantageous to use because they also automatically store data in usable formats, such as Excel files (Wright, 2005), and they protect against accidental data loss (Lefever et al., 2007). Qualtrics (Qualtrics, Provo, UT) stores data protected by advanced firewalls with regular scans to identify any weaknesses so that they may be repaired. Qualtrics also holds several data safeguarding certifications (SOC 2 Type II, ISO 27001, 27017, 27018) and a FedRAMP authorization standard for US government security. Gorilla Experiment Builder (www.gorilla.sc) stores data in the Republic of Ireland and has a backup storage located in the Netherlands. Additionally, Gorilla Experiment Builder adheres to the British Psychological Society (BPS) and National Institute of Health Research (NIHR) standards in addition to General Data Protection Regulation (GDPR) legislation. Therefore, both Qualtrics and Gorilla Experiment Builder are considered safe and reliable platforms for creating and hosting experiments.

There are, just as with any method of research and data collection, limitations to online research that should be discussed. These limitations were considered carefully, and they were mitigated as best as possible. The first set of limitations to online research pertains to the participant population sample. By the nature of online research, experimenters are largely unable to control who responds to survey/task/experiment (Lefever et al., 2007), which can ultimately lead to issues with participant recruitment. One such issue is sampling bias, where participants may choose to respond to the recruitment call due to their interest or abilities in the subject (Andrade, 2020; Wright, 2005), which in turn affects the random sampling and could potentially skew the results towards larger Type I errors, in which the null hypothesis is falsely rejected (Banerjee et al., 2009; Janssens & Kraft, 2012) because the sampling is not a true representation of the population. To counteract these issues as much as possible, the study links were distributed through numerous online channels, such as social media, organisation email lists, and university student populations, rather than just focusing on recruitment from one particular area (*e.g*., recruiting participants only through the experimenter's Facebook).

Because the experimenter was not physically present during data collection, there was no way to ensure the responses given by the participant were correct and non-fraudulent (Chandler & Paolacci, 2017; Lawlor et al., 2021). Preliminary examination of the data can identify if participants did not give true responses, for example, answering all A's in multiple choice questions, or clicking the same spot on the screen during an object-finding task. However, it is easy for participants to lie or make up demographic information online (Chandler & Paolacci, 2017; Storozuk et al., 2020), such as their polo handicap rating, or level of sporting experience. This is not easily detected or remedied, unfortunately, but in-person data collection also carries this risk (Chandler & Paolacci, 2017). A recent risk to fraudulent responses has arisen with bots responding to the surveys, especially if there is a monetary reward attached to the completion of the study (Storozuk et al., 2020). Fortunately, many of the experiment hosting platforms have added bot-checking options to their software such as CAPTCHA (Completely Automated Public Turin tests to tell Computers and Humans Apart), thus mitigating this risk. Other methods of detecting bots involve examining the email and IP addresses, open-ended responses, and completion time of the participants (Storozuk et al., 2020). Data collected for the thesis that seemed fraudulent were closely examined and removed from analysis.

Another set of limitations from online research arise from the technical side of creating, hosting, and distributing experiment links. For instance, participants were required to have internet access and a device to complete the experiment, such as a mobile phone, computer, or tablet (Andrade, 2020). This can unintentionally exclude participants who do not have internet access or devices. However, a report released by the International Telecommunications Union (ITU) showed that the majority of the United States and United Kingdom have internet access

(89% in the United States and 95% in the United Kingdom) (ITU, 2022), and a separate report showed that mobile smartphone access reached 81.6% of the population in the United States and 78.9% of the population in the United Kingdom (Lariccha, 2023); therefore, the issue of internet accessibility was considered negligible.

Online studies can come with a high participant drop-out rate, with one study showing 10% of participants drop out immediately, with an additional 2% dropping out for each 100 items in a survey (Hoerger, 2010). This can ultimately affect the quality of the data because as more participants drop out, the less representative the sample is of the overall population (Hoerger, 2010). This was seen in multiple studies in this PhD project, where many participants responded to the study link but failed to complete the task. One method to lessen the likelihood of participants dropping out of the study is to make the experiment length as short as possible to reduce participant fatigue and boredom (Hoerger, 2010). Another method is to include payment or rewards for completing the study (Frick et al., 1999). Through the Nottingham Trent University SONA system, any student who completed the experiments were awarded with credit points which are required to collect data for their final-year undergraduate projects. In this project, there was a low student participant drop-out rate when incentivised with SONA credits; additionally, Studies 2.2 and 3 provided non-student (*i.e.,* non-NTU students not eligible for SONA credits) participants with a £10 Amazon voucher, which greatly improved the completion rate of the individual study and eased the burden of participant recruitment, suggesting a reward system is useful for recruiting and retaining participants.

Lastly, online experiments are somewhat limited in the type data they can collect. For instance, it may be more difficult (albeit not impossible) to collect eye movement behaviours or other biological data such as brain activity, heart rate, or skin response to stress using online methods (Brock & Laifer, 2020). However, laboratory settings using specialised equipment and calibration procedures have been shown to be more accurate than web-camera, particularly when measuring eye movement behaviours (Semmelmann & Weigelt, 2018). Therefore, the researcher must decide what type of data is needed for the study and then decide the best method for collecting that data. For this thesis, the first four studies did not require any biological data—only behavioural data easily collected through specific experiment platforms. However, from this behavioural data, inferences can still be made about participants' cognitive abilities (Alhadad, 2018; Gigerenzer, 1991). For instance, higher accuracy in the STB and WHN tasks can indicate that a participant has better perception and anticipation—and thus SA—abilities compared to participants with lower accuracies. This has been shown in the literature with SA and Hazard Perception and Hazard Prediction tasks in the transportation field (Crundall & Kroll, 2018; Horswill & McKenna, 2004). Researchers can infer a driver's experience level and capability through their behavioural and performance data in various video-based tasks, with experienced drivers typically out-performing their novice counterparts (Crundall, 2016; Crundall & Kroll, 2018). Additionally, cognitive load and processing skills can also be inferred from simple behavioural data. For instance, drivers who perform worse on the Hazard Perception tasks (*i.e.,* respond to a hazard too slowly or not at all) arguably have longer processing times and potentially a higher cognitive load which may cause them to insufficiently search their environment and miss potential hazards (Borowsky et al., 2010; Borowsky & Oron-Gilad, 2013; Crundall, 2016; Kaber et al., 2016; Kinnear et al., 2013; Kovácsová et al., 2020; Mackenzie & Harris, 2015; Underwood et al., 2011, 2013). Therefore, behavioural data collected through online means still provides valuable information about sports cognitive skills and processing in SA tasks.

2.3 Experimental stimuli editing software and processes

2.3.1 Adobe® Photoshop®.

2.3.1.1 Phase I: 'Spot the Ball' studies.

The 'Spot the Ball' (STB) tasks presented in Studies 1.1 and 1.2 used open-source Google images of polo (and soccer) static-image stimuli and asked participants to predict the location of a digitally removed ball. Study 1.1 used 40 polo and 40 soccer images, and Study 1.2 used 80 polo images which were obtained from open access internet sources, such as Google images and Shutterstock. The stimuli (saved as JPEGs) were all high-resolution images (300 dpi) and were taken within the last 10 years. The images were sorted into conditions with the aim of identifying the visual cues beneficial to prediction. The stimuli images for the studies in Chapter 3 were edited using Adobe® Photoshop® software (Version 22.1.0) licensed through Nottingham Trent University. A Think Centre computer and Samsung monitor were used during the editing process. Each image selected to be used as stimuli for the studies was uploaded into Adobe® Photoshop® and sized to 960 x 640 pixels (landscape orientation) or 640 x 960 pixels (portrait orientation) (Figure 2.1). For each image, the center of the ball was recorded using pixel Cartesian (x, y) coordinates and imported into an Excel file with the image name and the coordinates. Once the coordinates were recorded, the ball was digitally removed in each image.

Figure 2.1 *Screenshot of Adobe Photoshop editing interface showing how to change the pixel dimensions (inset).*

To remove the ball, the Lasso tool was used to draw a circle around the ball, thus selecting the area to be removed (Figure 2.2).

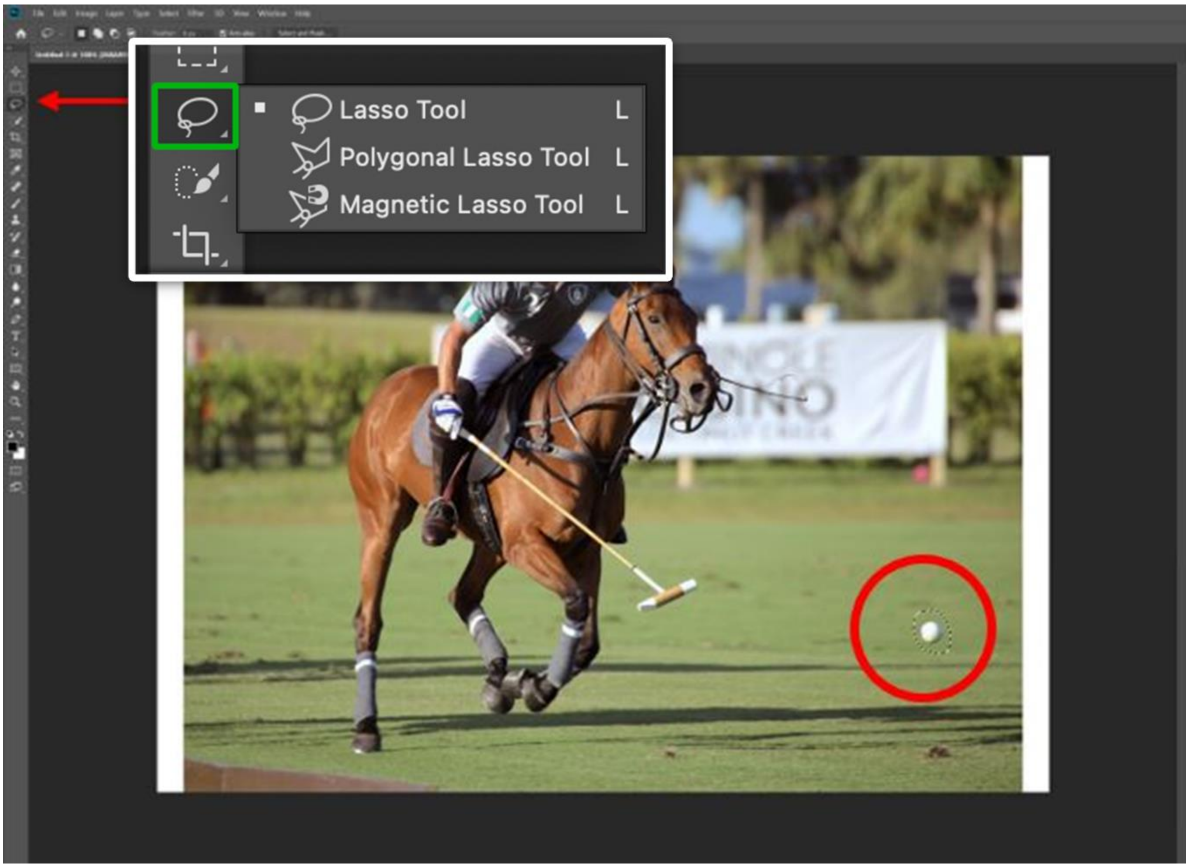

Figure 2.2 *Screenshot of Adobe Photoshop editing interface showing how to use the Lasso tool (red arrow and inset) to select the ball to remove it (red circle).*

Then, with the Fill command (Edit > Fill) with the Content-Aware option selected, the ball was removed from the image (Figure 2.3). To ensure a seamless removal, the Blending Mode was set to Normal, and the Opacity set to 100%.

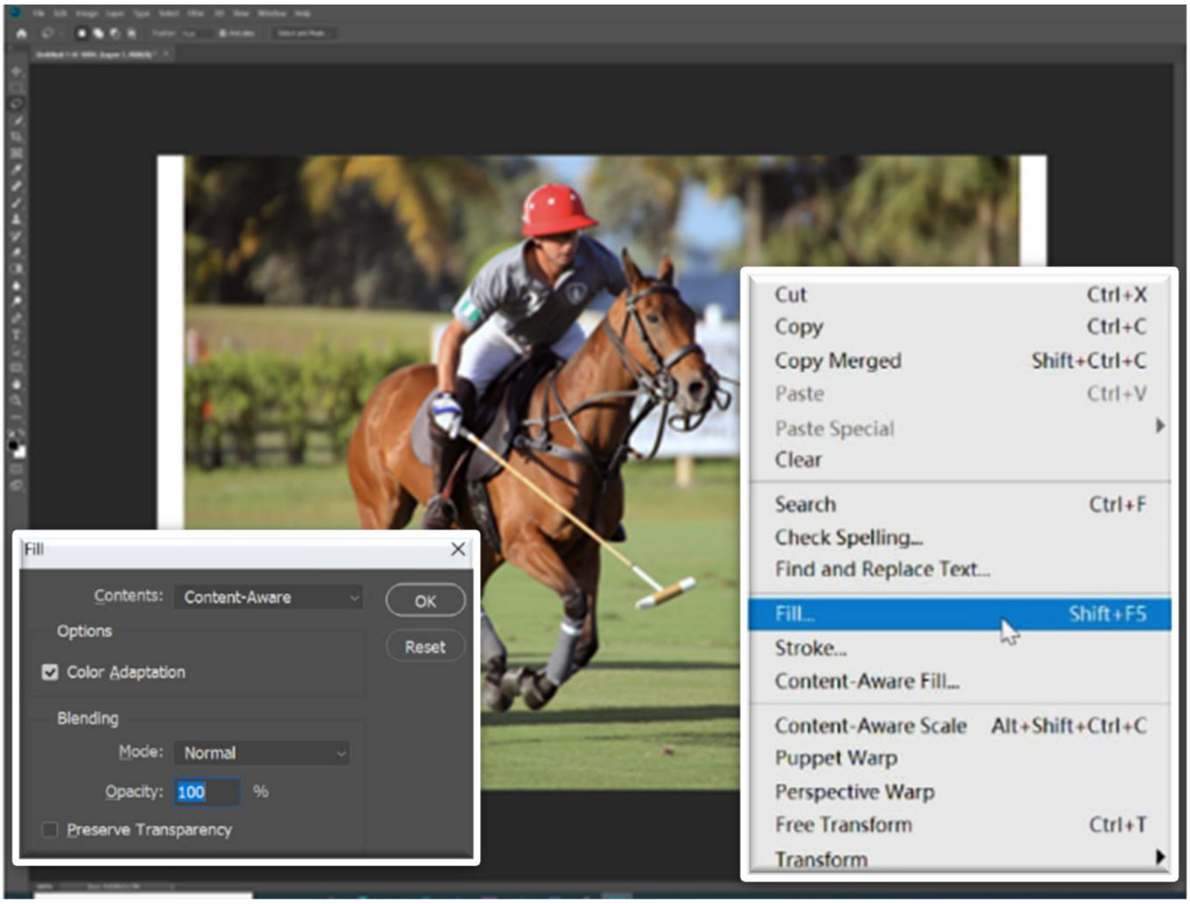

Figure 2.3 *Screenshot of Adobe Photoshop editing interface showing how to use the Fill option (right click > Fill) (right inset) to remove the ball. The Content Aware option was selected (left inset).*

If the image needed to be touched-up (*i.e.,* the removal process left patchy areas) the Clone Stamp tool was selected to blend the surrounding areas, such as grass texture (Figures 2.4 and 2.5).

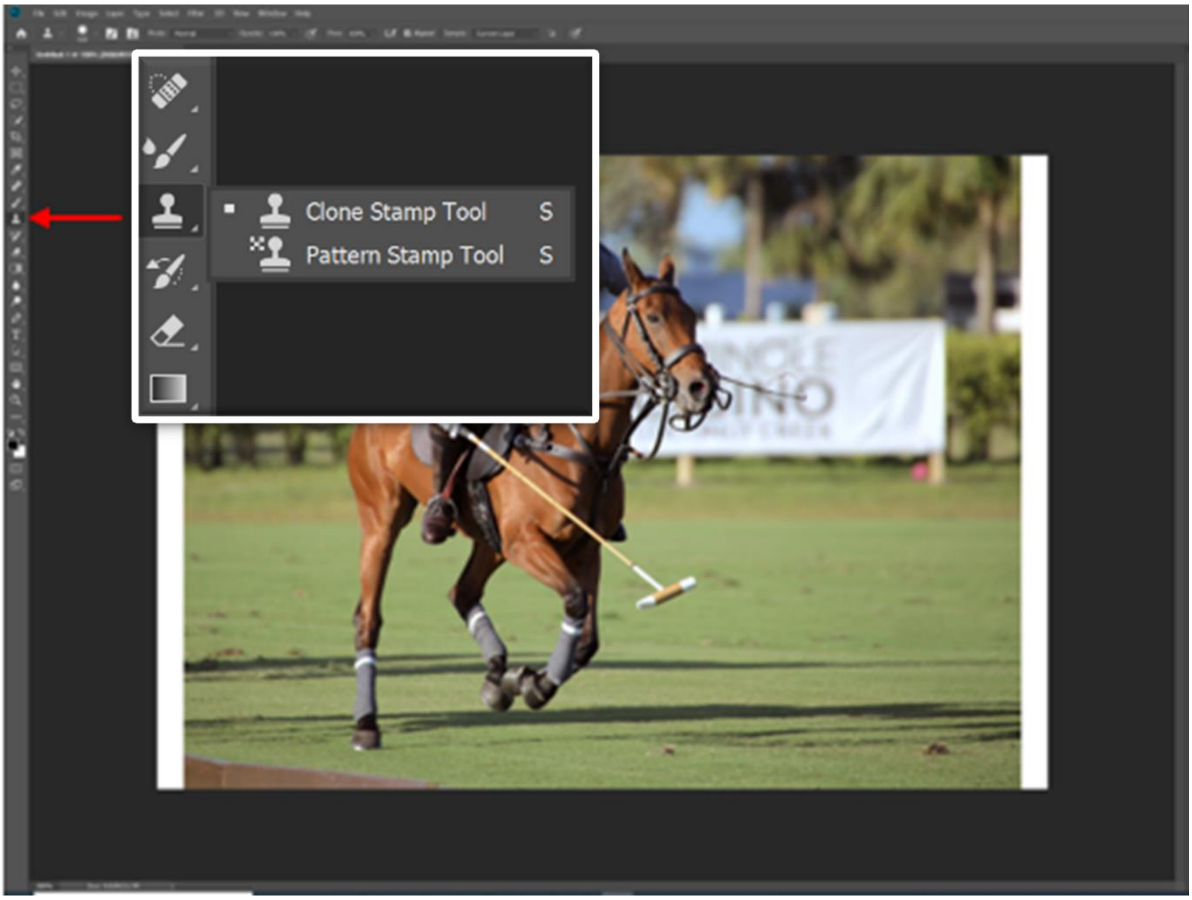

Figure 2.4 *Screenshot of Adobe Photoshop editing interface showing how to use the Clone Stamp (red arrow and inset) to blend the area around the removed object.*

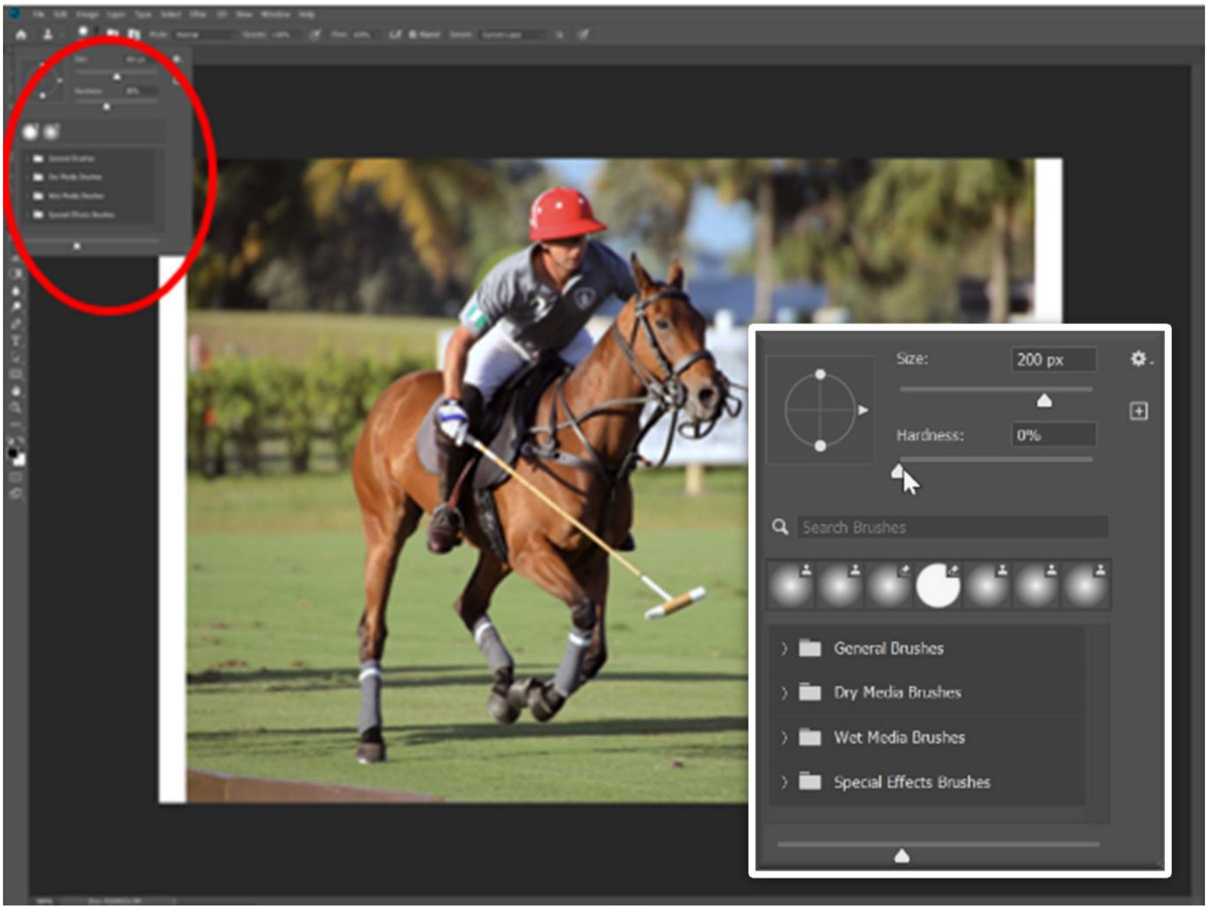

Figure 2.5 *Screenshot of Adobe Photoshop editing interface showing how to use the Clone Stamp tool and brush effects (red circle and inset) to blend the area around the removed object.*

The same process was repeated for the stimuli in Study 1.2 where the polo mallet was removed in addition to the ball. Each image was exported as a .jpg file (Figure 2.6).

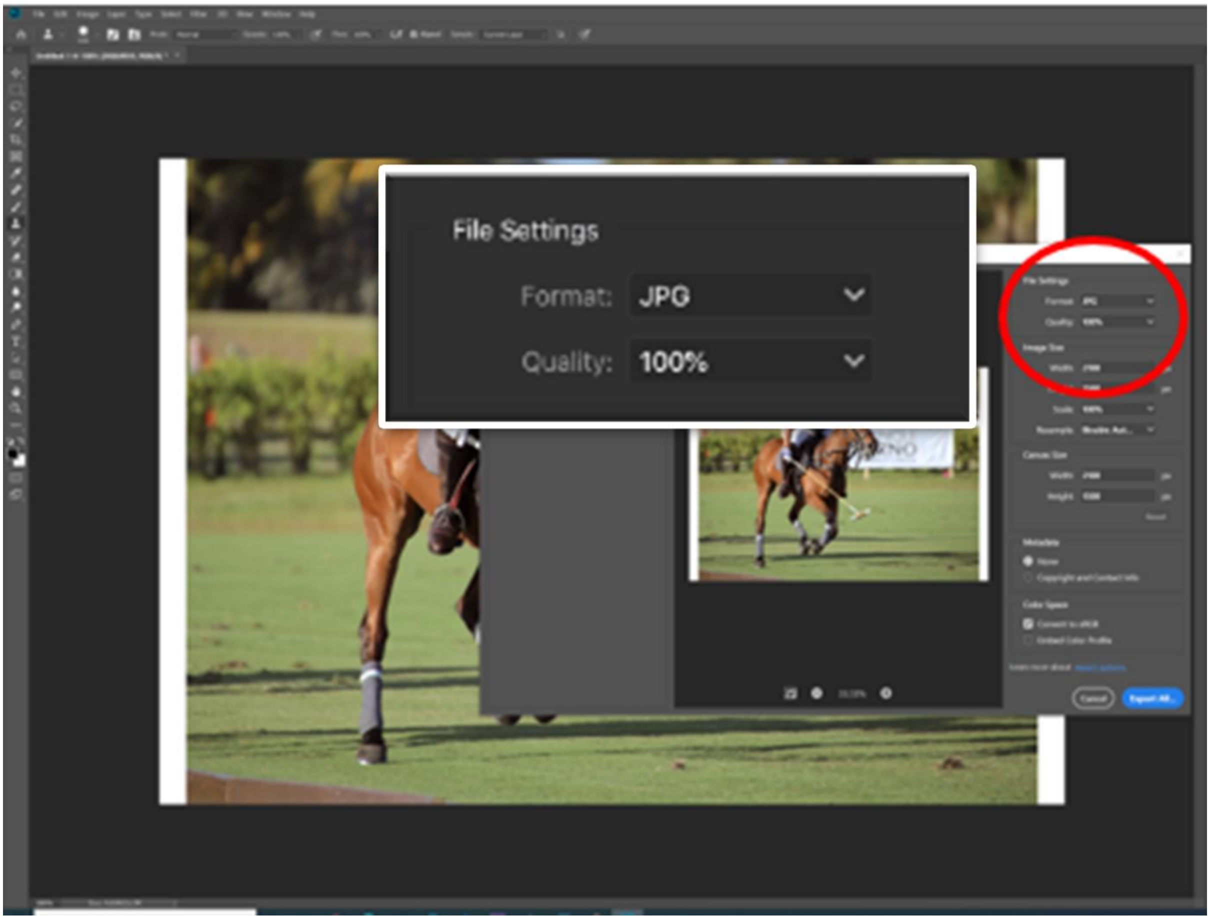

Figure 2.6 *Screenshot of Adobe Photoshop editing interface showing how to export (File > Export > Export As) the image in a .jpg format (red circle and inset).*

2.3.2 Adobe® Premiere Pro®.

2.3.2.1 Phase II: 'What Happens Next?' studies.

The 'What Happens Next?' (WHN) tasks presented in Studies 2.1, 2.2, and 3 used short polo video clips obtained with permission from Global Polo TV (see Appendix 2 for permissions grants), separated into offensive and defensive conditions, which paused randomly and prompted the participant to predict what would happen next. Studies 2.1 and 2.2 used 18 video clips (9 offensive and 9 defensive), and Study 3 used 41 video clips (18 in the Pre-training

WHN test, 5 in the training conditions, and 18 in the Post-training WHN test). Each video clip was chosen based on the play and clarity of visual precursors (cues) that would allude to the outcome of the play. Additionally, the clips all showed common play scenarios that occur frequently throughout the game, including throw-ins, knock-ins, and field plays. The polo video stimuli for the studies in Chapter 4 and Chapter 5 were edited using Adobe® Premiere Pro® software (Version 13.1.5) licensed through Nottingham Trent University. A Think Centre computer and Samsung monitor were used during the editing process. The full video was uploaded into a new sequence in Adobe® Premiere Pro®, and the audio was removed by unlinking the video and audio (Right click > Unlink) and deleting the audio section in the Timeline (Figure 2.7).

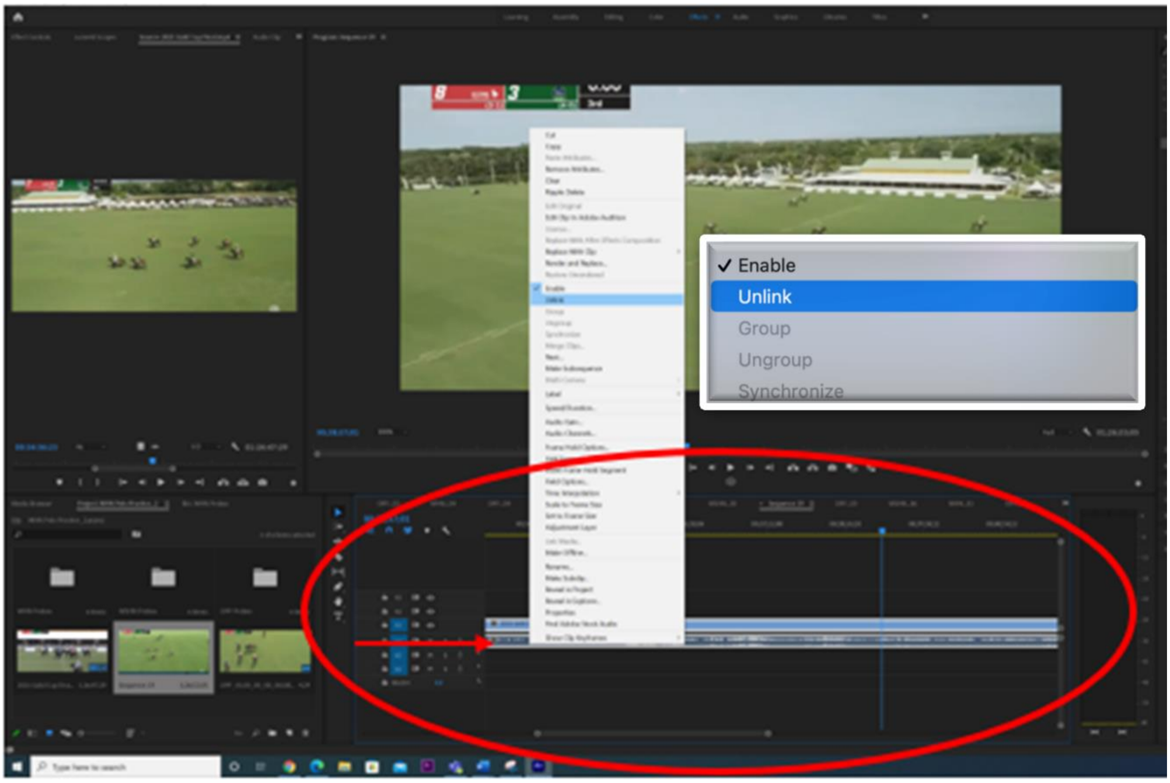

Figure 2.7 *Screenshot of Adobe Premiere Pro video editing interface showing how to unlink the video and audio components (inset) in the timeline (red circle). The audio component (red arrow) was then deleted.*

Individual clip timestamps were marked using the Razor tool in the Timeline. This separated the full-length video into several smaller clips. Each smaller clip was then copied from the original into their own sequence, thus creating several small, individual clips (Figure 2.8).

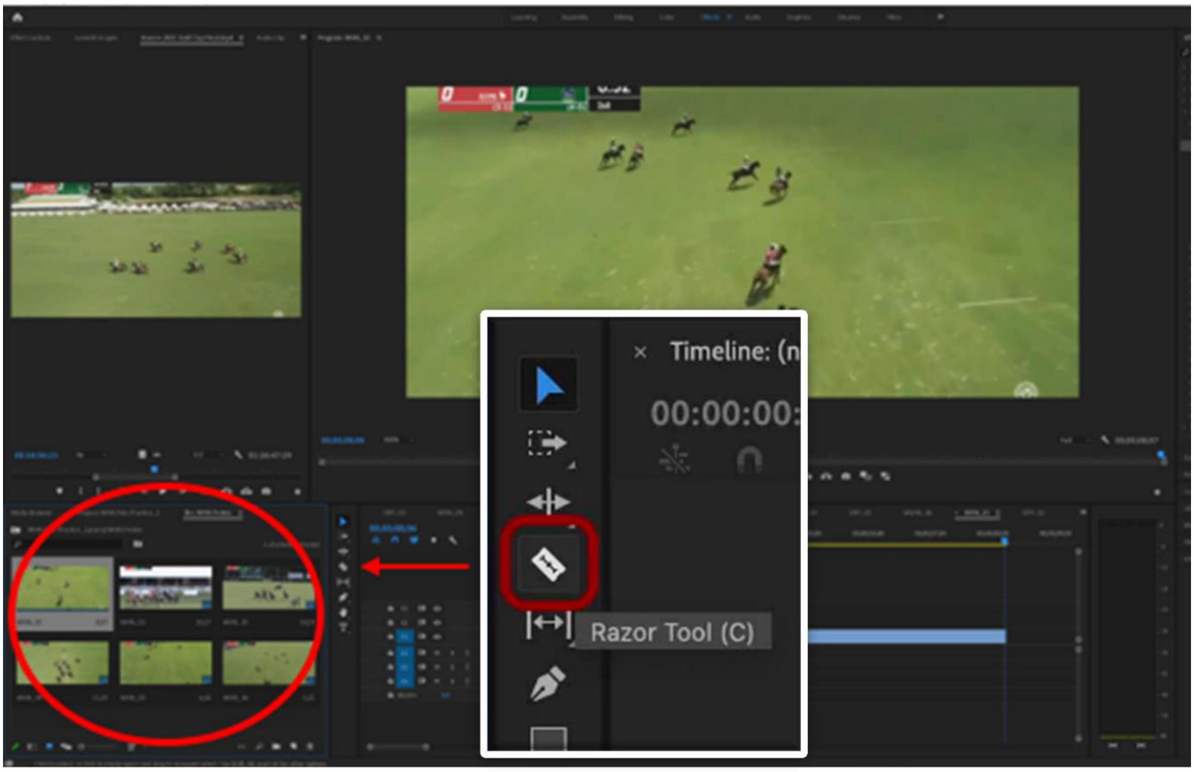

Figure 2.8 *Screenshot of Adobe Premiere Pro video editing interface showing the different sequences (red circle) created using the Razor tool (red arrow and inset).*

The individual clips were trimmed further using the Razor tool to the exact start and end points. The Export Frame option on the Timeline was used to create a freeze frame image, saved into the project file as a .jpg image (Figure 2.9).

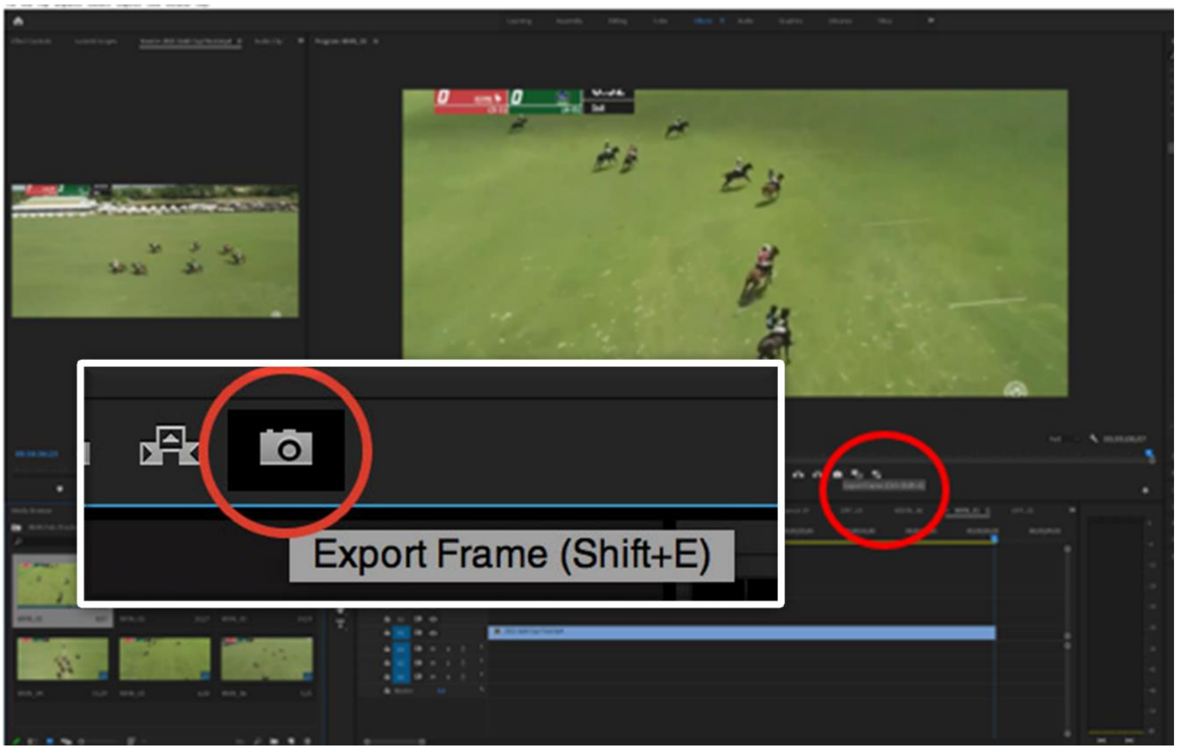

Figure 2.9 *Screenshot of Adobe Premiere Pro video editing interface showing how to use the Export Frame (red arrow) option to create the freeze frame. The frame was saved as a .jpg and inserted into the timeline.*

That image was then imported into the video clip Timeline and set to be visible for 20 seconds for Study 2.1 (Figure 2.10) and 10 seconds for Studies 2.2 and 3 (same method).

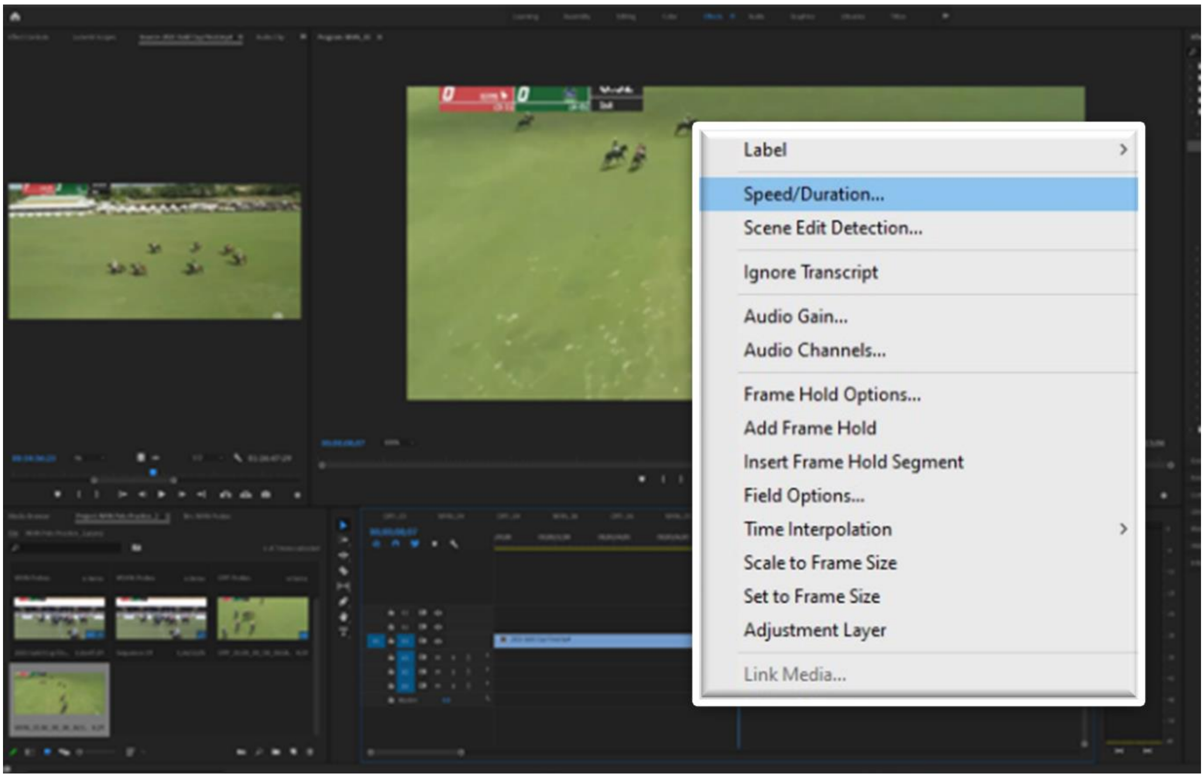

Figure 2.10 *Screenshot of Adobe Premiere Pro video editing interface showing how to extend the freeze frame in the timeline using the Speed/Duration (inset) option. The frame was extended for 20 seconds.*

Each player visible in the frame was labelled using the Text option (*e.g.*, R1, G1, R2, G2, *etc.*) set to White Size 40 Tacoma. The WHN questions and multiple-choice answers were also created using the Text option with the same font and size but were set in a grey background set to 75% (Figure 2.11).

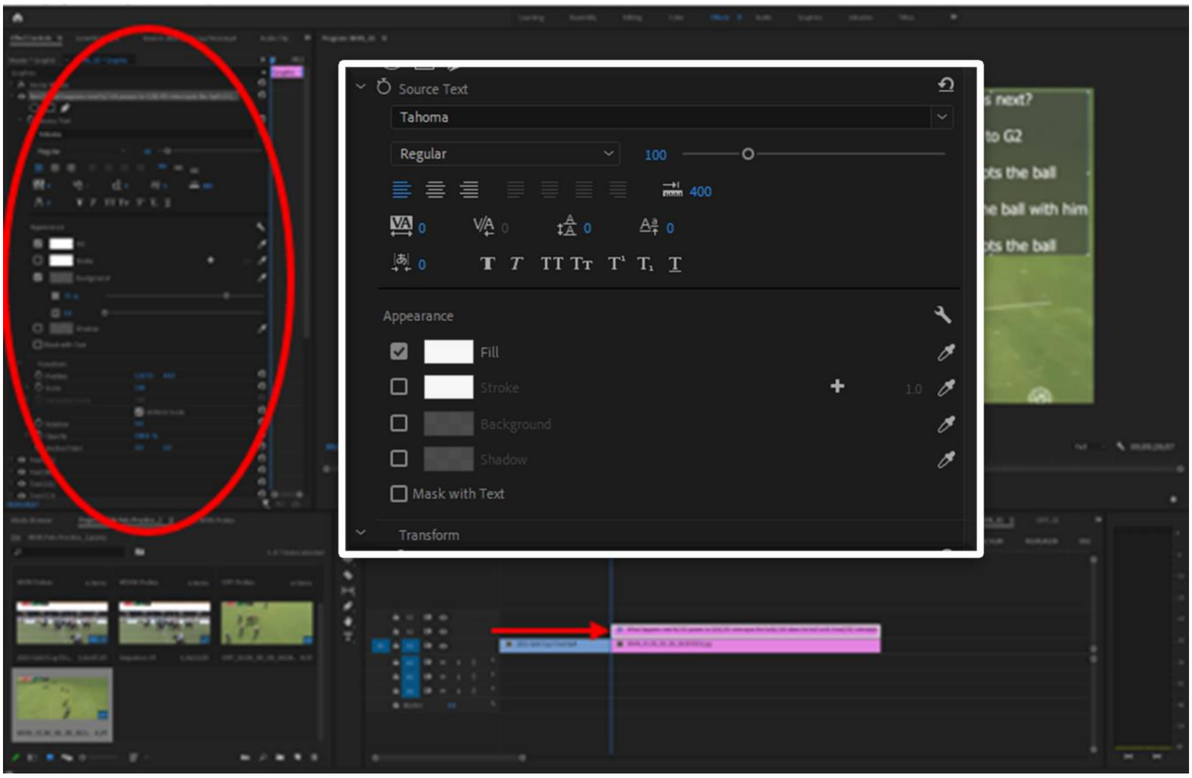

Figure 2.11 *Screenshot of Adobe Premiere Pro video editing interface showing the player labels in the timeline (red arrow) and the WHN question and answers. The text was edited using the Effects Controls panel (red circle and inset).*

The labels and questions were visible for 20 seconds (Study 2.1) or 10 seconds (Studies 2.2 and 3) in conjunction with the freeze frame. The blurred effect on the freeze-frame was created with the Camera Blur effect. (Figure 2.12).

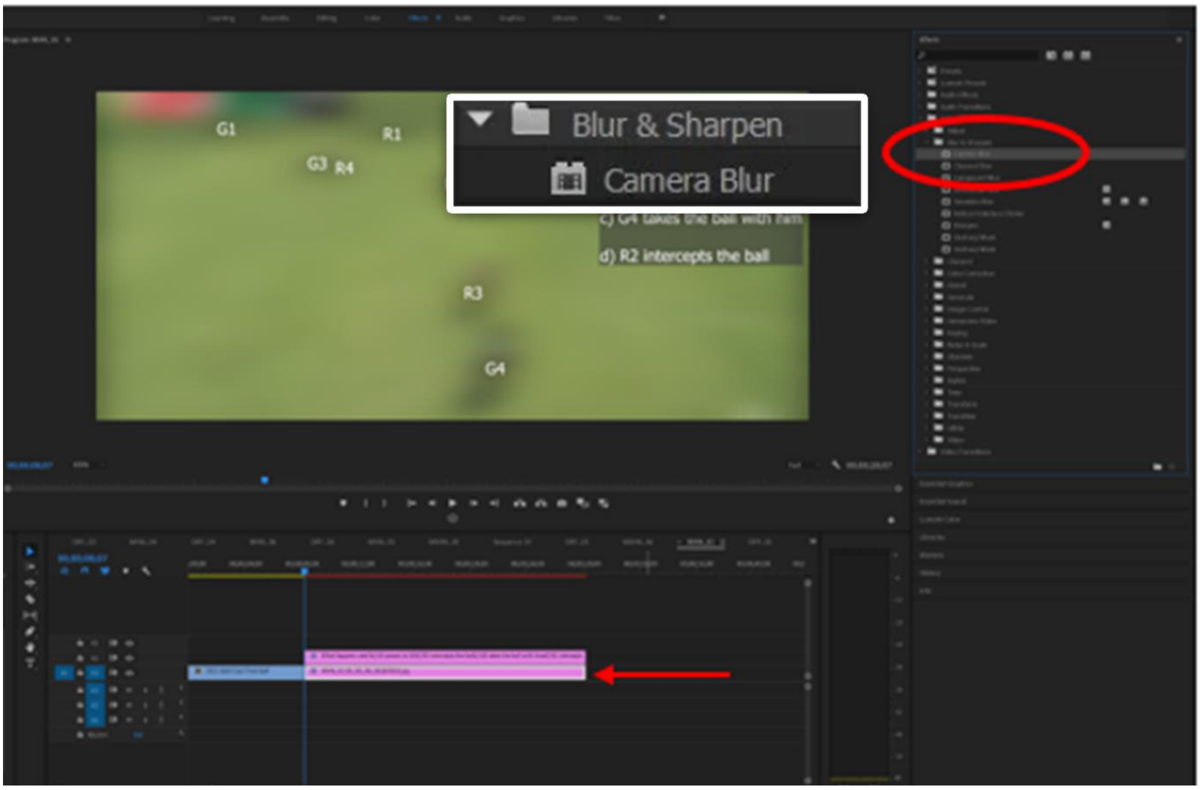

Figure 2.12 *Screenshot of Adobe Premiere Pro video editing interface showing how to add the Camera Blur effect (red circle and inset) to the freeze frame in the timeline (red arrow).*

Each video was exported with an H.264 format (Figure 2.13).

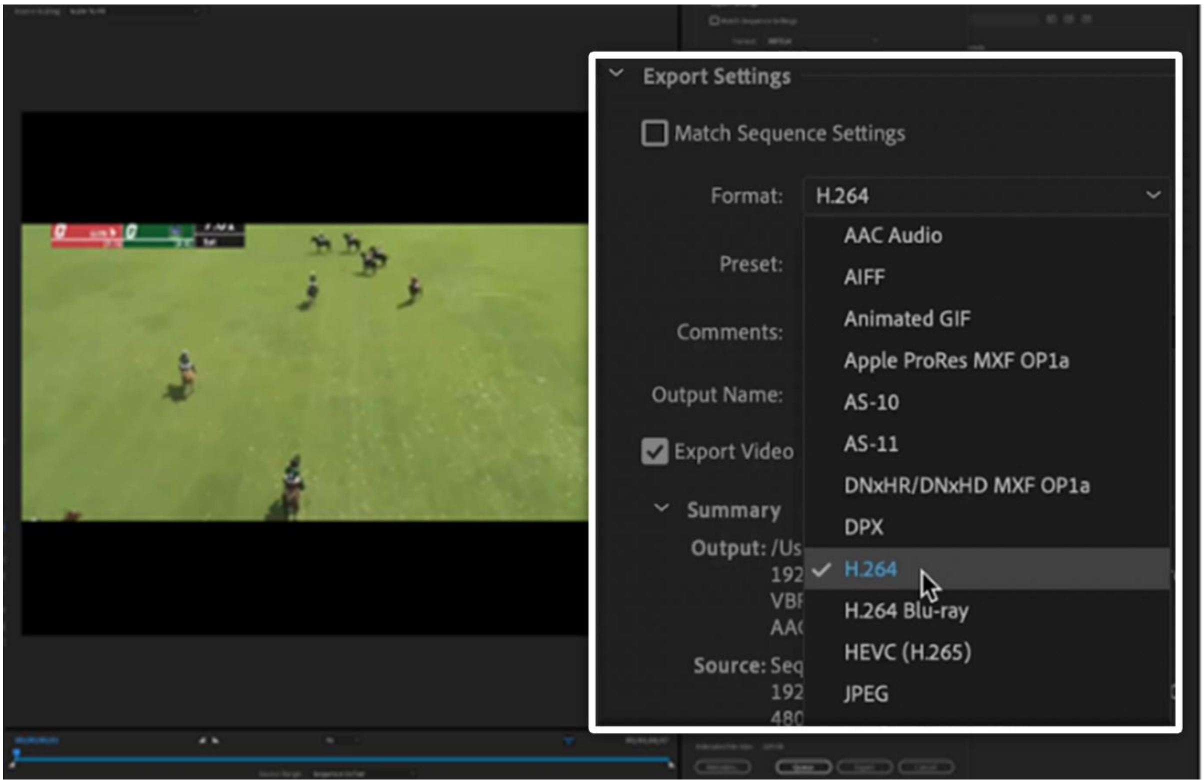

Figure 2.13 *Screenshot of Adobe Premiere Pro video editing interface showing how to export (File > Export > Media) the final video clip with an H.264 format (inset).*

See Appendices 7.3 through 7.10 for complete descriptions of all the WHN video stimuli, including the play description, total length (ms), time of play onset (ms), multiple-choice question answer choices, the correct answer choice, and the YouTube links to view the stimuli.

2.3.2.1.1 Process for determining freeze-frame points in the What Happens Next? (WHN) task stimuli.

First developed within the transportation field, visual occlusion techniques investigated the visual attentional demand and the visual information in a driving scene necessary for driving performance (Senders et al., 1967). The overarching purpose of occluding visual scenes is to evaluate how much time is necessary to gather and process visual information about a scene when anticipating future outcomes. Today, research has shown that the appropriate freeze point timing in video stimuli is important for anticipation and decision-making studies in not just driving (Kujala et al., 2023), but also in sports (Gredin et al., 2020).

There is a balancing act for creating freeze-frame or occlusion points which show the necessary visual precursors with which to anticipate a future outcome, but also not showing too much visual information so that the task is too easy and there is a ceiling effect or a lack of discrimination between experience levels. The precursors immediately before an occlusion point must allude to an event occurring; they provide cues that then alert the participant to a following action (Crundall & Kroll, 2018). In driving hazard prediction tasks, occlusion points typically occur after the onset of a hazard (Crundall & Kroll, 2018), and may include gradual-onset (slowly developing) or abrupt-onset (suddenly developing) hazards (Underwood et al., 2013). Many sports anticipation studies used progressive temporal occlusion paradigms where participants must respond to the stimuli (*i.e.,* anticipation or decision-making tasks) at different occlusion points in relation to ball-contact/release (Aglioti et al., 2008; Müller et al., 2009). Progressive temporal occlusion has often been used to investigate experience differences in how athletes process visual information. For instance, Farrow et al. (2005) showed that later occlusion points allowed both skilled and novice tennis players to predict more accurately shot direction. Importantly, it has been demonstrated in multiple studies progressive temporal occlusion studies that more experienced or expert (highly-skilled) athletes exhibit earlier visual information processing compared to less experienced or novice (less-skilled) athletes (Aglioti et al., 2008; Baker et al., 2009; Loffing & Hagemann, 2014b; Müller et al., 2006, 2009). However, even skilled athletes require some amount of time to make accurate predictions, as shown with skilled adolescent cricket batters who required between 100—200ms of ball flight information (Taliep et al., 2023).

The WHN studies presented in this thesis, however, do not follow these approaches exactly; as this is new research into polo and sports (the usage of the WHN paradigm), a new approach was trialed which did not utilize a progressive temporal occlusion paradigm or set occlusion points at strict time following ball contact. Instead, these studies focused on the key visual information that was available prior to a play occurring, which may not have even occurred in conjunction with a ball hit. For example, in a knock-in play where the ball-handler passes to a teammate, the clips were often occluded *before* the ball contact, as any occlusion after would give away too much information. In concordance with the driving literature, the play onset times (described as 'hazard onset' times in driving; Crundall & Kroll, 2018)—defined as the earliest possible time a participant could correctly anticipate the outcome—and play offset times ('hazard offset' times)—defined as when the play was fully developed—were analysed for each clip. To determine the play onset and offset times, two independent researchers first identified the play event (*e.g.,* a pass to a teammate or a hook), the time at which the event was developed (play offset), and the time at which relevant precursors became available (play onset). The positioning of the players, body kinematics, mallet and/or horse angles, and gaze directions were analyzed to determine the 'play onset' times. At the occlusion point, the researchers examined and ensured the presence of the precursors and cues that alluded to the outcome of the play. Importantly, while the visual cues available immediately before the freeze-frame were evident, the cues were also somewhat ambiguous to not make the task too easy or create a ceiling effect.

The availability of visual cues to be seen and processed often occurred in a short period of time given the nature of the sport. A knock-in play must be made within five seconds or the team risks getting a delay-of-game penalty and awarding a free hit to the opposing team.

Oftentimes, a knock-in play will occur within less than five seconds; once the umpire announces the play, the clock will start counting down. In high-pressure situations, a player must act quickly—when a game is tied with 20 seconds on the clock, converting a possession play (knock-in) to a goal is imperative, and the player cannot waste time deciding on a play. Similarly, defensive plays occur within a matter of seconds or less; when opportunity strikes, a player must capitalize. Thus, rapidly developing and updating SA is required throughout the entire game. The clip lengths of the WHN stimuli ranged in duration from approximately three seconds to almost 30 seconds to showcase the variety in play structure; in polo, some plays develop rapidly (*e.g.,* knock-in plays) whereas others take longer to unfold (*e.g.,* field plays). To make the WHN tasks as ecologically similar to the game, it was decided to include both 'short' and 'long' clips to test the participants' SA.

2.3.2.1.2 Process for creating multiple-choice question (MCQ) distractors used in the WHN tasks.

The WHN tasks presented in Chapter 4 (Studies 2.1 and 2.2) and Chapter 5 (Study 3) used a multiple-choice question (MCQ) format to gauge the accuracy of participants' anticipation, and thus SA, skills. MCQs have been demonstrated to successfully discriminate driving experience in hazard prediction tests using a WHN paradigm (Ventsislavova & Crundall, 2018). For the WHN tasks presented in this thesis, following the freeze-frame in the video clip, participants were asked to predict, "What happens next?". Four answer choices (labelled a, b, c, and d) were given to choose from, and the correct answer was determined by the actual outcome of the play. The distractor answer choices were created using plausible play outcomes, but which importantly, showed no evidence of occurring through visual cues or precursors. Ventsislavova et al., (2022) has previously discussed the importance of developing

MCQ distractors for WHN tasks, stating that distractors cannot be implausible or non-reflective of the situation, as they may be easily identified and 'thrown out'. This may then allow a participant to easily rule out the distractors and artificially raise the success scores of the participant. Haladyna et al. (2002) described many suggestions for proper MCQ development, including creating effective choices, making all distractors plausible, keeping the answer choices similar in word length, avoiding giving clues to the correct answer, and varying the locations of the correct answer within the distractors. These protocols were followed for the creation of the WHN MCQ answers and distractors used in the thesis.

The MCQs were developed for each clip, and an SME identified the actual outcome and three distractors—or plausible outcomes—related to the play. For instance, an offensive knock-in play set-up (in which a player would hit the ball in from the end zone onto the field of play) could have four distinct outcomes: 1) The player could pass the ball to a teammate to the left side of the field, 2) the player could pass the ball to a teammate to the right side of the field, 3) the player could run with the ball to the left side of the field, and 4) the player could run with the ball to the right side of the field. What would determine the correct answer or outcome would be the visual cues, or precursors, available immediately before the freeze-frame. Such visual cues could include the angle of the ball-handler (*i.e.,* which direction is his horse facing?), the openness of his teammates (*i.e.,* are his passing targets open or defended?), the pressure of the defense on the ball-handler (*i.e.,* is a defender close or far away?), or the field positioning of the players (*i.e.,* is there an open space on the field?)

Likewise, in a defensive situation where a play must be made to intercept the ball, there may be four distinct outcomes: 1) The defending player hooks the ball-handler on his nearside (left side of horse), 2) the defending player hooks the ball-handler on his offside (right side of horse), 3) the defending player bumps the ball-handler off the LOB, and 4), the defending player intercepts and steals the ball. As with the knock-in play, the correct answer would be determined by the precursors available immediately before the freeze-frame. Such visual cues could include the defending player's mallet position in relation to his horse (*i.e.,* is it on his offside or nearside?), the LOB and the defender's position in relation to the ball-handler (*i.e.,* is the defender on the right or left side of the ball-handler?), or the closeness of the ball to the players (*i.e.,* is the ball kept within a mallet's reach, or is it farther away?)

The wording of the MCQs was also considered. The language used to describe the play outcomes (including in the distractors) used simple language and sentence structure to avoid confusion. Importantly, sports-neutral terms, such as "pass the ball", "intercept the ball", "backshot", or "run with the ball", were used as much as possible. However, some polo-specific terms, such as "hooking the player's mallet" or "bumping the player", were used when there was no sports-neutral term to describe the action. This is, undoubtedly, a limitation and drawback of using MCQs for a sport which has specialized language and actions. There is, ultimately, a concern that the task may discriminate experience based solely on the participant's understanding of the terms used, however, it was decided for the studies presented in this thesis that such a concern was small. First, the mixed effects modelling statistical analyses used (described in Section 2.5.2) accounted for the variance in stimuli (such as MCQ distractors), and second, familiarity with the language used in the sport could be considered important prior knowledge, thus indicating sport experience. Lastly, the knowledge of the language would not guarantee a successful choice given that the distractors were mirrored with the correct answer with minor changes indicating directional movement. See Appendices 7.3 through 7.6 for complete descriptions of the WHN studies stimuli, including MCQ answers and distractors.

The piloting and validation of WHN MCQs has been argued to be important for the rigor of the task (Ventsislavova et al., 2022)—if the questions are too easy or too difficult, the test may not accurately show what it claims to be measuring. The MCQs were created by one polo SME and one experienced athlete (soccer, rock climbing) so that the wording was deemed appropriate for the situation; the clips were then piloted by a non-sport control participant. This participant gave feedback about the wording of the answer choices, which was taken into consideration for the final clips.

2.3.2.2 Phase III: Visual cueing training.

The training stimuli presented in Chapter 5: Study 3 aimed to direct the visual attention of participants to relevant locations to improve SA in a WHN task. Two training interventions were created. The visual cueing training stimuli for Chapter 5: Study 3 followed the same editing format as the Chapter 4 and 5 WHN stimuli, however, non-content information was added that cued the viewer towards pertinent visual information necessary for successful SA and anticipation (de Koning et al., 2009). The non-content information included various coloured circles and arrows which followed a moving object (a player) or stayed static on the field. To create the cueing training stimuli, video clips were imported into the Timeline to create a new sequence (Figure 2.14).

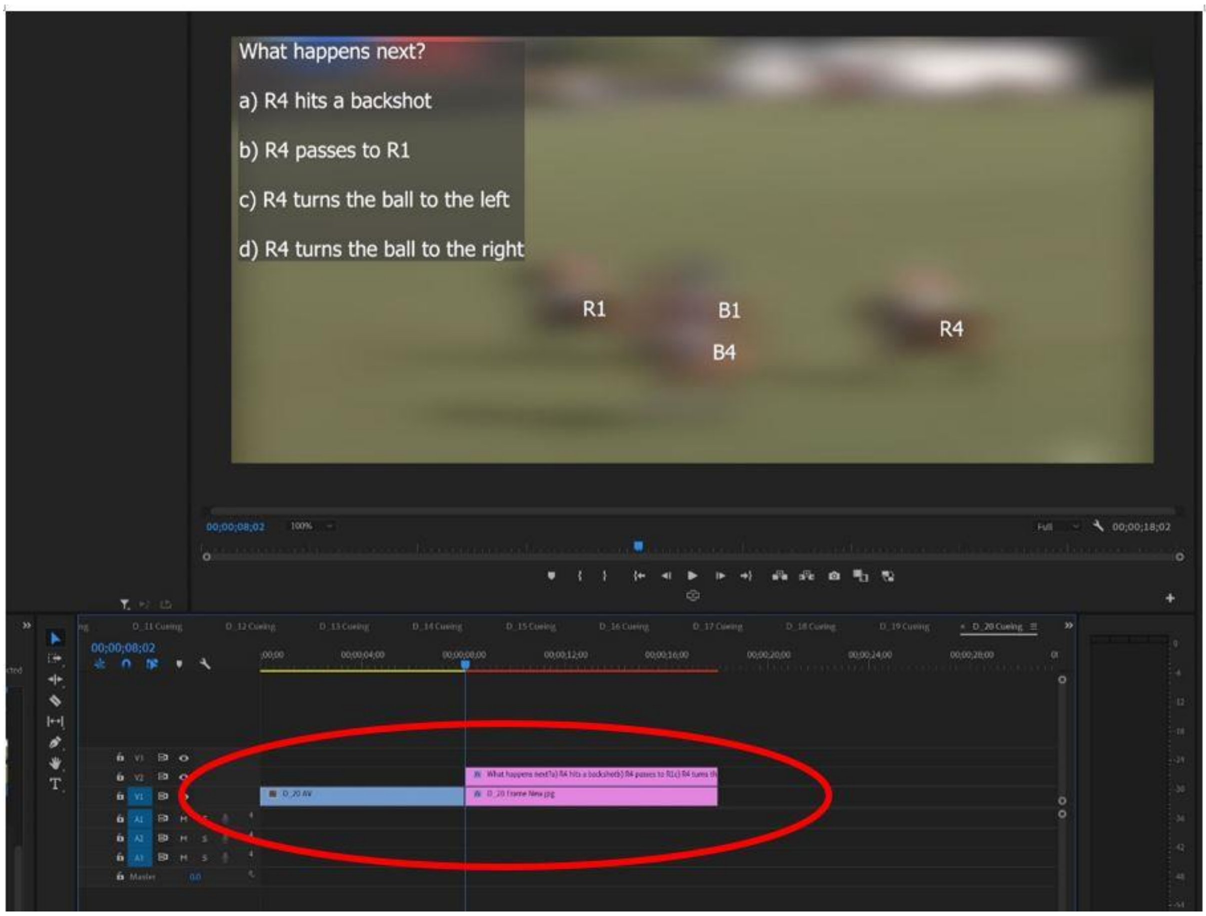

Figure 2.14 *Screenshot of Adobe Premiere Pro video editing interface showing a video clip imported into the Timeline as a new sequence (red circle).*

To create the non-content information (*i.e.*, circles), a Legacy Title (File > New > Legacy Title) was created (Figure 2.15).

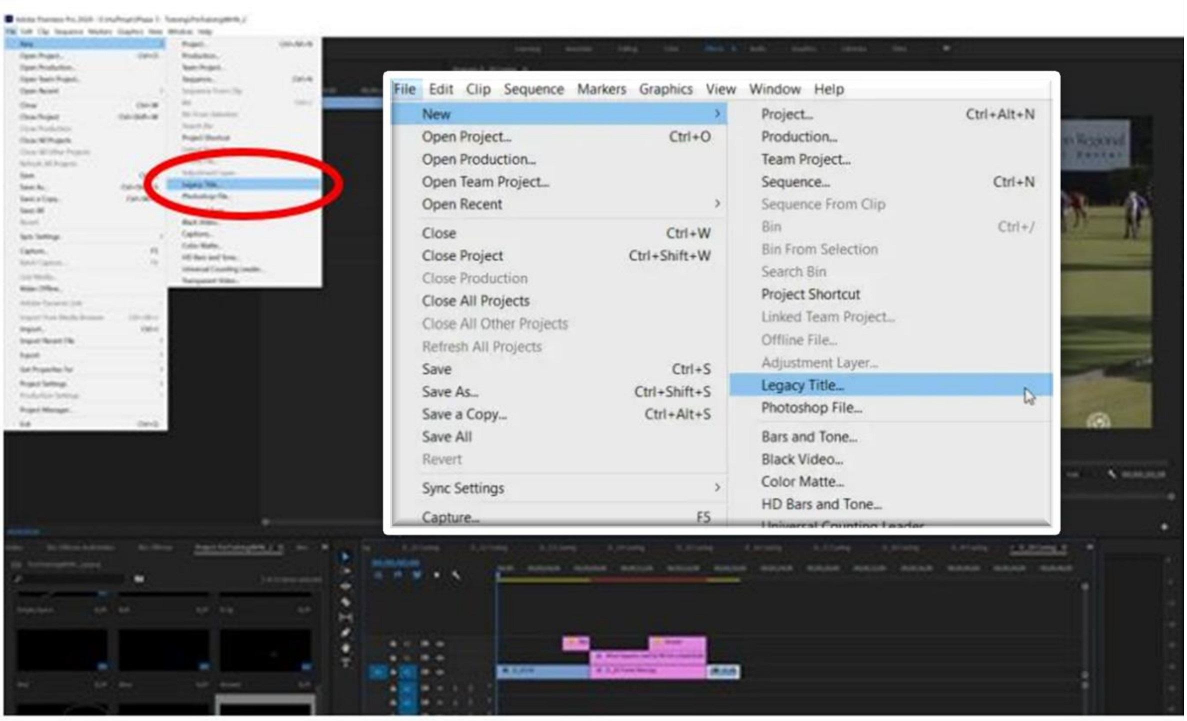

Figure 2.15 *Screenshot of Adobe Premiere Pro video editing interface showing how to create a Legacy Title (File > New > Legacy Title) (Red circle and inset).*

The non-content information was drawn out using the circle/ellipses shape options. The shape was then modified using the Legacy Title Properties to alter colour, stroke line size, and rotation (Figure 2.16).

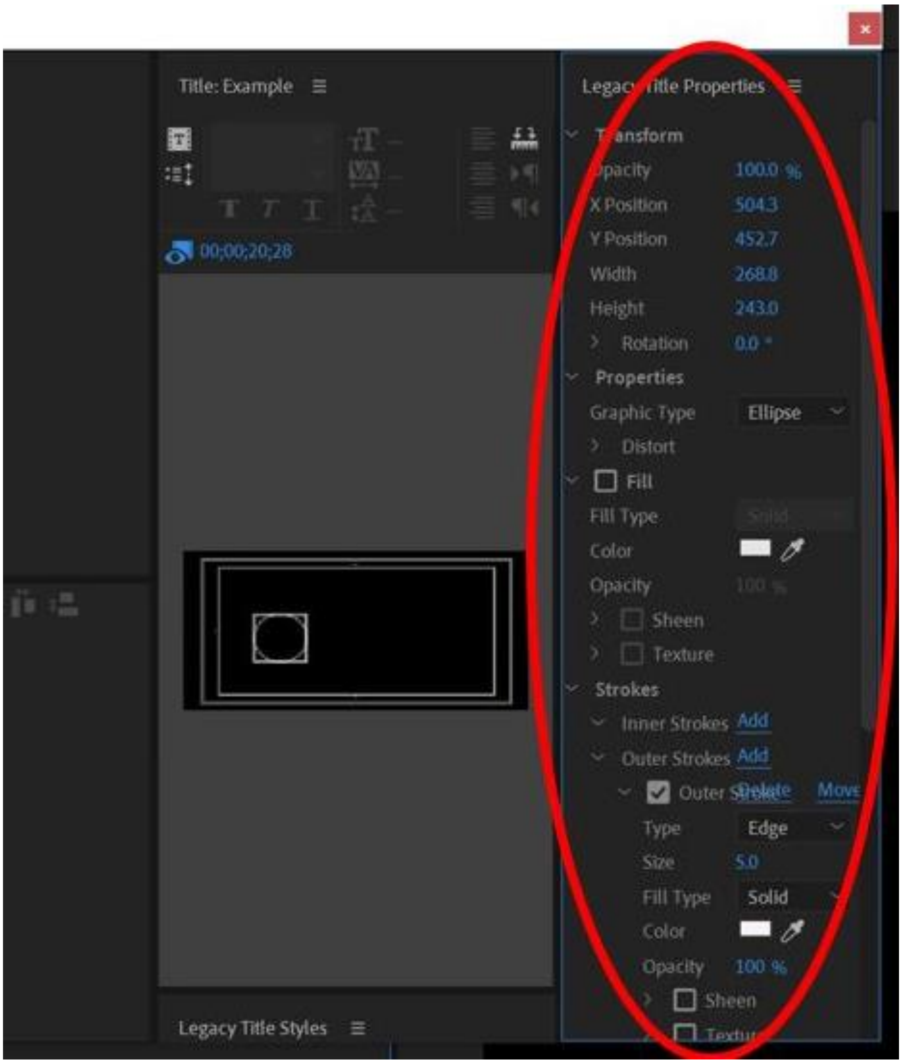

Figure 2.16 *Screenshot of Adobe Premiere Pro video editing interface showing how to alter the Legacy Title properties such as colour and stroke size (red circle).*

Once the Legacy Title was created, it was dragged into the Timeline (Figure 2.17).

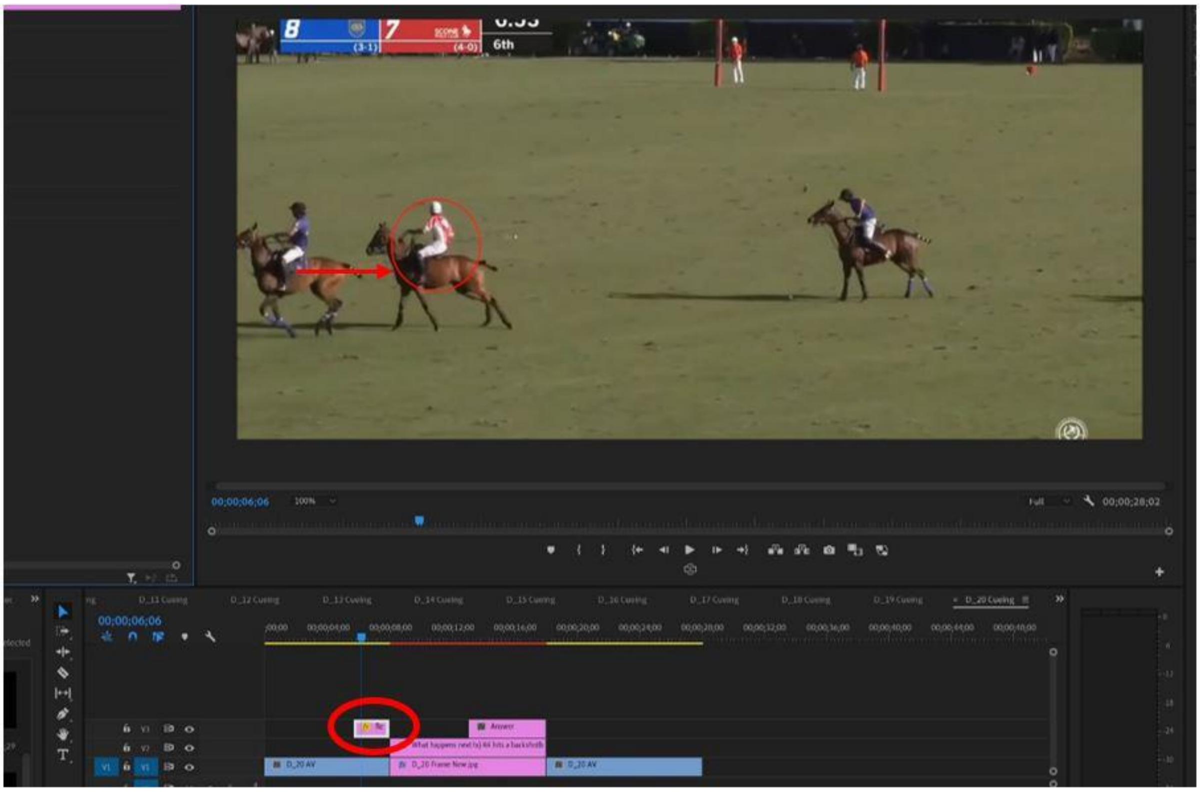

Figure 2.17 *Screenshot of Adobe Premiere Pro video editing interface showing the non-content information (Legacy Title) (red arrow) imported into the timeline (bold red circle).*

Its position was changed using the Effects Controls panel (Figure 2.18). To ‘track’ a player, the FX Motion > Position was enabled by clicking the stopwatch icon, and the position was changed for each frame of the video.

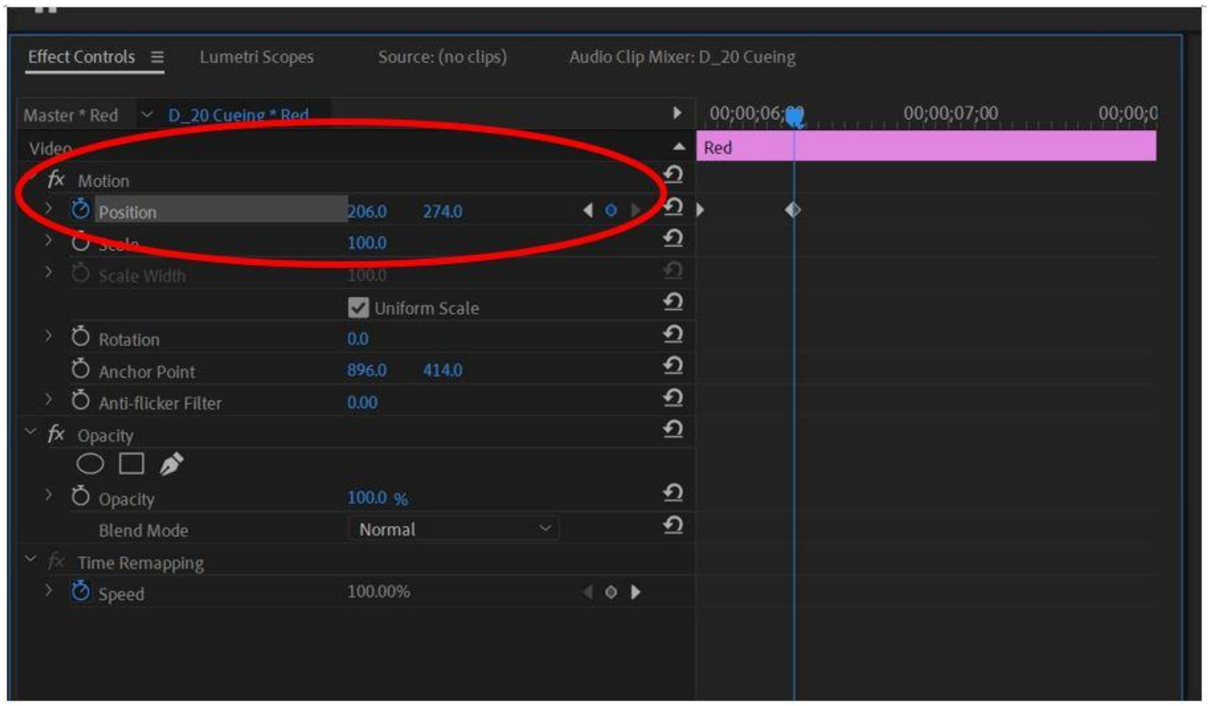

Figure 2.18 *Screenshot of Adobe Premiere Pro video editing interface showing how to change the position of the non-content information using the FX motion > Position option (red circle).*

Finally, each clip was exported with an H.264 format. See Appendix 7.6 for descriptions of both the visual cueing training and expert commentary training video stimuli and Appendix 7.10 for the YouTube links to view the training stimuli.

2.3.3 Audacity®.

2.3.3.1 Chapter 5 Study 3: Expert commentary training intervention.

The expert commentary training voiceover was recorded using Audacity® recording and editing software (Version 3.1.1) on a Lenovo ThinkCentre computer with a Rode NTI-A microphone (S/N0871635). The voiceover for each training video was provided by the experimenter who has over 15 years of polo experience and coaching. Two experimenters (one with polo experience, and one with a specialty in visuo-cognitive sporting research) generated the script for each training video after analysing the full clip (from beginning to the end of the play/beginning of the next play). The clip was analysed for overall outcome (*e.g.,* pass to teammate, run with the ball, intercept the ball, *etc*.), interactions between teammates and opponents, executions of set-plays (*e.g.,* knock-in from the end zone), and visual cues such as player head orientations, mallet positioning, horse positioning, and field formations. The audio clips were exported as .mp3 files and inserted over the same training clips as used in the visual cueing training intervention.

2.3.4 SMI eye tracking software.

2.3.4.1 Chapter 5 Study 3: eye movement behaviours during pre-training and post-training What Happens Next (WHN) tests.

Total number of gaze fixations, gaze fixation durations (ms), and area of gaze fixation dispersions were recorded using a SensoMotor Instruments iView X RED500 eye tracker and BeGaze Analysis software on a Lenovo laptop and screen. The stimuli and gaze behaviour statistics were exported into a .txt file and then converted to an Excel file for further analysis. The AOI Fixation Statistics exported from BeGaze included AOI parameters, such as name, size (px) and coverage (%), and fixation details directed towards the AOI, such as dwell time, glance duration, diversion duration, first fixation duration, glances count, revisits, fixation counts, fixation durations, and participant hit count. Fixation dispersions (px) were analysed separately using the Event Detailed Statistics.

2.3.4.2 Selection and creation of the Chapter 5: Study 3 areas of interest (AOI).

There are several different methods of constructing areas of interest (AOIs), with numerous procedures outlining what an AOI should and should not include (Hessels et al., 2016). For the analysis of the number of gaze fixations and gaze fixation durations in Chapter 5: Study 3, AOIs were created for each stimuli clip. There were two distinct AOIs created: ball-proxim and off-ball. The AOIs were determined and created manually by a Subject Matter Expert (SME) using the BeGaze software. The ball-proxim AOI included the ball and ball-handler if the ball was within reach of the player's mallet. If the ball was out of reach of the mallet, the ball-proxim AOI contained just the ball. The off-ball AOI included the entire scene with exception to the ball-proxim AOI. These two distinct AOIs were chosen based on the rationale that participants who were unfamiliar with the scene would follow the ball to gain information, whilst those with some level of knowledge or training might exhibit more off-ball searches of the scene.

To create the AOIs, the stimuli video clip was imported into BeGaze and loaded into the AOI Editor interface (Fig. 2.19).

Figure 2.19 *Screenshot of the SMI BeGraze AOI Editor interface with the WHN stimuli imported.*

Within the AOI Editor Toolbar, the Rectangular AOI tool was selected, which was used to manually draw and adjust the 'ball-proxim' AOI (Fig. 2.20).

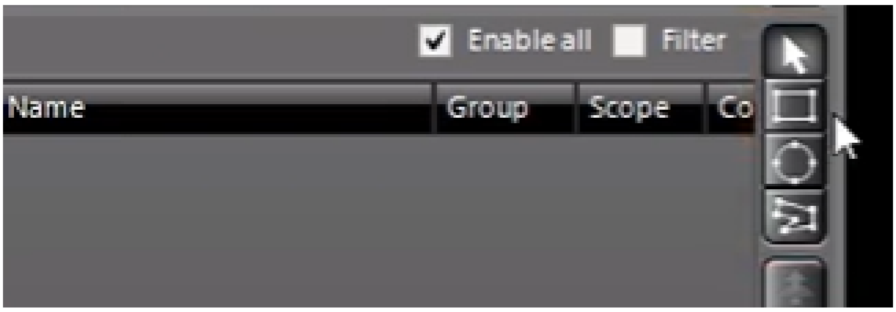

Figure 2.20 *Screenshot of the SMI BeGaze AOI Editor drawing tools.*

This AOI was set so that there was no more or less than +/- 1-degree 'padding'. This was done to ensure that the AOI would register a 'hit' with the eye tracker's +/- 0.3-degree precision. Once the AOI was set, it was named 'ball-proxim.' The ball-proxim AOI was created to be dynamic, meaning it changed location and size depending on the video. To do so, the ball-proxim AOI was selected, and in the AOI player control view, the time cursor was positioned on the video frame (Fig. 2.21). The AOI was then moved to its new position, following the ball/ball-handler. The size was adjusted as necessary. Once positioned, BeGaze would automatically set a key frame for the position. This was repeated for each video.

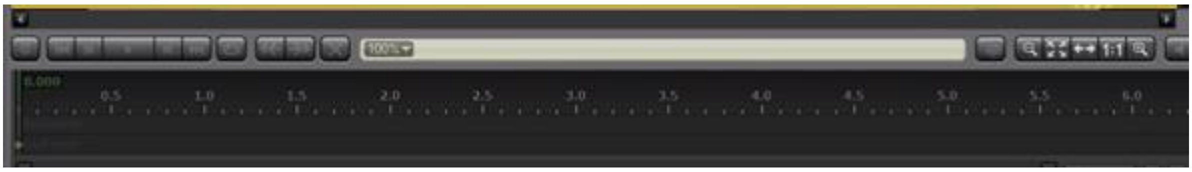

Figure 2.21 *Screenshot of the SMI BeGaze AOI Editor showing the video timeline for frame selection when creating a dynamic AOI.*

The off-ball AOI was created and named using the same steps but was drawn so that the entire screen was covered; it was kept static throughout the clip. To ensure that the off-ball AOI contained the entire scene minus the ball-proxim AOI, the priority was changed so that it had lower priority than the ball-proxim AOI. Examples of the ball-proxim and off-ball AOIs are shown in Figure 2.22.

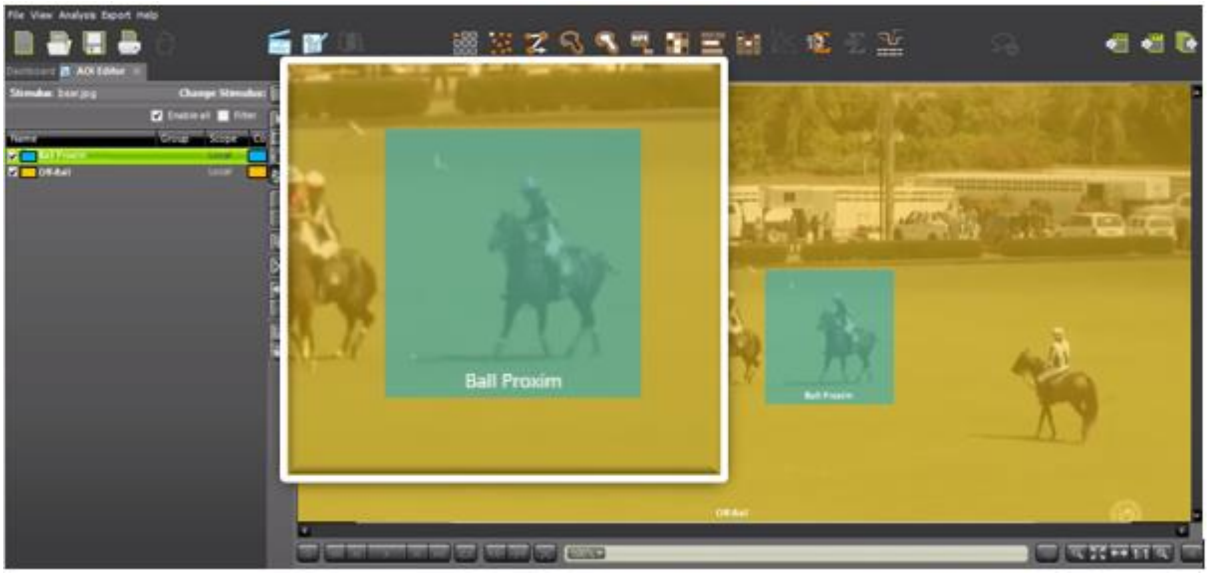

Figure 2.22 *Screenshot of SMI BeGraze AOI Editor showing the 'ball-proxim' (blue) and 'off-ball' (yellow) AOIs.*

2.4 Experiment hosting platforms.

2.4.1 Qualtrics.

The tasks for Chapter 3: Study 1.1 and Study 1.2 were created and hosted using Qualtrics software, Version 11.2020 (Qualtrics, Provo, UT). The image stimuli for Studies 1.1 and 1.2 were uploaded into Qualtrics. The Heat Map function was applied to each image which recorded the Cartesian (x, y) pixel coordinates of a participant's click. A link for each experiment was distributed online through email and social media (*e.g.*, Twitter, Facebook, and Instagram). The USPA advertised both studies in their online weekly newsletter, and the HPA featured the studies on their Instagram story. The participant demographic information and the training videos were presented using Qualtrics software for Chapter 5: Study 3.

2.4.2 Gorilla Experiment Builder.

The tasks for Chapter 4: Study 2.1 and 2.2 were created and hosted online using Gorilla Experiment Builder (www.gorilla.sc). A link to the experiments were distributed online through email and social media, similarly to the distribution of the Qualtrics links for Chapter 3: Study 1.1 and Study 1.2. The USPA advertised the Chapter 4: Study 2.1 and Study 2.2 tasks in their online weekly newsletter and on their Twitter feed (@PoloAssociation).

2.5 Data analysis software and statistical models

2.5.1 R.

All analyses were conducted using R (R Core Team, 2020) and the '*lme4*' package (Bates et al., 2015). Raw data was downloaded from their respective host sites (Qualtrics or Gorilla Experiment Builder) as Excel files. These Excel files were then wrangled and imported into R for data analysis. Datasets were further cleaned and wrangled in R as needed.

2.5.2 Mixed effects modelling.

The performance and behavioural data for each experimental chapter were analysed as mixed effects models in lieu of more traditional analysis of variation (ANOVA) models because of their ability to analyse repeated measures more accurately and to take into account the variability across participants and stimuli (Bates et al., 2015; Gueorguieva & Krystal, 2004; Laxton et al., 2022) and reduce the likelihood of a Type I (false positive) error (Meteyard & Davies, 2020). Linear mixed effects modelling with fixed slopes (*lmer* function in R) (Bates et al., 2015; R Core Team, 2020) were used the analyse the STB performance data in Chapter 3: Study 1.1 and 1.2 and the eye movement behavioural data in Chapter 5: Study 3. A binary logistic generalised mixed effects model with fixed slopes (*glmer* function in R) (Bates et al., 2015; R Core Team, 2020) was used to analyse the WHN performance data for Chapter 4: Study 2.1 and 2.2, and Chapter 5: Study 3 owing to the binary nature of the data (with 1 = correct and 0 = incorrect) (Laxton et al., 2022). Model comparisons were used to determine the overall best 'fit' of the data. Each model was run sequentially in order of increasing complexity, beginning with a null model (a model with constants instead of fixed effects). Each main (fixed) effect was added to the model and compared with the previous model. Interaction effects were also examined. Post-hoc Tukey tests and reduced-maximum likelihood ratios (REML) were used to compare the current model with the previous one to generate *p*-values (Luke, 2017). The Akaike Information Criteria (AIC) was also used to determine the model's fit, with the lower the AIC value, the lower loss of information, thus meaning a better overall fit (Akaike, 1973).

2.6 Ethical approval

The studies in this thesis were approved by the Nottingham Trent University Business Law and Social Sciences Schools Research Ethics Committee (BLSS SREC). Participants gave informed consent prior to taking part in the study. Undergraduate NTU psychology students received an appropriate amount of SONA credits for their participation in each study (1 credit per 10 minutes of study time). Non-students were awarded £10 Amazon vouchers for their participation in Studies 2.2 and 3 (Chapter 4 and 5, respectively).

2.7 Methodological limitations and suggestions for future research

2.7.1 Recruiting elite athletes, small sample sizes, and underpowered studies.

One of the main difficulties in collecting data for the studies presented in this thesis was the recruitment of a highly specialised population, namely polo players. Polo players, as has been discussed previously, make up a relatively small population (Darroux, 2016), and are often difficult to contact without being a member of the polo community to begin with. Therefore, the United States Polo Association (USPA) and Hurlingham Polo Association (HPA), the governing bodies for polo in the United States and Great Britain, respectively, were monumental in participant recruitment through advertising in their newsletters. However, despite the advertisement's large scope, actually getting players to take part and finish the studies (Studies 1.1, 1.2, 2.1, and 2.2) was rather difficult, and ultimately the desired polo player sample size was not met in Study 2.2.

Low specialist recruitment, however, is not an unfamiliar challenge faced by sport psychologists and researchers. Other sport psychology studies have also fallen victim to the inherent difficulty in sampling elite athlete populations (Macquet, 2009), with some studies (particularly those involving SA in sports) presenting sample sizes many psychologists would consider to be far below the necessary mark for an appropriately powered study (*e.g.,* Macquet & Stanton (2014); Macquet (2009); Salmon et al. (2017)). Thus, with the increasing interest in studying elite athletes' cognitive abilities, procedures and protocols should be put in place for contacting and recruiting specialist individuals to ease the difficulties of obtaining an appropriately sized sample. One suggestion is for researchers to develop working relationships with their chosen sport's governing body (*e.g.,* the USPA and HPA) to promote their research and recruit athletes. Another suggestion is for researchers to work closely with their affiliated university's sports clubs (if there are intramural clubs dedicated to the chosen sport) and to attend matches/tournaments between universities/clubs to make connections with the athletes and coaches on a personal level. However, as was the case of this thesis where such connections were made before and during the data collection period, there are still significant challenges with recruiting a specialised population.

All studies presented in this thesis underwent a sample size calculation prior to data collection to determine the number of participants needed for an appropriately powered study. The statistical power of a study is the ability for the design to produce an effect and correctly reject a false null hypothesis (Vadillo et al., 2016; Wegener et al., 2022), with a higher power resulting in a greater ability to detect a true effect with less Type II errors (Baker et al., 2020). Statistical power is also often used to estimate the likelihood that the results will be replicated in future studies; a study with a low statistical power is less likely to be replicated (Wegener et al., 2022). In experimental psychology studies, a desired statistical power is greater than 80% (Cohen, 1992), and ideally at 95% for conservative estimates (Kumle et al., 2021). Recently, researchers have begun to closely examine the statistical power of published studies, and they have found a prevalence of underpowered studies in psychology (Baker et al., 2020). In fact, Bakker et al. (2012) argued that around 96% of papers in the psychological literature (at the time) were underpowered with too-small sample sizes. A meta-review of implicit processes studies revealed that many only reported *p*-values and did not report effect sizes or even *t*- or *f*-values, making it difficult to determine Cohen's *d*, and thus the overall power of the studies; when the researchers worked through the sample size calculations independently, they discovered the median sample size was $N = 16$ with a Cohen's d of 0.31 (small effect size), which resulted in a statistical power of 0.21—quite underpowered by many psychological standards (Vadillo et al., 2016). This review highlighted the pervasiveness of underpowered studies in psychology—a danger considering that the conclusions drawn from many of these studies could potentially be erroneous, thus distorting the true results and implications. Long-term, this could have negative consequences if other studies build upon literature that is underpowered and more likely to result in Type II errors (Bates et al., 2020).

Generally speaking, to increase the statistical power, larger sample sizes are required (Baker et al., 2020), however, given the resources required for recruitment, it is not ideal to recruit more participants than necessary (Cohen, 1992). Therefore, a balance must be struck between having enough participants to produce a sufficient power while keeping participant numbers manageable for the researcher given their time and cost resources. A sample size calculation is a robust method for determining the appropriate number of participants a study needs to produce an effect (Beribisky et al., 2019). A sample size (N) calculation relies on several components, the first being effect sizes of previous or related studies (derived from the likes of Cohen's d, η^2 (eta-squared), ηp^2 (partial eta-squared), ω^2 (omega-squared), or r (Baker et al., 2020; Cohen, 1992; Hertzog, 2008). The effect size is the standard deviation of the distribution associated with the interested effect (*i.e.,* the difference between the means of two experimental conditions) (Wegener et al., 2022) and is generally referred to as being 'small', 'medium', or 'large' (Cohen, 1992). The second component is the Type II error probability, β. The third component, the Type I error probability, α, was set at 0.05. Statistical power followed the formula of $(1 - \beta)$ (Cohen, 1992), which for the studies in this thesis was set at a conservative 0.95 (Chapter 3 Study 1.2 were set at a $\beta = 0.80$). Lastly, the number of groups, number of measurements, and the study design (between-subjects, within-subjects, interaction) are considered for each individual calculation (Faul et al., 2009). The studies in this thesis were, for the most part, appropriately powered, and therefore the conclusions stated follow the traditional rules of rejecting the null hypothesis if the p-value is less than 0.05. Because of their appropriate statistical power level, the results of Studies 1.1, 1.2, and 2.1 can be considered robust. However, Studies 2.2 and 3 were underpowered in that they did not achieve the desired sample size due to the cost and time constraints presented to the researcher. Based on the guidelines presented by Lakens (2022), the justification for these sample sizes in Studies 2.2 and 3 were the result of resource constraints, namely cost and time. The results of those studies, however, should not be discounted, but perhaps treated as more of the results of a pilot study. Importantly, based on a systematic review of anticipation in sports studies, there is a mean sample size of 36 participants (Smith, 2016). The sample sizes of Studies 2.2 and 3 (sample sizes of 40 and 38, respectively) are not far off from the literature. Thus, there is still valuable information and knowledge to be gained from these studies, even if the results can only be comfortably referred to as trends. The results show evidence of an effect which can arguably be used to justify further research into the area.

2.7.2 Polo handicaps—a truly objective measurement of a player's ability?

The measure used to objectively state a polo player's overall game abilities is their polo handicap, which ranges from -2 – 10 goals, with the higher numbers representing better players ("HPA Rules & Regulations for Polo 2019," 2019; USPA, 2020). The polo handicap is awarded to players based on a committee decision in which the appropriate handicap committee (Outdoor, Arena, Women's) will vote on a player's handicap (USPA, 2020). The handicap awarded to a player is based on their game knowledge and skills, horsemanship, strategy skills, team play ability, and sportsmanship (Franklin Polo Academy, 2020). Therefore, the handicapping process and awards are essentially subjective and are not based entirely on objective game performance. This rating system of a player's worth may have implications when investigating the link between player performance and SA as the handicaps are not entirely objective and are based on several skills, not just game knowledge and skill. Perhaps, future research into polo performance and SA abilities should use a purely objective measurement of a player's ability, like performance metrics. Polo game analysts record several performance metrics for both individual players and teams. Table 2.1 shows examples of two players' performance statistics taken from the 2024 USPA® Open Championship® tournament. As is evident from the metrics presented in the table below, the 10-goal handicapped player exhibited overall better statistics than the 3-goal player, thus showing a link between game metrics and player handicap. However, these metrics provide objective ratings of game performance and a player's ability on the field, which could—in future polo SA research—be used to examine the relation of SA abilities and game performances.

It should be noted that when examining the skill level of athletes, no one method is perfect or able to capture the intricacies or idiosyncrasies of each sport, particularly when comparing multiple types of sports. As has been presented by Swann et al. (2015), there is an assortment of characteristics used by researchers which attempt to define the skill level of an athlete. The authors created a model to potentially objectively classify the skill levels of athletes so that they may be compared within and across sports. However, definitively classifying sport performance and skill level is a complicated process, which as of yet, is still to be perfected.

Table 2.1 *2024 USPA® Open Championship® player statistics by handicap.*

Player Initials, USPA Handicap	P.C, 10	R.M., 3
Games Played (GP)	5	5
Wins (W)	5	5
Total Goals (G)	19	4
Goals per Game (GPG)	3.8	0.8
Field Goals Made (FGM)	16	4
Field Goals Attempted (FGA)	38	10
Field Goal Percentage (FG%)	42.1%	40.0%
Field Goals per Game (FGPG)	3.2	0.8
Penalty Goals Made (PGM)	3	0
Penalty Goals Attempted (PGA)	8	0
Penalty Shot Percentage (P%)	37.5%	-
Penalty Goals Made Per Game (PGPG)	0.6	0.0
Throw-Ins Won (TW)	27	4
Throw-Ins Won per Game (TWPG)	5.4	0.8
Total Fouls Committed (F)	9	14
Fouls Committed per Game (FG)	1.8	2.8
Total Assists (AST)	11	5
Assists per Game (AG)	2.2	1.0
Total Steals (S)	33	15
Steals per Game (SG)	6.6	3.0
Total Hooks (H)	17	5
Hooks per Game (HG)	3.4	1.0
Total Turnovers (T)	126	77
Turnovers per Game (TG)	15.4	19.0

These performance metrics may remove the potential subjective bias of the handicapping rating system and thus would allow a more robust analysis. Potentially, these objective measurements could also be categorised to fit a player's role on the team (*i.e.,* offensive or defensive player). A more offensively skilled player would be expected to score more goals than a defensively skilled player, but both are equal and important to the overall team's success. Additionally, the SA abilities may be different based on the player's position/role on the team, and therefore should be assessed differently when investigating the link between performance and SA.

However, given that the handicapping system is used for determining the level of the player in a global standard (handicaps are generally carried over or converted for players playing outside their home country; for example, a 10-goal handicap in the United States might be translated to a 9-goal handicap in Argentina), the handicaps given to players can be considered a fair representation of the players' abilities and 'worth' on a team. Additionally, it is the handicapping system that determines the team handicap (a summation of all the players' handicaps) used during tournaments, which also sets the level of play. For instance, as was the case for the stimuli used in Studies 2.1, 2.2, and 3, the team handicaps were set at 22-goals, indicating that the teams were comprised of experienced players. Conversely, if a team handicap is 4-goals, the players would all be mostly inexperienced players. Therefore, the handicapping system is an integral part of polo and should arguably not be ignored, even if other performance metrics, such as play statistics, are also used in future research.

Chapter 3 Phase I: Sport experience, visual cues, perception accuracy, and transfer of skills in a static-image Level I Situation Awareness task

This experimental chapter aims to investigate the validity of a static-image 'Spot the Ball' tool as an inference measure of Level I Situation Awareness (perception) in polo. It also aims to explore the role of sports experience and visual cues, such as gaze orientation and player grouping, on SA performance. Lastly, it aims to understand the transfer of sports perception skills between novel, but similarly structured, sports. The results provide insight into how SA is acquired in sports which will be incorporated into the subsequent studies in this thesis.

3.1 Study 1.1—The role of sport experience, gaze orientation, and environmental cues on perception accuracy and transfer in a polo and soccer static-image Level I Situation Awareness task.

3.1.1 Introduction.

Several inconsistencies and shortcomings were identified in the literature (Chapter 1), suggesting that Situation Awareness (SA) in sports research, at least in those studies specifically using the term 'Situation Awareness', is underdeveloped and in need of empirical data and replications (Ng et al., 2013). One of the main limitations of the existing body of literature is that some methods used to directly assess SA in sports are underdeveloped, retroactive, and do not provide enough empirical evidence to link SA abilities to performance (*e.g.,* Distributed Situation Awareness, Shared Situation Awareness). These methods often make no reference to the adequacy of SA or to the overall performance of the athletes in relation to their SA; simply put, they are descriptive with no means of investigating a potential link between SA and performance. Therefore, without the discrimination of performance and SA levels, these methods lack the validity of more robust methods, such as the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 2021a), which has only been used once in a sport setting (Ng et al., 2013) at the time of writing.

Another limitation identified is that of the studies which do provide objective, empirical data, the role of sports expertise or experience in relation to SA abilities is not clearly investigated or understood. For instance, Ng et al. (2013) used the three-level framework (Endsley, 1995b) and SAGAT method (Endsley, 1995a) to examine teenage basketball SA abilities, but the authors did not account for the experience of the players when looking at SA as a predictor of basketball performance. All players had (roughly) the same levels of experience such that there were no obvious differences in the cohort. Experience, perhaps, is a main driver of SA (Crundall, 2016; Endsley, 1995b) and sports performance (Abernethy, 1990; Decroix et al., 2017; Garland & Barry, 1990; McPherson, 1999; Memmert et al., 2009; Mori & Shimada, 2013; Raab & Johnson, 2007; Savelsbergh et al., 2002; Sim & Kim, 2010; Wright et al., 2011), where individuals with more experience typically perform better than novices in a domain-specific task. Thus, the role of sports experience should be explicitly investigated in sports SA studies and tasks. Discriminating performance from each experience group would also give a level of validity to the assessment tool used if the experienced players outperformed their inexperienced counterparts. Lastly, there are few studies that explores how specifically SA, rather than simply 'experience', is acquired during sports, and the potential role of visual cues on SA acquisition. Endsley (1995b) suggests that the lowest level of SA is perception, in which individuals search their surroundings and perceive visual cues that provide them with information used to gain SA. As discussed in Chapter 1, domain-specific memory, visual search behaviours, and attention influence perception abilities. There are plenty of studies investigating the role of visual cues in sports anticipation tasks (Jackson & Morgan, 2007; Loffing & Cañal-Bruland, 2017; Savelsbergh et al., 2002; Smeeton & Huys, 2011; Williams & Jackson, 2019; Williams et al., 2009; Wright et al., 2011; Wu et al., 2013), but of these studies, there is no definitive link to SA. There has also been research into domain-specific memory development (Afonso et al., 2012; Furley & Wood, 2016; Hall et al., 2009) and visual scanning behaviours (Abernethy, 1990; Afonso et al., 2014; Aksum, et al., 2021; Kato & Fukuda, 2002; Murray & Hunfalvay, 2017; Roca et al., 2018; Savelsbergh et al., 2002, 2005; Singer et al., 1996; Vaeyens et al., 2007; Ward et al., 2002) in sports used as a predictors of performance, however, these studies do not generally refer to these skills as predictors of SA specifically. This again highlights the need for an explicit link of cognitive skills to SA, as discussed in Chapter 1.

3.1.1.1 Inferring Level I Situation Awareness (perception) using the 'Spot the Ball' tool.

To address one of the identified shortcomings of the sports SA literature, this study aims to develop and validate an objective SA inference tool that may be used in a sport setting. As discussed in Chapter 1, SA is often described as the perception of elements in an environment, the comprehension of their meaning, and the projection of the future state of the environment (Endsley, 1995b). This three-level framework has distinct hierarchal levels: Level I (perception), Level II (comprehension), and Level III (projection); for a person to have adequate SA, they must notice elements in their environment, understand the elements' meaning and significance, and then predict how those elements will change in the near future.

As an example of the three levels of SA in a polo context, Level I (perception) would be perceiving the elements of the field, such as the players and where they are located, what colour jersey is each player wearing, the ball, the goals, the boards, the horses, the speed of the play, and the umpires. Level II (comprehension) would be understanding the meaning of these elements. Which players, based on jersey colour, are teammates and which are opponents? Where is the ball, which player last hit the ball, and what is the current LOB and ROW to the ball? Which goal is being attacked or defended? Which zone, offensive, defensive, or neutral, are the players in? What are the strengths and weaknesses of the players and their horses? Lastly, Level III (projection) would be using the Level I and Level II information to predict what will happen next. In short, player Red 1 perceives a player running towards the ball (Level I). This player is wearing a blue jersey, indicating they are an opponent. Blue 1 is travelling towards a goal, which Red 1 identifies as his defending goal. On the field, Blue 1 is between the 40 and 60-yard marks on the boards, indicating that Blue 1 is in Red 1's defensive zone (Blue's offensive zone). Red 1 recognises the horse Blue 1 is on and remembers the horse's strength is speed but its weakness is physicality. Red 1 sees the ball and knows that Blue 1 is on the offside of the LOB and has the current ROW to the ball (Level II). Red 1 can reasonably predict that Blue 1 will make an offside forehand shot towards the goal (Level III). To defend this shot, Red 1 decides to bump Blue 1 off the LOB and make a nearside backhand to clear the ball out of his zone (subsequent decision-making).

One important element in sports, such as polo and soccer, is the ball. Savelsbergh et al. (2002) identified the ball as an important source of visual information for soccer goalkeepers, with experts fixating more on the ball and areas near the ball when making a save. In polo, players must be aware of the ball—not only because they are looking to score goals, but because the ball—and the line (direction) it came from—dictates the overall flow of the game (Dale, 2015; Goodspeed, 2005; Watson, 1989). The line of the ball (LOB) is a keystone in the framework of field awareness (FA), which is the polo-equivalent of SA, and the LOB ultimately determines the right-of-way (ROW) much like a lane divider on a road (Goodspeed, 2005). See Chapter 1, Section 1.2.1 for a detailed description of both the LOB and ROW in polo. Therefore, knowing where the ball came from, its current location, and the direction it is heading is vital information for a polo player's performance. Sighting the ball, however, can be a daunting task given the immense size of the polo field (200 yards by 300 yards) compared to the relatively small size of the polo ball (3.5 inches in diameter). Within a game of polo, it is also common to lose sight of the ball; when players are several dozens or even hundreds of yards away from the ball, such a small object can be difficult to locate, particularly if it is occluded by a horse or lost in a sun glare. Thus, players cannot always just look at the ball—they may potentially rely on more salient visual cues to aid in the location of the ball. Understanding how polo players locate (perceive) the ball and identifying which visual cues are important to perception abilities in polo may be important aspects of polo SA research. As such, a potential SA assessment tool could target a polo player's ability to accurately locate the ball and investigate the visual cues which aid in that ability.

The 'Spot the Ball' (STB) tool was designed as an inference measure to assess Level I SA (perception) abilities in polo players by targeting their ability to locate a digitally removed ball in static images. This tool was developed as a pre-requisite for assessing full SA, and it aims to only to assess a participant's Level I SA (perception) abilities. The objective of this tool is to capture perception skills by assessing an individual's ability to accurately look at an object that is not actually present. It does not aim to measure reaction to an object, and therefore it only targets the top-down perception abilities and knowledge to look at the right thing given visual information and cues. The STB tool also aims to identify important visual cues which drive perception abilities in polo, and lastly, it was designed to investigate the role of sport-specific experience and familiarity on perception. In other words, does experience in a sport allow an individual to successfully interpret visual cues to locate an object that itself is not visible?

Theoretically, participants with more experience would be more accurate in their location ability than those with less, or no, experience in the sport. Previous literature has shown that skilled or more experienced athletes are better able to predict the direction and location of a ball (Li & Feng, 2020; Navia et al., 2013; Sáenz-Moncaleano et al., 2018; Savelsbergh et al., 2002, 2005; Timmis et al., 2018; Wu et al., 2013) through visual cues, such as body positioning (Navia et al., 2013; Smeeton & Huys, 2011; Wright et al., 2011), kinematics (McEllin et al., 2018; Müller et al., 2014), and contextual cues (Gredin et al., 2019; Loffing et al., 2015b; McRobert et al., 2011; Runswick et al., 2019; Runswick et al., 2018). It is believed that experienced athletes are better at utilising such visual cues because they have more accurate mental models of the situations built through experience, more efficient gaze strategies and information pick-up processes, and a wider knowledge of situational probabilities, which guide top-down processes, such as visual search, leading to better anticipation (and additionally, decision-making) in sports (Loffing & Cañal-Bruland, 2017). Thus, the STB tool aims to discriminate participants with polo experience and those with no polo experience based on the accuracy in locating the 'missing' ball. Should the STB tool discriminate polo experience, the tool would achieve a level of validity for assessing perception abilities in polo.

3.1.1.2 Sport experience and the potential for the transfer of prediction skills.

In Chapter 1, Section 1.3.1.1, domain experience was discussed as a driver of SA within the three-level framework (Endsley, 1995b). However, what has not typically been investigated in traditional SA (and many sports) studies are any potential transfer of SA skills, such as perception, between sports. Skill transfer generally refers to the phenomenon where prior skills developed in one area influences performance in a different area (Newell, 1996; Seifert et al., 2019). So, would the visual search strategies honed through experience in one sport (*e.g.,* equestrian polo) transfer to another sport where there is little or no experience at all (*e.g.,* soccer)? Thorndike (1914) proposed that transfer effects occur due to the similarities of one learned skill and a new skill through his identical elements theory of transfer. Later, it was argued that the more similar the stimulus and response actions are between different skills, the greater the transferability between those actions would be (Holding, 1976). Additionally, Schmidt & Young (1987) suggested that if the performance of one skill is aided by experience in another skill, then the two skills were transferable. Similarly, the primitive elements theory posits that skills are comprised of small elements, some of which are task-relevant and some that are more general; during the learning process, these elements are combined and built upon to form task models. Transfer occurs when there is overlap in the elements and tasks so that the models from one task may be used in another (Taatgen, 2013). Therefore, it is possible that transfer of sports cognitive skills occurs due to an overlap in task models.

In the sports literature, physical movements such as running, jumping, and throwing were suggested to be precursors to more complex movements such as a tennis serve (an advanced form of throwing) (Zebas & Johnson, 1989), thus making these physical skills (*i.e.,* throwing to serving) transferable. The transfer between basic physical skills and complex sports skills was tested by Weigelt et al. (2000), who had soccer players perform a foot-and-knee juggling task with a soccer ball. Those who had practiced foot-only juggling performed better than those who had no juggling practice, suggesting that the juggling motor skill transferred to a ball control task despite using different body parts. 'Donor sports', categorised as different sports with similar environments, plays tactics, and temporal constraints, may also influence skill transfer (Travassos et al., 2018). For example, Oppici et al. (2018) showed that soccer players who engaged in futsal training had better passing accuracy during a soccer game, suggesting that the constraints of futsal (smaller playing area, increased technical skills) positively impacted the soccer players' technical abilities.

However, there has also been evidence that seemingly related skills have little transfer effects, which would suggest that complex motor tasks are highly specialised and non-transferable (Henry & Rogers, 1960; Schmidt & Young, 1987). Ericsson (2008) argues that expert performance (*i.e.,* specialized sports skills) is developed through deliberately practicing those skills and not through the practice of a seemingly related skill. Oppici & Panchuk (2022) suggest that specific skill transfer may occur over time, and not just in a single session, as is examined in many sports transfer studies. It is also possible that different complex motor skills require specialised motor coordination but also specialised cognitive skills, for instance, visual processing or attention (Schmidt & Young, 1987), which would make exploring the role of cognition in skill transfer necessary for understanding how athletes develop sports cognitive skills.

Cognitive skills important to sports performance (Hadlow et al., 2018) have been found to transfer between sports (see reviews by Broadbent et al., 2015 and Oppici & Panchuk, 2022). Additionally, it has been noted that many elite athletes participated in several different sports in their youth (Davids et al., 2017; Güllich, 2018; Seifert et al., 2019), suggesting that some skills developed in one area may transfer to another. Allard & Starkes (1992) demonstrated that basketball and ice hockey players could recall sport-specific patterns of the non-familiar sport, and Smeeton et al. (2004) found that athletes could recognise action sequences in sports with similar structures more quickly than with sports with dissimilar structures. Soccer, field hockey, and volleyball players viewed action sequences for each sport and were required to identify previously viewed sequences. The soccer and field hockey players were quicker and more accurate identifying soccer and field hockey sequences, but were slower and less accurate with volleyball sequences, suggesting a transfer of pattern recognition between similar sports, but not dissimilar sports (Smeeton et al., 2004). Abernethy et al. (2005) presented expert and novice field hockey, netball, and basketball players with a pattern recall task specific to each different sport in which participants watched short plays from each sport and reproduced the positioning of each player on a diagram. The results showed skilled athletes in their specific sport were the most accurate. Interestingly, the skilled athletes were also fairly accurate in unfamiliar sports, outperforming the novices, which suggests there was evidence of pattern-recall transferability in expert athletes. The authors suggested that this transfer effect may be due to experience the athletes had playing other sports in adolescence which helped to develop the pattern-recall skills (Abernethy et al., 2005).

However, Müller et al. (2015) showed that anticipation skills may actually be sport-specific. The authors had expert and novice rugby players anticipate the final action outcome of a rugby and baseball play, and while the expert players outperformed the novices during the rugby clips, none of the players could transfer their anticipation skills to the baseball clips.

Decision-making also appears to be transferable only between sports with similar structures; Causer & Ford (2014) showed that decision-making abilities transferred between invasion sports (*i.e.,* soccer, basketball, hockey, rugby) but did not transfer between non-invasion sports (*i.e.,* tennis, golf). Thus, transfer of sport cognitive skills may depend on the similarity of sport structure (*i.e.,* invasion versus non-invasion).

Complex sports cognitive skills are undeniably an important part of an athlete's performance, and given the discrepancies found in the literature pertaining to transfer of these skills between different sports, it can be suggested that these skills may be difficult to transfer—especially if the athlete has little overall sports experience or the different sports are dissimilar in structure. One such explanation, particularly when examining the difficulty of cognitive skill transfer between dissimilar sports (*e.g.,* team invasion sports versus individual non-invasion sports) is the idea of near-transfer and distant (far)-transfer. Near-transfer refers to the transfer of skills between similar tasks or related domains, whereas distant-transfer refers to the transfer of skills between dissimilar tasks or unrelated domains (Woltz et al., 2000; Mestre, 2006). Research has shown little evidence of distance-transfer (Singley & Anderson, 1989), potentially because of how expertise is developed. Sala & Gobet (2017) posit that expertise occurs when an individual is able to perceive and memorise domain-specific patterns ("chunks"; Simon & Chase, 1973). Even if two sports share similar patterns or common elements, the likelihood of transfer would be slim because of the difference in perceptual patterns (Gobet, 2017). Of course, as with any domain, individual differences may see a break from the norm when looking at cognitive skill transfer between sports. As mentioned, athlete upbringing has been shown to play a role in such transfer. Diversification of sports participation at an early age may develop perceptual-motor and tactical skills (Seifert et al., 2019; Travassos et al., 2018) and behavioural adaptability (Ranganathan & Newell, 2013) needed for cognitive skill transfer between sports. Additionally, in a broader sense not relating to sports, self-efficacy, goal orientation, and organisational support have also been shown to influence skill transfer (Chiaburu & Marinova, 2005).

With some evidence of cognitive skill transfer between sports (Oppici & Panchuk, 2022), particularly in sports with similar structures or 'flow' (Causer & Ford, 2014; Smeeton et al., 2004), the current study will therefore investigate cognitive skill transfer between equestrian polo and soccer; both sports are played on a large pitch and display similar play characteristics, such as passes to teammates or opponents intercepting or stealing the ball. Therefore, these sports would fall into a 'donorsports' category; on the surface, these two sports would appear unrelated, but a deeper dive into the play tactics would suggest otherwise. Polo is an equestrian sport (4 v 4) played on a pitch measuring 300 yards by 200 yards in which players hit the ball with long mallets, and soccer (11 v 11) is a sport played on a smaller pitch measuring 75 yards by 120 yards in which players kick the ball. However, both sports are characterised by sporadic actions of maximum efforts (long runs at maximum/near-maximum speed) and sharp movement patterns of stopping, turning, and explosive bursts of speed (Di Salvo et al., 2007; Travassos et al., 2018; Best & Standing, 2019a, 2019b, 2019c, 2019d). While soccer is undeniably a more popular sport than polo (see Chapter 1, Section 1.1 for the sports demographics), it may be useful to investigate the transfer of SA skills between a widely played and viewed sport and a sport that is relatively niche. Do differences in sport visibility or passive knowledge affect how such skills are transferred? One aim, therefore, is to explore the transfer of cognitive skills (*i.e.,* SA and perception) between polo and soccer players in a SA task. If such evidence of transfer exists, then it would be expected that the athletes with sport experience (polo and soccer players) would be more accurate than participants with no sport experience, even in a sport they are unfamiliar with.

3.1.1.3 The role of visual cues in Situation Awareness acquisition.

There is limited discussion in the existing literature on how specifically SA is acquired in sports, and which visual cues are important in such SA acquisition. In sports, decisions must be made within tight time restrictions and with a high level of accuracy (Klostermann et al., 2015; van Maarseveen, Oudejans, et al., 2018), and athletes must focus on relevant information to help guide their decisions and predictions (Hutton & Klein, 1999), which is often attributed to having good SA (Mason, 2020). Visual cues may offer insight into an opponent's actions and can help with anticipation (Cañal-Bruland et al., 2011 Mann et al., 2014). Skilled performers have been found to pick-up and use advanced visual cues from an opponent better than less-skilled performers (Mann et al., 2007), and it has been proposed that elite athletes may use environmental elements such as postural cues to anticipate unfolding plays (Vaeyens et al., 2007), the movements of their opponents (Marinovic et al., 2010; Wood et al., 2017), and shot direction (Cañal-Bruland et al., 2011). Elite athletes also may use visual and auditory cues to predict shot power (Stone et al., 2017), and the offensive moves of their opponents (Allerdissen et al., 2017). Importantly, there has been no research into specific visual cues that would aid in polo performance, and visual cues for equestrian performance have only been investigated in show jumping courses (Hall et al., 2014), which does not directly apply to polo as they are vastly different environments. However, based on research from other sports, visual cues for polo could include player gaze positioning/helmet orientation (Sawyer et al., 2015), mallet positioning (similar to racquet positioning in tennis; Shim et al., 2005), player body positioning and postural cues (Abernethy, 1990; Smeeton & Huys, 2011; Runswick et al., 2020), player positioning on the field (Laakso et al., 2017), and ball flight information (Chalkley et al., 2013). In soccer, visual cues such as player body positioning and postural cues, including support foot progression angle, pelvis rotation, kicking hip, ankle flexion, kicking leg knee flexion angle, support leg shank, and thigh angles (Lees & Owens, 2011), or more broadly the head, shoulder, arm, trunk, hips, kicking and non-kicking leg, and the ball (Savelsbergh et al., 2002). Savelsbergh et al. (2002) also suggested that the kicker's head may be an important source of visual information, potentially as the goalkeepers may try and read facial expressions or characteristics indicating the kicker's upcoming movements.

Eye-tracking studies have shown that athletes have distinct scan paths and fixation points to pick up valuable information from their environment (Harris et al., 2022), which are typically sport-specific, experience dependent, and can vary from film to in situ environments (Afonso et al., 2014). For instance, Murray & Hunfalvay (2017) found that during a tennis pre-serve, elite tennis players displayed longer fixation durations on the shoulders and arms when compared to novices, and Ward et al. (2002) demonstrated that elite tennis players fixated mostly on the head-shoulder-trunk-hips region while novices fixated more on the racquet. Sáenz-Moncaleano et al. (2018) showed that skilled tennis players' fixation/tracking was longer during the early stages of the ball's trajectory, suggesting they gathered important ball flight information in these early stages. In soccer, Lees & Owens (2011) found that goalkeepers likely use the penalty kicker's foot progression angle, pelvis rotation, and angles of the kicking hip and ankle to decide which direction the ball would go, and Savelsbergh et al. (2005) showed that successful goalkeepers were more accurate in predicting the height and direction of the ball, and they focused their attention longer on the non-kicking leg. Additionally, Alder et al. (2014) found that badminton players who focused on irrelevant kinematic locations were less accurate in predicting shot direction than the players who focused on the correct locations. Thus, the body of literature suggests that part of an athlete's performance stems from their ability to read and interpret visual cues from the environment.

Interestingly, Sawyer et al. (2015) even suggested that defensive backs in American football could use the quarterback's gaze direction (through his helmet orientation) to predict (and thus block) his passing target. Thus, a person's gaze can provide a wealth of knowledge about that individual's thoughts, feelings, and intentions (Baron-Cohen, 1994) which may then be used to aid in sports performances. There is a coupling in gaze location and attention, which indicates that what or where a person is looking is the focus of that person's attention (Frischen et al., 2007). The idea that gaze-cueing can determine attention orientation was influenced heavily by Posner (1980), who found that target detection was faster when accompanied with visual cues. In social situations, gaze direction provides insights into what a person is attending (Böckler et al., 2011), and therefore joint attention, or attending to the same stimuli as another person (Ciardo et al., 2015) is possible if two (or more) people attend to the same object, such as the ball in sports. Athletes in invasion-style sports may potentially use the gaze of another athlete to locate the ball or identify passing targets or intents. Bukowski et al. (2015) demonstrated joint attention by showing that participants will automatically compute what is in the line-of-sight of an observed person, particularly when provided with task instructions or context. Additionally, the gaze-cueing effect, or the phenomena that observers respond faster to stimulus targets when cued by others' gaze direction, has been widely researched in social psychology studies. For instance, Hood et al. (1998) showed that gaze directions can trigger attention shifts in infants as young as three months, suggesting that humans follow other's gazes even at an early age. Likewise, eye-gaze directional cues elicit faster responses compared to peripheral cues on the sides (Nagata et al., 2011). While stimuli may be attended to covertly, or without direct gaze (Innocenti et al., 2012), it is suggested that attending to an object whilst directing gaze to another object is difficult (Hoffman & Subramaniam, 1995); however, athletes are no strangers to covert attention, with expert athletes demonstrating a better use of their periphery during anticipation tasks (Schorer et al., 2013; Vater et al., 2020). For example, a polo player may dribble the ball, attending to it using his periphery, whilst also searching the field for a passing target.

In sports, gaze cueing effects have been investigated in situations where athletes use deceptive manoeuvres (*i.e.,* a head-fake in basketball; Polzien et al., 2021; Weigelt et al., 2020), as well as in penalty kick situations with soccer goalkeepers (Greenlees et al., 2008).Weigelt et al. (2020) examined the head-fake in basketball, in which a player will look in one direction and pass in another, thus faking out their opponent. The authors, however, examined whether the head-fake was effective due to the actual gaze orientation (thus, just the eyes), the head orientation (excluding the gaze), or a coupling of gaze and head orientation. Participants with no experience in basketball were shown portraits of a basketball player about to pass a ball; the gaze orientation (via the eyes) was either present or occluded and was congruent (direct pass) or incongruent (head-fake) with the pass, and the head orientation was either congruent (direct pass) or incongruent (head-fake) with the pass direction. The authors found that the head-fake effect was present when the head-orientation was incongruent and the gaze was congruent, but the effect disappeared when the head orientation was congruent, and the gaze was incongruent. The authors suggested that the head-fake was likely based on the head orientation, but not the gaze orientation, despite the findings of social psychology studies (Weigelt et al., 2020). Polzien et al. (2021) also demonstrated that head-fakes produced the largest effect when the head turn (thus head orientation) precedes the pass by 300ms; the authors suggested that the head turn provided a priming effect to the observer, and the short temporal lag between the turn and pass which facilitated the head-fake effect was due to the observer 1) being primed to anticipate a pass in one direction, and 2) the observer having to reorient and shift their attention in the opposite direction, which took longer to process than a congruent head orientation-pass direction, leading to the observer being 'faked out.' Thus, these studies demonstrate the importance of head—and gaze—orientation on deceptive manoeuvres in sports.

Greenlees et al. (2008) demonstrated the importance of gaze information provided by a penalty kicker on the goalkeepers' expectancies of success. The authors found that penalty kickers showing gaze for 90% of the time elicited a lower expectation of goal-stopping success by the keepers, thus suggesting that opponents' gaze is important in developing expectations in sport. Therefore, based on the existing body of literature, in situations where athletes must rely on anticipation skills, an opponent's gaze could potentially provide valuable information regarding their intentions, and the athlete could thus plan how to work around those intentions (Poortvliet, 2010). Simply put, it may be possible for athletes to use their opponent's gaze and head orientation to help gain SA and thus anticipate their opponent's (or teammates') next moves, similarly to how postural cues can help with the anticipation of shot direction and speed (Smeeton & Huys, 2011). Thus, this study will explore the role of gaze orientation of an athlete (whether the athlete is looking at the ball or away from the ball) on SA performance through perception.

In polo, field positioning is another keystone in the FA framework (Goodspeed, 2005), with players required to know the positioning of the players (teammates and opponents) and umpires for successful performance. With limited literature investigating the role of field positioning—or more broadly, a specific grouping of players—on team sports anticipation abilities, this study lastly aims to explore how the visual cues provided by group of players ultimately affects perception in polo. Team invasion sports offer different sources of visual information compared to individual, non-invasion sports. The addition of multiple team members and opponents adds to the complexity of the sport, but potentially also provides a wealth of information that an experienced athlete can use to improve their SA and game performances (North et al., 2016). Where, for instance, a single athlete may provide postural, gaze, and other kinematic cues necessary for anticipation, a group of athletes may provide such visual cues in addition to contextual priors—cues that are non-kinematic sources of environmental information used to improve anticipation performance (Gredin et al., 2020). It is believed that athletes use contextual priors to generate expectations of what may happen next

(Gredin et al., 2018), which is an important component of SA (Level III Projection) (Endsley, 1995b). According to Gredin et al. (2020), a dynamic contextual prior occurs as the play develops and is often related to opponent positioning on the field or court. For instance, skilled athletes have been found to more accurately recognise patterns and structures which may arise from the positioning of players on a field in a set play (North et al., 2016). Roca et al. (2013) found that when anticipating the outcome of 'far' video clips, where the ball was far away from the viewer, skilled soccer players were more accurate than novices, suggesting that the structure of the players on the field is important in anticipation. Similarly, North et al. (2016) showed skilled soccer players were found to better anticipate the result of a play compared to novices, and when anticipating play outcomes viewed from a distance (where individual postural cues could not be seen), player positioning was more important than postural cues. However, Runswick, Roca, et al. (2018) demonstrated that sport-specific contextual information, such as field positioning and game situational information had a negative effect on batting performance in cricket. Experienced cricket batsmen were pitted against a skilled spin bowler. The batsmen were provided with the locations of the fielders in one condition and no information in another. The results showed that the batsmen missed the ball more times during the condition in which they were provided with contextual information. The contextual information, however, did not negatively affect the anxiety or cognitive load of the batsmen. The authors suggested that sports performance is mediated independently from anxiety and cognitive processes, and that the expert batsmen's anxiety or cognitive load was unaffected by the contextual information because they were accustomed to receiving and integrating such information (Runswick et al., 2018). However, what is not explained, is the decrement in batting performance due to the additional information about the fielders' positioning.

The current study looks to also investigate the role of player grouping (*i.e.,* a group of players versus a single player visible in an image) on the performance in a SA sports task. The literature reviewed, however, focuses mainly on players' positioning on the field/court, and not the number of players visible, however, it can be inferred that the more players visible would form a more complete picture of what is happening on the field. For instance, a player facing the whole field/court and able to see all of the players (and their respective positions) might be able to gather much more visual information compared to a player with their back to the field/court, who is, say, guarding one individual player. Therefore, it can be argued that the number of players visible on the field is helpful when viewing and interpreting field/court positions to anticipate future plays.

3.1.1.4 The current study, aims & objectives, and hypotheses.

From the literature above, the study has three aims: 1) to investigate if the STB methodology could discriminate sport experience in a Level I SA (perception) task, 2) to investigate potential transfer of perception performance across polo and soccer, and 3) to explore the role of visual cueing, in particular gaze orientation and player grouping information, and how it may inform perception abilities in the STB task. For this study, sport experience will refer to participants who have experience (familiarity) within a sport, not necessarily that they are 'experienced' meaning expert or elite. The first hypothesis is that athletes (polo and soccer players) will be more accurate compared to control participants in the STB task. The second hypothesis is that athletes will be more accurate for their respective sport (*i.e.*, polo players with polo images and soccer players with soccer images) but would still be more accurate than the control participants even in their non-respective sport, thus showing a transfer effect of perception abilities. The third hypothesis is that participants will be more accurate in the conditions where the photographed athlete is looking directly at the location of the ball. Lastly, the fourth hypothesis is that participants will be more accurate in the condition showing a group of players (mixture of teammates and opponents).

3.1.2 Methods.

3.1.2.1 Design.

The experimental design was a 3 x 2 x 2 x 2 quasi-experimental mixed factors design of sport experience by image sport by gaze type by image grouping, but that statistical design was not explored due to the complexities in interpreting a four-way analysis and because of the decreasing statistical power with each additional interaction (Cohen, 1992). Therefore, the four-way analysis was split into a 3 x 2 and 2 x 2 design to each explore a different aim separately. These designs are discussed separately below and in more detail in Section 3.1.3.2.

Design 1: To explore whether sport experience influences STB performance, a 3 x 2 quasi-experimental mixed factors design of sport experience (polo players, soccer players, controls) by image sport (polo photos, soccer photos) was used. Sport experience was analysed as the between-subjects variable, and the image condition was analysed as the within-subject variable. The Euclidean Distance Accuracy (EDA), the distance between the *x, y* coordinates of where the participant clicked and the *x, y* coordinates of the centre of the (invisible) ball was analysed as the outcome variable.

Design 2: To explore the role of visual cues in SA, a 2 x 2 within-subjects design of gaze type (gaze on the ball, gaze off the ball) by image grouping (group of athletes, single athlete) was used. The Euclidean Distance Accuracy (EDA) was analysed as the outcome variable.

3.1.2.2 Participants.

Participants were recruited online. Polo players were recruited through targeted advertisement posted in newsletters and on social media by the United States Polo Association (USPA), Hurlingham Polo Association (HPA), and the experimenter's personal social media. Soccer players and control participants were recruited through advertisement on the NTU SONA website and on the experimenter's personal social media. A sample size calculation was performed prior to recruiting participants using R (Version 3.6.3). Using a general linear model approach, previous studies using perception tools have reported moderate effect sizes of around 0.25 (f^2) (Faul et al., 2009). Therefore, a power of $\alpha = 0.05$ and $\beta = 0.95$ with four predictors yielded a total sample size of 65 participants (22 participants per sports group). Participants were excluded if they completed less than 80% of the study, answered in a systematic way (*i.e.,* clicking the same location repetitively for more than five images in a row), or were under the age of 18. Two hundred thirty-one participants took part in this study, but 24 (9 soccer players, 15 controls) were excluded due to incompletion of the study. In total, 207 participants (84 polo players, 48 soccer players, and 75 controls) were included in this study. Participants were initially asked to declare which sport they played: equestrian polo, soccer, both equestrian polo and soccer, or neither equestrian polo nor soccer. Based on their response, the participants were separated into their sports experience groups. Participants who did not play polo or soccer were allocated to the control group; however, they may have played other sports, but importantly did not play the targeted sports of this study (polo and soccer). The participants who played both polo and soccer were excluded from the study, as it intended to examine only athletes who played separate sports. However, future research investigating athletes who play in multiple sports would be warranted for examining sport cognitive skill transfer.

Eighty-four polo players ranging in age between 18 – 73 (*M* = 45.01, *SD* = 15.68) completed the task. The players in the current study reported a handicap range between -1 – 5 goals (*M* = 0.47, *SD* = 1.23). The handicaps were: -1 (*N* = 10), -0.5 (*N* = 3), 0 (*N* = 23), 0.5 (*N* = 3), 1 (*N* = 9), 1.5 (*N* = 2), 2 (*N* = 7), 3 (*N* = 1), 4 (*N* = 1), 5 (*N* = 1), Not Rated (NR) (*N* = 24). As clarification, NR does not necessarily equate to having no experience in polo. In polo, handicaps are awarded to actively playing members who participate in official tournaments. A player may still participate in practice events without being awarded a handicap, or a retired player may opt out of receiving a handicap if they are no longer playing. To better gauge player abilities, participants also completed an 11-Point Likert Scale to assess their self-rated polo abilities (0 = Novice and 10 = Expert). The players reported a range of Likert Self-Rated Polo Abilities scores between 0 – 8 (*M* = 3.79, *SD* = 1.89). See Table 3.1 for the polo player participant demographics.

Table 3.1 *Polo player participant demographics.*

	M	*SD*
Age (years)		
18—73	45.01	15.68
Handicap (goals)		
-1—5	0.47	1.23
	N	%
NR	24	28.57
-1	10	11.90
-0.5	3	3.57
0	23	27.38
0.5	3	3.57
1	9	10.71
1.5	2	2.38
2	7	8.33
3	1	1.67
4	1	1.67
5	1	1.67
Self-Rated Abilities	*M*	*SD*
0—8	3.79	1.89
	N	%
NA	5	5.95
0	1	1.19
1	6	7.14
2	15	17.86
3	17	20.24
4	14	16.67
5	11	13.10
6	9	10.71
7	1	1.19
8	5	5.95

Note. N = 84.

Forty-eight soccer players (19 recreational, 23 amateur, 4 semi-professional, 2 professional) ranging in age between 18 – 54 (*M* = 28.20, *SD* = 8.89) completed the task. To better gauge player abilities, participants also completed an 11-Point Likert Scale to assess their self-rated soccer abilities (0 = Novice and 10 = Expert). The players reported a range of Likert

Self-Rated Soccer Abilities scores between 2 – 8 (*M* = 5.40, *SD* = 1.71). See Table 3.2 for the soccer player participant demographics.

Table 3.2 *Soccer player participant demographics.*

	M	*SD*
Age (years)		
18—54	28.20	8.89
Player Levels	*N*	%
Recreational	19	47.92
Amateur	23	39.58
Semi-Professional	4	8.33
Professional	2	4.17
Self-Rated Abilities	*M*	*SD*
2—8	5.40	1.71
	N	%
2	5	10.42
3	3	6.25
4	3	6.25
5	11	22.92
6	13	27.08
7	9	18.75
8	4	8.33

Note. N = 48.

Seventy-five control participants with no polo or soccer experience ranging in age between 18 – 67 (*M* = 26.30, *SD* = 11.99) completed the task. The participants rated their watching involvement in polo, football, and other sports through a 10-point Likert scale (1 = No Watching and 10 = Watching all the Time). The polo-watching Likert scores ranged between 1 – 6 (*M* = 1.13, *SD* = 0.74). The soccer-watching Likert scores ranged between 1 – 8 (*M* = 2.35, *SD* = 1.99). The other sports-watching Likert scores ranged between 1 – 8 (*M* = 3.20, *SD* = 2.35). See Table 3.3 for the control participant demographics.

Table 3.3 *Control participant demographics.*

	M	*SD*
Age (years)		
18—67	26.30	11.99
Polo-Watching Levels	*M*	*SD*
1—6	1.13	0.74
	N	%
1	72	96.00
2	1	1.33
5	1	1.33
6	1	1.33
Soccer-Watching Levels	*M*	*SD*
1—8	2.35	1.99
	N	%
1	28	37.33
2	31	41.33
3	8	10.67
6	1	1.33
8	7	9.33
Other Sports-Watching Levels	*M*	*SD*
1—8	3.20	2.35
	N	%
1	18	24.00
2	25	33.33
3	11	14.67
5	7	9.33
6	4	5.33
8	10	13.33

Note. N = 75.

3.1.2.3 Materials.

3.1.2.3.1 Stimuli.

Participants viewed 40 still images of polo (10 images per image condition) and 40 still images of soccer (10 images per image condition), which were obtained from open access internet sources, such as Google images and Shutterstock. The stimuli (saved as JPEGs) were all high-resolution images (300 dpi) and were taken within the last 10 years. Images were selected to meet the criteria of the following conditions: Image Sport: The "Polo" conditions showed images of polo. The "Soccer" conditions showed images of soccer. Gaze Type: The "Gaze-On" conditions showed the athlete (person in possession of the ball) directly looking at the ball. The "Gaze-Off" conditions showed the athlete (person in possession of the ball) looking away from the ball or images where the athletes' gaze cannot be determined (*i.e.,* images from behind). Image Grouping: The "Group" conditions showed images with multiple athletes from both teams. The "Single" conditions showed images with only one player. Images were selected based on their ability to meet the above criteria whilst also showcasing commonly implemented player body positions and shots. For instance, the polo images displayed a variety of the four main shots: offside forehand, offside backhand, nearside forehand, and nearside backhand, as well as the two main defensive plays: bumping and hooking. The soccer images displayed a variety of different kicks: push kick, instep kick, outside kick, back heel, toe kick, volley kick, and free kick.

The images were edited using Adobe® Photoshop® software (Version 22.1.0). The Cartesian (x, y) pixel coordinates of the centre of the ball were recorded for each image. The ball was then digitally removed from each image, and the images were sized to 960 x 640 pixels (landscape-orientation) and 640 x 960 pixels (portrait-orientation). See Chapter 2, Section 2.3.1.1 for a description on how the stimuli were edited. Each condition included 10 images. See Figure 3.1 for examples of gaze-on polo images before and after removing the ball and Figure 3.2 for examples of gaze-off polo images before and after removing the ball. See Figure 3.3 for examples of gaze-on soccer images before and after removing the ball and Figure 3.4 for examples of gaze-off soccer images before and after removing the ball.

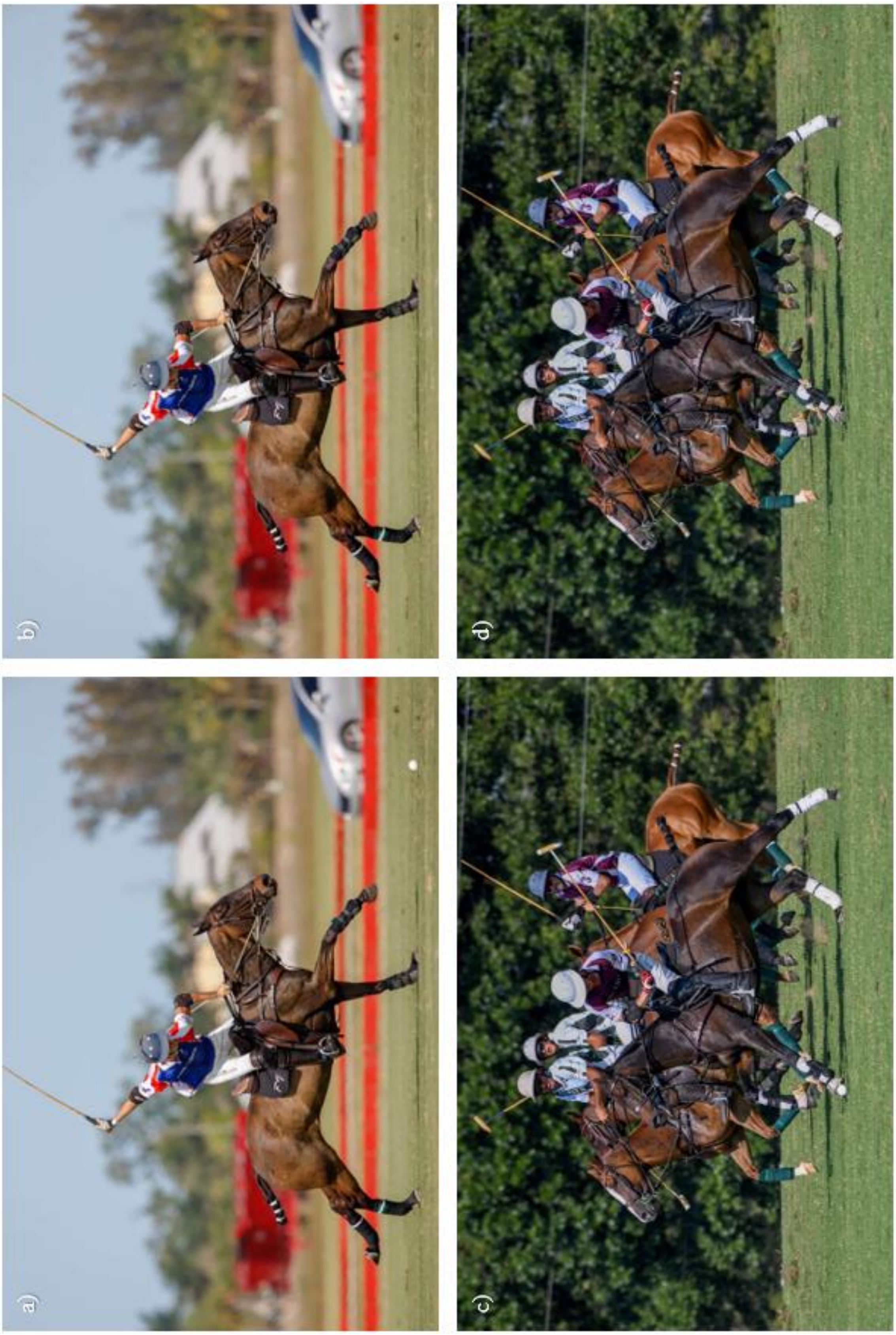

Figure 3.1 *Examples of gaze-on polo image stimuli before and after the ball was removed. Fig. 3.1a—Before (single); Fig. 3.1b—After (single); Fig. 3.1c—Before (group); Fig. 3.1d—After (group).*

Figure ***3.2*** *Examples of gaze-off polo image stimuli before and after the ball was removed. Fig. 3.2a—Before (single); Fig. 3.2b—After (single); Fig. 3.2c—Before (group); Fig. 3.2d—After (group).*

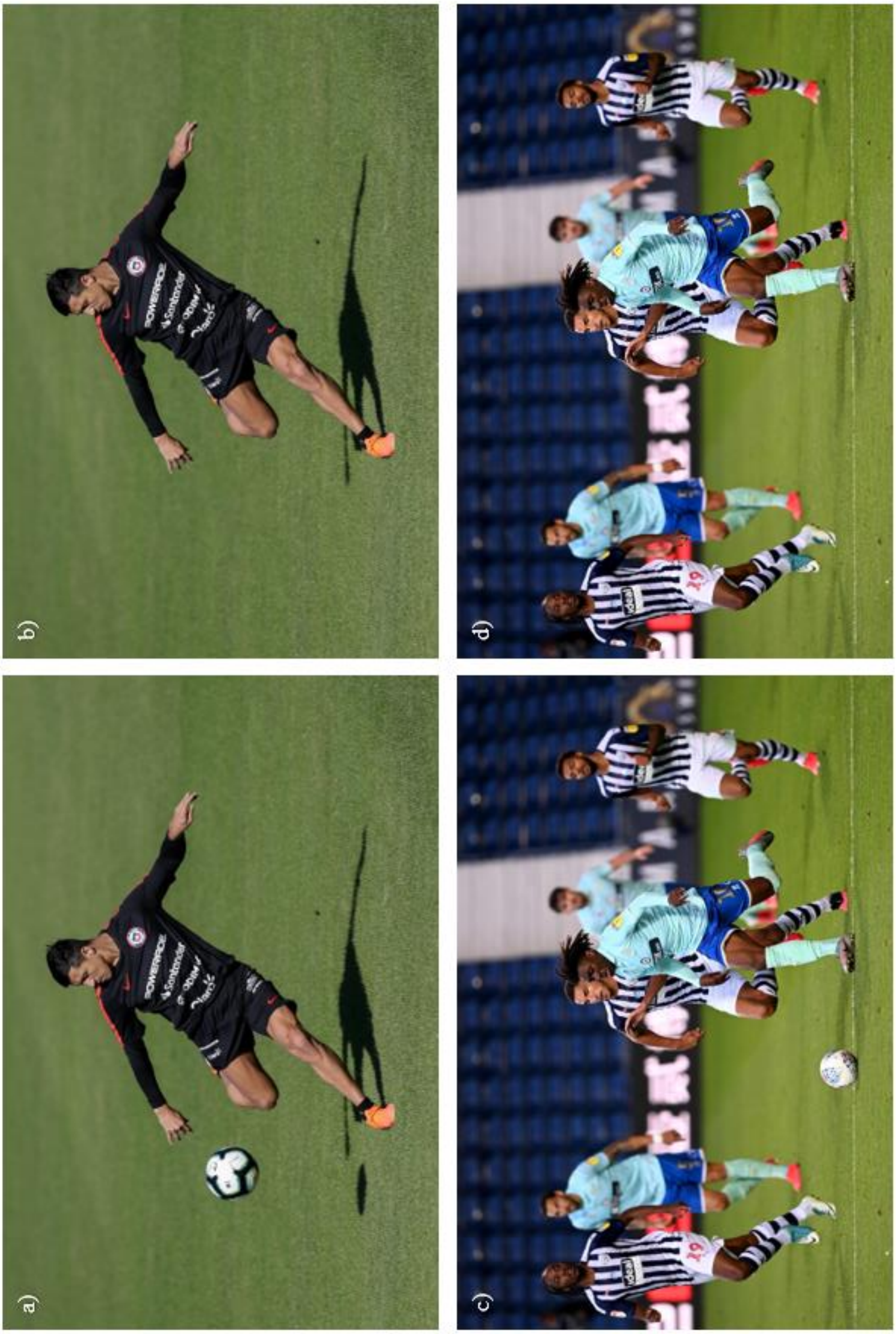

Figure 3.3 *Examples of gaze-on soccer image stimuli before and after the ball was removed. Fig. 3.3a—Before (single); Fig. 3.3b—After (single); Fig. 3.3c—Before (group); Fig. 3.3d—After (group).*

Figure 3.4 *Examples of gaze-off soccer image stimuli before and after the ball was removed. Fig. 3.4a—Before (single); Fig. 3.4b—After (single); Fig. 3.4c—Before (group); Fig. 3.4d—After (group).*

3.1.2.3.2 Apparatus.

3.1.2.3.2.1 Adobe® Photoshop®.

The polo video stimuli for this study were edited using Adobe® Photoshop® software (Version 22.1.0) licensed through Nottingham Trent University. A Think Centre computer and Samsung monitor were used during the editing process. The editing process is described in Chapter 2, Section 2.3.1.1.

3.1.2.3.2.2 Qualtrics.

This experiment was created and hosted online through Qualtrics Version 11.2020 (Qualtrics, Provo, UT). Data was collected between 22 October 2020 – 05 February 2021.

3.1.2.4 Procedure.

Participants completed the task online through the Qualtrics software on their personal laptop, desktop computer, or mobile device (*i.e.,* mobile phone or tablet)[1]. The task was distributed online through email, mailing lists, and social media (*e.g*., Twitter, Facebook, and Instagram). The United States Polo Association (USPA) and Hurlingham Polo Association (HPA) distributed links for the study in their respective newsletters. After consenting to take part in the study, each participant completed a brief questionnaire to determine their sport

[1] Using a linear mixed effects model with a predictor variable of 'device' and fixed effects of participant username and trial, the results showed that there were no differences in device types (χ^2 (1) = 4.05, p = 0.40).

expertise (*i.e.,* polo or soccer player, or control with no experience). Participants were given the instructions to view each image and click where they believed the centre of the ball to be. Participants viewed eight practice image trials (four polo trials and four soccer trials) to familiarize themselves with the apparatus and procedure. Following the practice images, the participants viewed two separate blocks consisting of 80 total image trials (Block 1: 40 polo trials and Block 2: 40 soccer trials). Each block presented the trials in a pseudo-randomised order, in which the images were randomly ordered within their block prior to data collection so that the gaze and grouping conditions were randomly dispersed. Each participant saw the same order of blocks (polo, then soccer) and images within those blocks. This is different to a true randomisation in which no participants saw the same order of images. The participants used a touchpad, mouse, or touchscreen to click on the images. Their exact Cartesian (x, y) pixel coordinates were recorded based on where they clicked or touched the screen. There were no limits to how many times a participant could click on the screen. Once the participant was happy with their response, they clicked an arrow on the bottom of the screen to progress to the next image. Only the final click or touch was recorded as their response. Following the completion of the task, participants were thanked and debriefed. The task took approximately 15 – 20 minutes to complete.

3.1.2.5 Data analysis.

The outcome variable measured was the Euclidean Distance Accuracy (EDA), or pixel distance between the participant's Cartesian (x, y) response and the correct Cartesian location of the centre of the ball for each image, determined by the Euclidean distance formula (Liberti et al., 2014):

$$d(x,y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$$

In this formula, $d(x, y)$ represents the two points in Euclidean space, or Euclidean distance; $(x_i - y_i)$ represents the Euclidean vectors beginning at the initial point of the space; n represents the n-space; $i = 1$ represents the number of variables in the dimension. However, because the distance was examined in a two-dimensional plane, the formula was simplified to:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

In this formula, d represents the EDA, x_1 represents the x-coordinate of the correct ball location, and x_2 represents the x-coordinate of the participant response; y_1 represents the y-coordinate of the correct ball location, and y_2 represents the y-coordinate of the participant response. Importantly, a smaller EDA would indicate better accuracy (better performance), while a larger EDA would indicate less accuracy (poorer performance) in the task.

Sport experience (polo, soccer, control), image sport (polo, soccer), gaze type (on, off), and image grouping (group, single) were considered as the main (fixed) effects predictor variables. The random effects variables were the participant ID and image. These random effects were analysed with a fixed slope. The participant ID was analysed as a nested random effect, and the image was analysed as a crossed random effect.

Linear mixed effects modelling was used to determine the relationships between the EDA and several predictor variables. The data analysis was performed using R (Version 3.6.3)

(R Core Team, 2020) with the *lme4* package (Bates et al., 2020). Model comparisons were used to determine the overall best 'fit' of the data. Each model was run sequentially in order of increasing complexity, beginning with a null model (a model with constants instead of fixed effects). Each main (fixed) effect was added to the model and compared with the previous model. For the main effects models, all fixed effects were included for each model comparison. Interaction effects were also examined. Reduced-maximum likelihood ratios (REML) were used to compare the current model with the previous one to generate *p*-values (Luke, 2017), and any interaction was broken down using post-hoc Tukey tests. For the interaction effects, the fixed effects were modelled as two, two-way models: 1) a 3 x 2 sport experience x image sport, and 2) a 2 x 2 gaze type x image grouping. As stated previously, this was to decrease the complexity of analysing a four-way interaction model as well as preventing the decrease in statistical power from each additional interaction (Cohen, 1992).

3.1.3 Results.

For the STB task, performance was measured as a function of Euclidean Distance Accuracy (EDA), or the distance between a participant's cartesian coordinate and the correct coordinate. The EDA was collected for each individual image (80 total images), with the images categorized into 8 groups (1. Polo Group Gaze-On, 2. Polo Group Gaze-Off, 3. Polo Single Gaze-On, 4. Polo Single Gaze-Off, 5. Soccer Group Gaze-On, 6. Soccer Group Gaze-Off, 7. Soccer Single Gaze-On, and 8. Soccer Single Gaze-Off). As a reminder, a larger EDA would represent the participant being further away from the location of the ball.

3.1.3.1 Main effects.

The mean EDA (and standard deviations) in pixels for the image condition (image sport, gaze type, and image grouping) by sport experience (polo, soccer, control) are shown in Table 3.4. A linear mixed effects model analysis was run to examine the effects of the predictor variables, participant sport, image sport, gaze type, and image grouping, on the outcome variable, or Euclidean Distance Accuracy (EDA). Fixed effects were added, one at a time, to models of increasing complexity and were compared using likelihood ratio tests to the model prior.

Table 3.4 *Mean Euclidean Distance Accuracy (EDA) and standard deviation (in pixels) of each image condition by sport experience.*

	Polo Images				Soccer Images			
	Gaze On		Gaze Off		Gaze On		Gaze Off	
	Single	Group	Single	Group	Single	Group	Single	Group
Polo	148.48 (92.17)	106.86 (92.75)	251.47 (172.93)	112.31 (89.55)	128.34 (85.27)	156.11 (130.42)	193.35 (163.58)	171.71 (150.07)
Soccer	144.67 (95.57)	110.93 (90.01)	282.16 (195.07)	142.96 (114.23)	110.32 (80.26)	124.89 (120.51)	164.11 (119.67)	141.89 (137.55)
Control	142.52 (96.52)	119.94 (92.35)	283.21 (188.54)	157.48 (123.72)	130.76 (93.14)	154.18 (129.50)	172.69 (129.79)	174.50 (151.48)

Note. $N = 207$.

See Table 3.5 for a list of the main effects model comparisons. Results showed that the main effects model with all the fixed effects (sport experience + image sport + gaze type + image grouping) best fit the data (χ^2 (1) = 4.04, $p = 0.04$). Figure 3.5 shows the EDA by sport experience. Paired comparisons with a Tukey correction revealed that polo players (M = 158.07, SD = 133.79) were more accurate than controls (M = 166.83, SD = 137.68; $p < 0.01$), and soccer players (M = 152.58, SD = 133.97) were more accurate than controls ($p < 0.001$).

There were no overall differences in accuracy between polo players and soccer players (p = 0.44). Figure 3.6 shows the EDA by image sport. There were no significant differences between polo images (M = 166.52, SD = 140.66) and soccer images (M = 153.21, SD = 129.34; p = 0.48). Figure 3.7 shows the EDA by gaze type. Overall, participants were more accurate in images when the gaze was on (M = 132.30, SD = 102.63) than when the gaze was off (M = 188.21, SD = 157.14; $p < 0.01$). Lastly, Figure 3.8 shows the EDA by image grouping. Participants were more accurate in group images (M = 139.90, SD = 122.45) compared to single images (M = 180.46, SD = 144.65; p = 0.05).

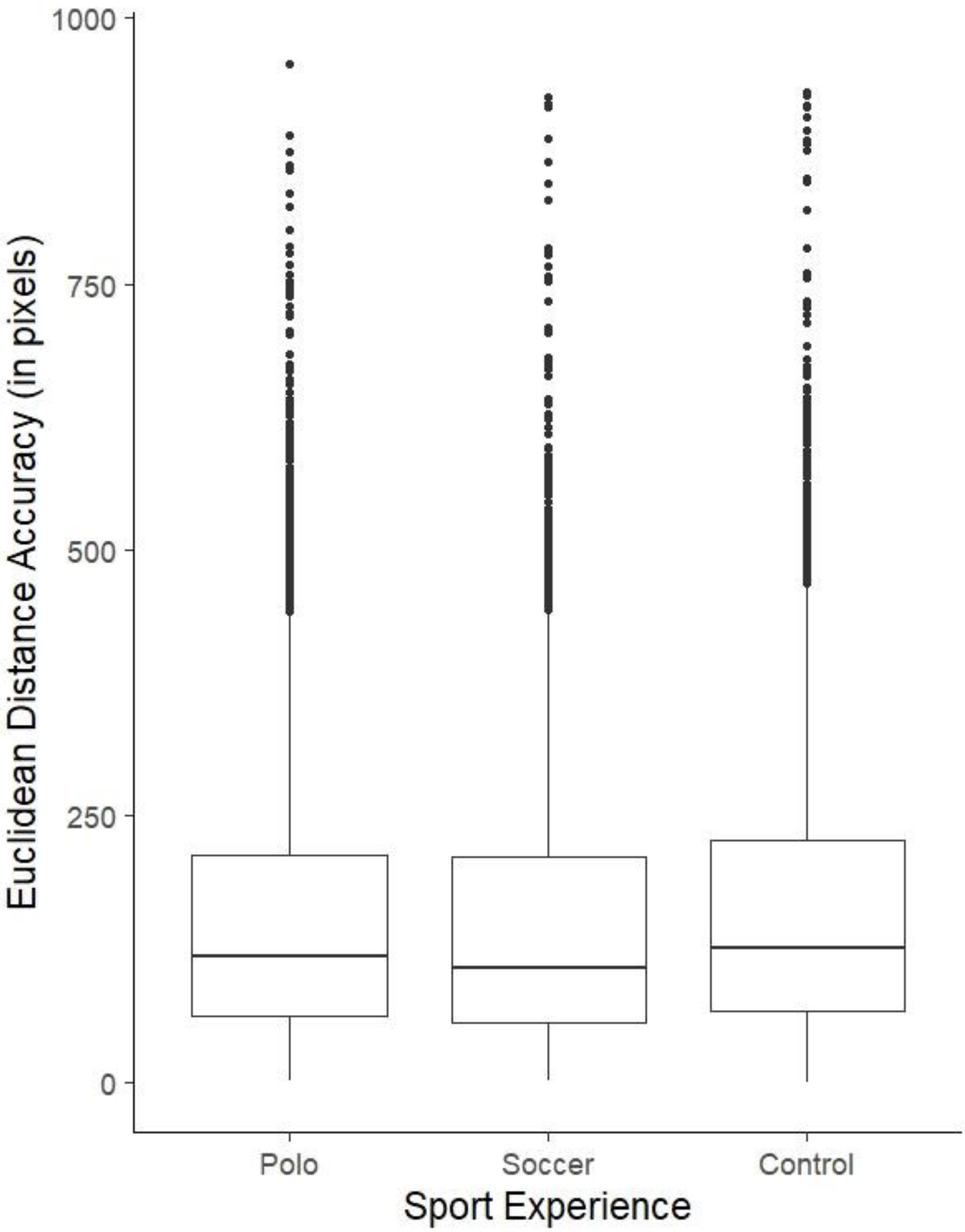

Figure 3.5 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) by sport experience.*

Note. N = 207.

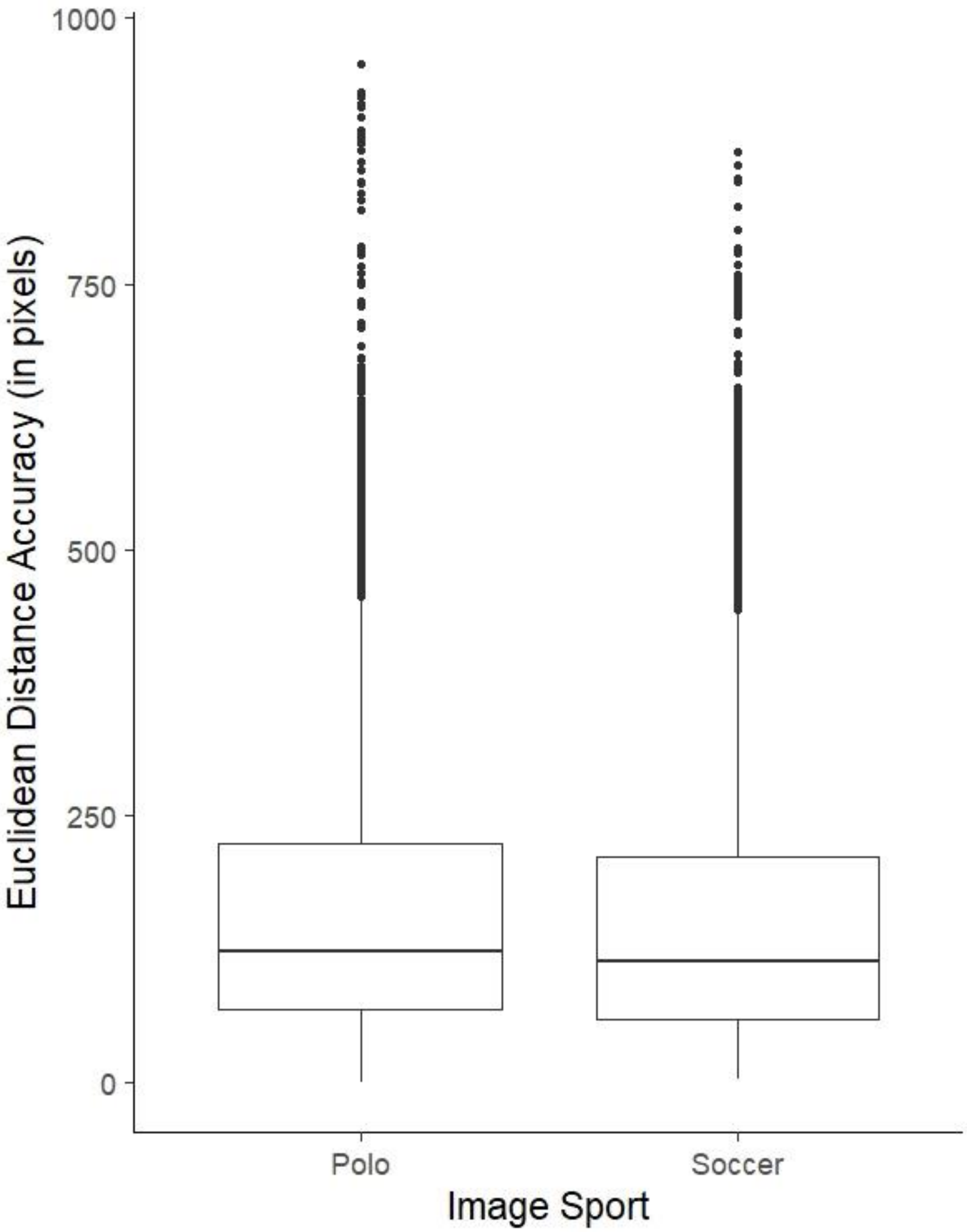

Figure 3.6 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) by the image sport.*

Note. N = 207.

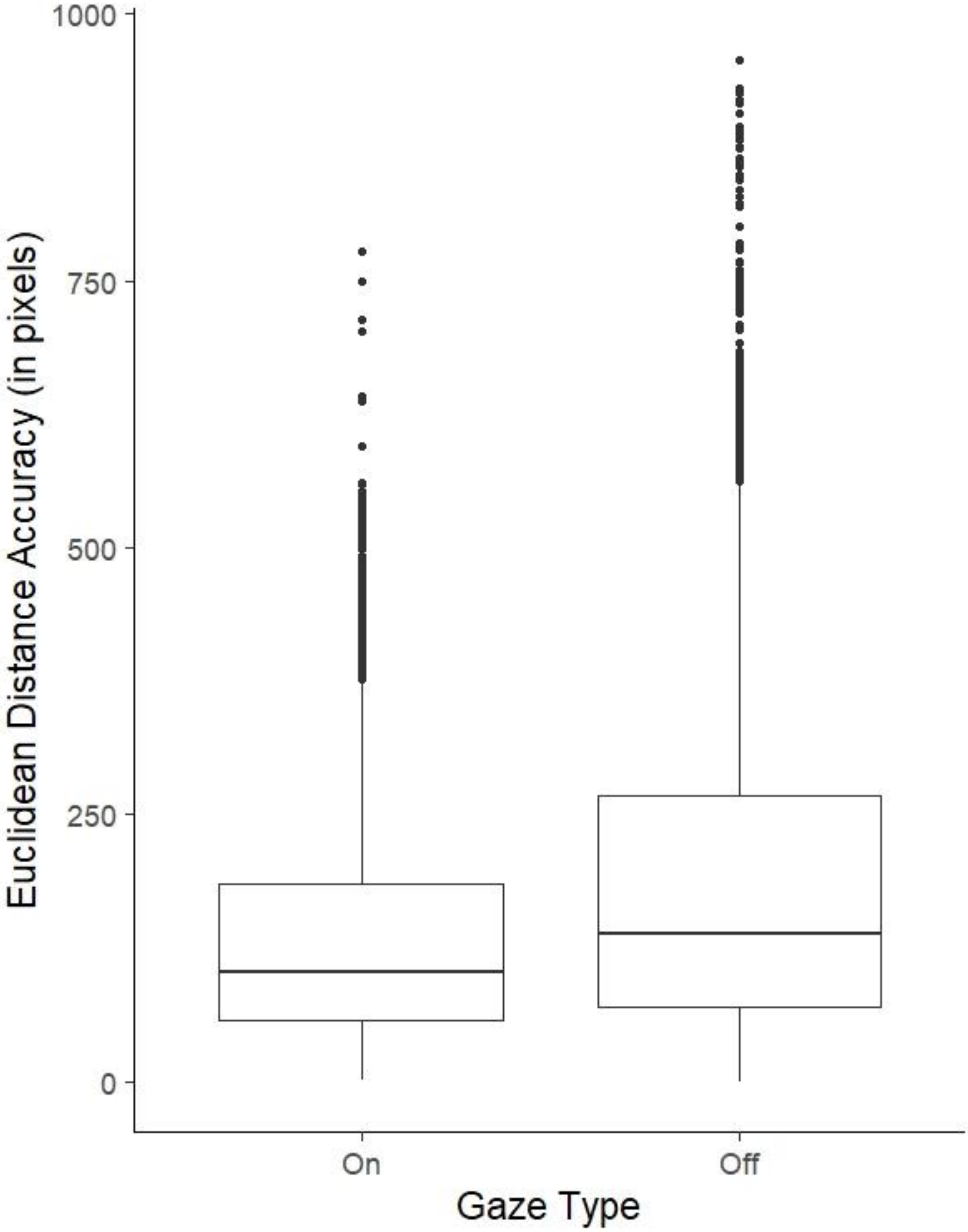

Figure 3.7 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) by gaze type.*

Note. N = 207

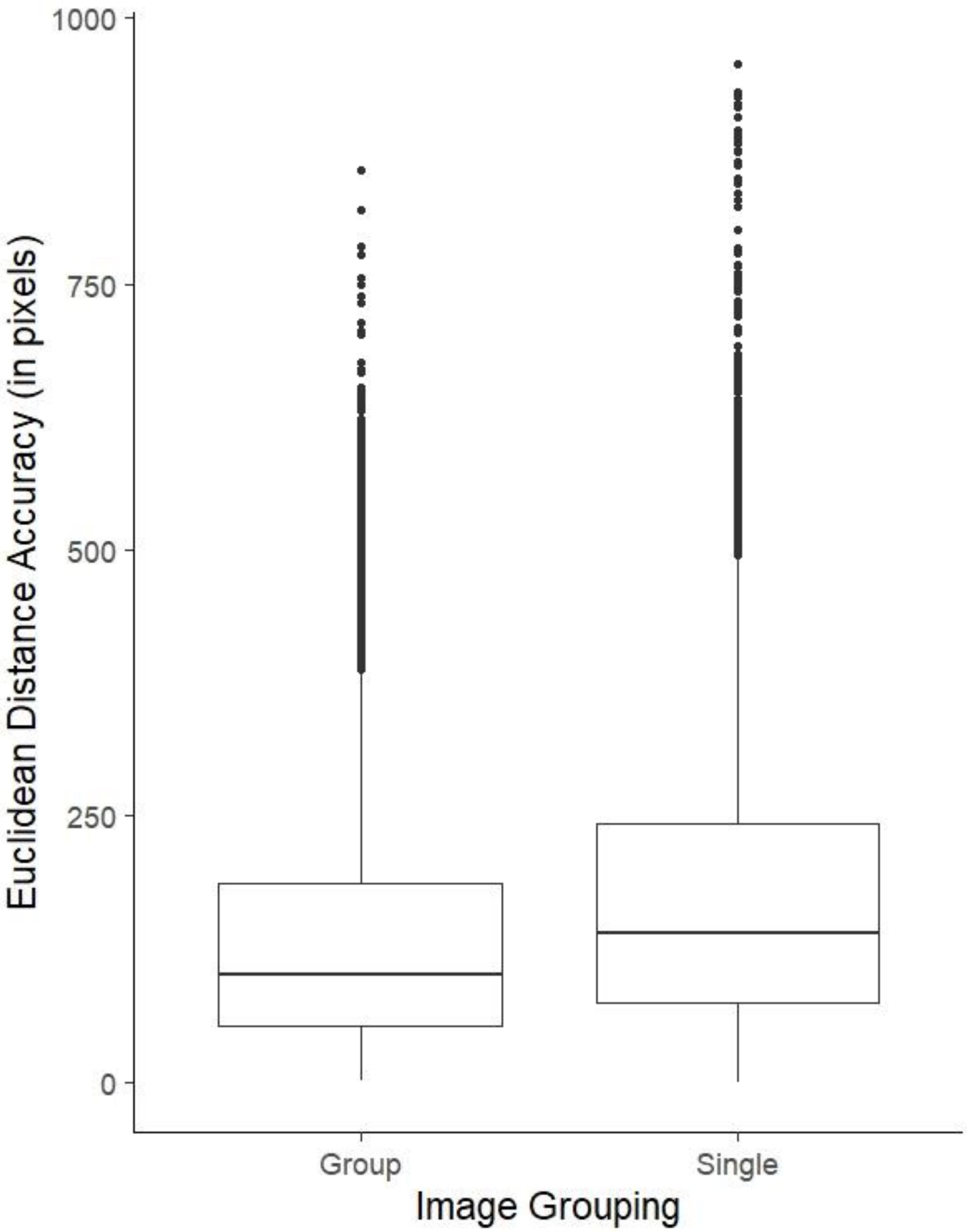

Figure 3.8 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) by grouping.*

Note. N = 207.

Table 3.5 *List of Euclidean Distance Accuracy main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	178895	-	-	-
ME1	Sport Experience	ME1 / Null	178895	16.35	2	< 0.001
ME2	Sport Experience + Image Sport	ME2 / ME1	178883	0.46	1	0.50
ME3	Sport Experience + Image Sport + Gaze Type	ME3 / ME2	178884	7.56	1	0.01
ME4	Sport Experience + Image Sport + Gaze Type + Image Grouping	ME4 / ME3	178879	4.03	1	0.04

Note. N = 207.

3.1.3.2 Interaction effects.

Mixed-effects models were used to determine if there were interactions between specific predictor variables. Two, two-way interaction models were used to decrease the complexity of analysing a four-way interaction and to prevent the decrease in statistical power that comes from each additional interaction (Cohen, 1992). As stated previously, the interactions were broken down into a 3 x 2 and 2 x 2 mixed factors design, each developed to address a specific aim.

3.1.3.2.1 Sport experience by image sport interaction effects.

To explore how sporting experience influences STB performance and to determine if there were any cross-sport performance transfer effects, a 3 x 2 mixed factors design of sport experience (polo, soccer, control) with the image sport (polo, soccer) was used. Table 3.6 shows the interaction effects model comparisons. Results showed the two-way interaction of sport experience x image sport fit the data better than the sport experience + image sport main effect model (χ^2 (2) = 105.08, $p < 0.001$). Figure 3.9 shows the visualization of the EDA of sport experience by image sport. Paired comparisons with a Tukey correction revealed that for polo images, polo players ($M = 154.83$, $SD = 130.83$) were significantly more accurate than controls ($M = 174.65$, $SD = 145.42$, $p < 0.001$). Polo players were significantly more accurate than soccer players ($M = 170.08$, $SD = 146.25$, $p < 0.01$). There were no differences between soccer players and controls ($p = 0.77$). In soccer images, soccer players ($M = 135.16$, $SD = 117.99$) were significantly more accurate than controls ($M = 157.98$, $SD = 128.87$, $p < 0.001$). Soccer players were significantly more accurate than polo players ($M = 162.13$, $SD = 137.32$, $p < 0.001$). There were no differences between polo players and controls ($p = 0.80$).

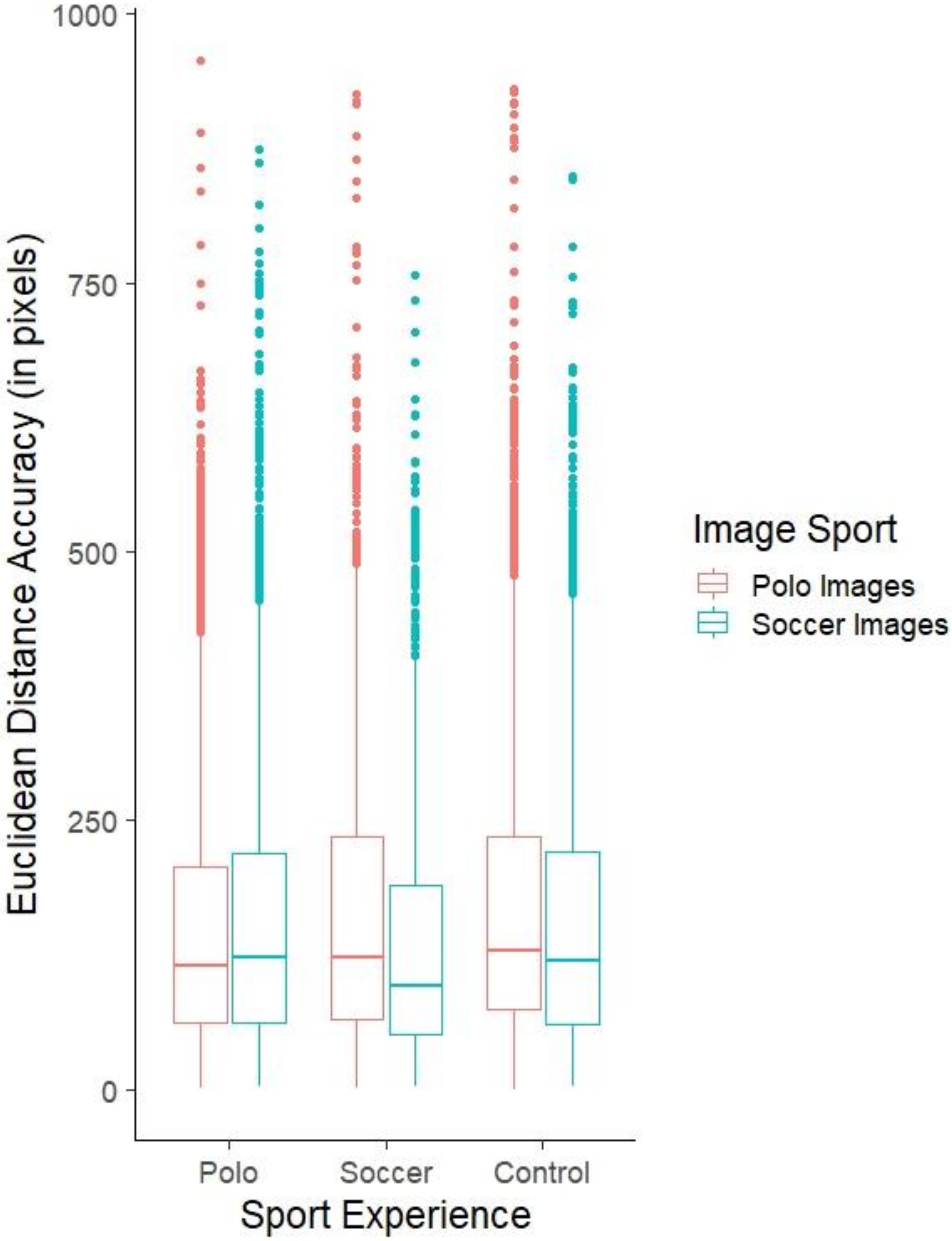

Figure 3.9 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) of sport experience by image sport.*

Note. N = 207.

Table 3.6 *List of Euclidean Distance Accuracy sport experience x image sport interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	178895	-	-	-
ME1	Sport Experience	ME1/Null	178895	16.35	2	< 0.001
ME2	Sport Experience + Image Sport	ME2 / ME1	178883	0.46	1	0.50
INT1	Sport Experience x Image Sport	INT1 / ME2	178783	105.08	2	< 0.001

Note. $N = 207$.

3.1.3.2.2 Gaze type x image grouping interaction effects.

To explore the role of visual cues in the STB task, a 2 x 2 between factors design of gaze type (on, off) by image grouping (group, single) was used. Figure 3.10 shows the visualisation of the EDA of the image grouping by gaze type. Table 3.7 shows the interaction effects model comparisons. Results showed the two-way interaction of gaze type x image grouping (χ^2 (1) = 3.18, $p = 0.07$) did not fit the data better than the gaze type + image grouping main effects model.

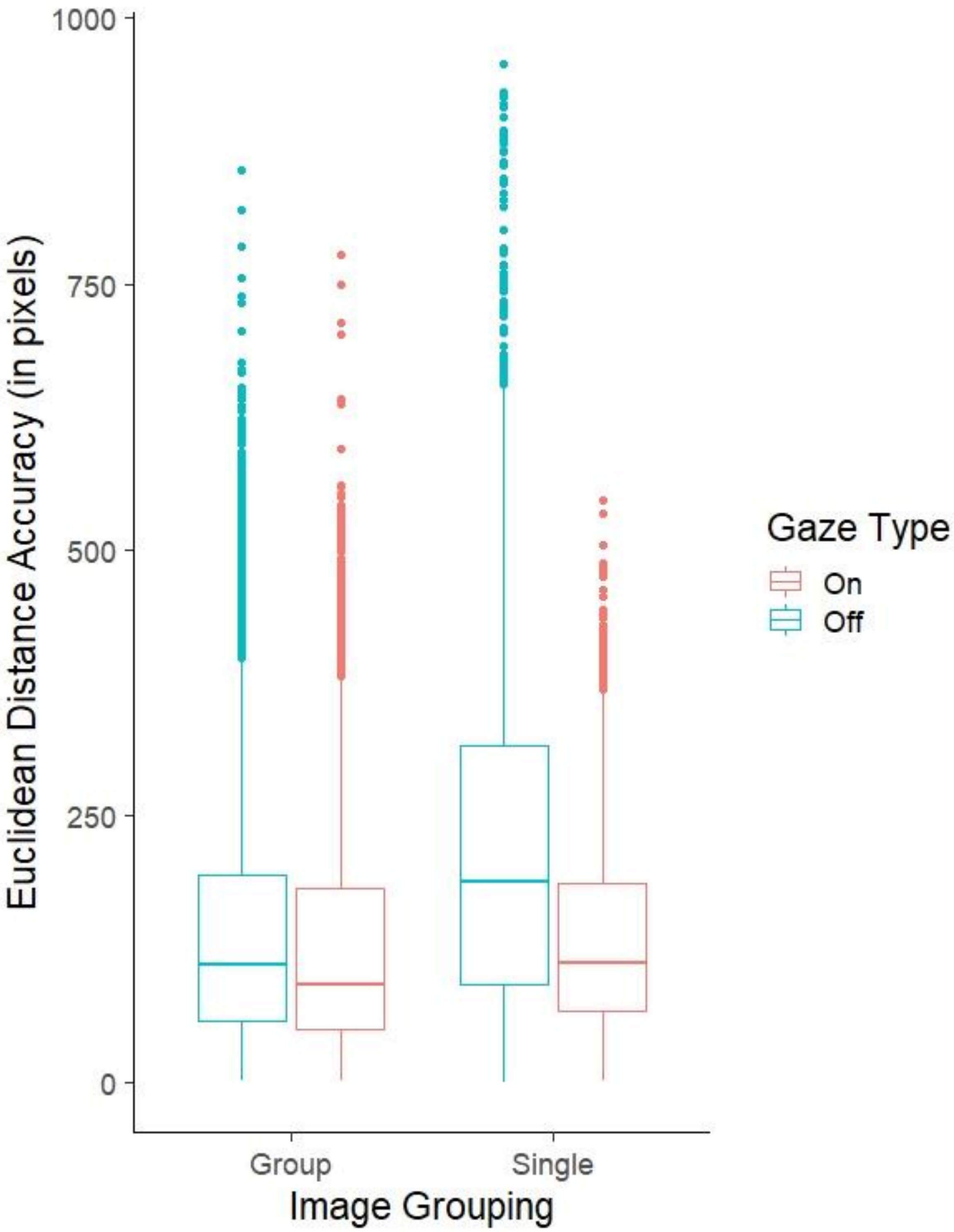

Figure 3.10 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) of the image grouping by gaze type.*

Table 3.7 *List of Euclidean Distance Accuracy gaze type x image grouping interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	178895	-	-	-
ME5	Gaze Type	ME5 / Null	178890	7.52	1	< 0.01
ME6	Gaze Type + Image Grouping	ME6 / ME5	178888	4.01	1	0.05
INT2	Gaze Type x Image Grouping	INT2/ ME6	178886	3.18	1	0.07

Note. N = 207.

3.1.3.3 Sport experience and STB performance correlation.

To investigate if sport-specific experience is correlated with sport-specific image accuracy, linear regression models were run for both polo and soccer players. The results indicated that overall, there was no correlation of sports-specific experience with STB performance (accuracy) for sports-specific images.

To assess if the polo player handicap was associated with STB performance in polo images, a linear regression model was run with the outcome variable set as the Euclidean Distance Accuracy (EDA) and the predictor variable set as the handicap. The results indicated there was no significant effect of polo handicap on the polo image accuracy ($F(1, 33) = 1.04$, $p = 0.31$, $R^2 = 0.03$). To investigate if the self-rated abilities scores were associated with STB performance in polo images, a linear regression model was run with the outcome variable set as the Euclidean Distance Accuracy (EDA) and the predictor variable set as the self-rated scores. The results indicated there was no significant effect of self-rated polo abilities on the polo image accuracy ($F(1, 46) = 0.96$, $p = 0.33$, $R^2 = 0.02$).

To assess if the soccer level of play was associated with STB performance in soccer images, a linear regression model was run with the outcome variable set as the Euclidean Distance Accuracy (EDA) and the predictor variable set as the level of play. The results indicated there was no significant effect of soccer level of play on the soccer image accuracy ($F(1, 36) = 0.39$, $p = 0.54$, $R^2 = 0.01$). To investigate if the self-rated abilities scores were associated with STB performance in soccer images, a linear regression model was run with the outcome variable set as the Euclidean Distance Accuracy (EDA) and the predictor variable set as the self-rated scores. The results indicated there was no significant effect of self-reported soccer abilities on the soccer image EDA ($F(1, 36) = 0.88$, $p = 0.36$, $R^2 = 0.02$).

3.1.4 Discussion.

The first aim of the study was to investigate if the STB methodology could discriminate sport experience in a Level I SA (perception) task. It was hypothesised that athletes (polo and soccer players) would be more accurate compared to control participants in the STB task. There was evidence that this hypothesis was supported, with polo players and soccer players having smaller (*i.e.,* more accurate) Euclidean Distance Accuracies (EDA). The second aim was to investigate potential transfer of perception performance across polo and soccer. It was also hypothesised that athletes would be more accurate for their respective sport (*i.e.*, polo players with polo images and soccer players with soccer images) but would still be more accurate than the control participants even in their non-respective sport, thus showing a transfer effect. There was no evidence to support this hypothesis; polo players were the most accurate in polo images, and soccer players were the most accurate in soccer images with no evidence of transfer when the EDAs were examined. The third aim was to explore the role of visual cueing, in particular gaze orientation and player grouping information, and how it may inform prediction abilities in the STB task. It was hypothesised that participants would be more accurate in the conditions where the photographed athlete is looking directly at the location of the ball. There was evidence to support this hypothesis, with all participants displaying more accurate EDAs in the gaze-on conditions when the photographed athletes were looking at the ball. Lastly, it was hypothesised that participants would be more accurate in the condition showing a group of players (mixture of teammates and opponents). There was evidence to support this hypothesis; participants were more accurate in images showing a group of players rather than a single player. The results and theoretical implications are further discussed below.

3.1.4.1 The 'Spot the Ball' tool as an inference of Level I Situation Awareness in sports.

As discussed previously, many of the methods used to assess SA within sports settings are generally underdeveloped, retroactive, and lacking in empirical evidence, thus making it difficult to properly assess SA in sports. Of the SA methods which do provide empirical data (*i.e.,* SAGAT) (Endsley, 1995b; Ng et al., 2013), the experience levels of the athletes were not investigated, making it difficult to infer the role of experience in sports SA tasks. Additionally, the existing sports SA assessment methods do not explore how SA is acquired in the first place. Therefore, this study attempted to address the limitations of the existing SA assessment tools by providing empirical data which could be used to investigate the role of sports experience in Level I SA (perception) performance, as well as the role of visual cues used for perception in sports.

The main question of this study is: did the Spot the Ball (STB) task discriminate sports experience, and thus, could it be an inference of perception (Level I SA) in a sports context? Based on the results, the STB tool may be a good candidate for inferring these lower-level SA abilities in sports. In the literature, there is no SA measure that has been validated against differing sports experience/expertise levels, and therefore, the STB tool has potentially addressed this limitation in the literature by sampling polo and soccer athletes (along with control participants with no polo or soccer experience). Importantly, the results show discrimination between sporting experience, suggesting that there are some underlying perception skills utilised during the STB task. Additionally, the STB tool could be considered a viable candidate for Level I SA (perception) measurement because it taps into a participant's ability to see and recognise sports visual cues.

The STB task presented static images of equestrian polo and soccer with the ball digitally removed; participants were required to view the images and locate the missing ball. The main premise, then, was that the participants with more experience in a sport (*i.e.,* polo players with polo images) would be more accurate with their perception skills because of their abilities to utilise the visual cues provided in the images, such as gaze orientation and player grouping, that were presented in the photographs. This discrimination would provide a level of validity to the STB tool as experienced athletes would have better perception abilities and would thus perform better in the task. The results showed that the task did discriminate experience, with polo players performing better with the polo images and soccer players performing better in the soccer images when the EDA was analysed. Those without any experience in a sport (*i.e.,* control participants and athletes of the different sport) were significantly less accurate in their predictions, suggesting that experience likely plays a role in SA—particularly through perceiving visual cues and using those cues to locate the missing ball.

This experience effect, demonstrated in many non-sporting SA studies (Dishman et al., 2020; Durso et al., 1999; Endsley, 2000a, 2021; Gugerty, 2011; Horswill & McKenna, 2004; Kaber et al., 2016; Underwood et al., 2013), is an important indicator in the STB tool's validity—thus, it is actually measuring what it claims to be measuring. What the sports SA domain is missing is an objective, validated, reliable method of assessing SA in athletes (and even coaches and umpires), and the STB tool potentially could be used as an inference measure for SA in a sporting context. The following study (Chapter 3: Study 1.2) aims to replicate these experience effects findings, which would further validate the use of the STB tool in sports SA assessment.

It is important to note that there are some limitations to the STB tool being used as an inference measure of SA. The STB tool, whilst it does discriminate sports experience, as discussed above, is still only an inference for Level I SA. It does not directly measure the levels of SA as does the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995b) or What Happens Next? (WHN) (Jackson et al., 2009) tools which target the individual SA levels or the prediction (Level III SA) of a sequence (*e.g.,* play) outcome. One could additionally argue that locating a missing ball is not enough to warrant the label of a SA measurement tool, as it is a static measure, and SA is generally described in dynamic environments. However, as stated in the introduction of this study, identifying the visual information that allows athletes to locate a ball is an important step in researching SA in sports; because the ball is such a crucial component to sports such as polo (Goodspeed, 2005) and soccer (Savelsbergh et al., 2002), the ability to locate a ball may form the foundation of an athlete's SA, which would then influence the overall quality of SA.

3.1.4.2 The role of sport experience in the 'Spot the Ball' task and transfer effects between similar sports.

Experience in a sport has been previously suggested to be a strong driver of performance in sports visuo-cognitive tasks (Catteeuw et al., 2010; del Campo et al., 2011; Gredin et al., 2018; Li & Feng, 2020; Macquet & Fleurance, 2007; Rowe et al., 2009;

Savelsbergh et al., 2002, 2005; Singer et al., 1996; Travassos et al., 2013) and SA tasks (Crozier et al., 2015; Dishman et al., 2020; Kaber et al., 2016; Lavoie et al., 2016), therefore, a second aim of the study was to investigate the role of sports experience on SA performance, and to explore any transfer effects between similarly-structured sports. The results showed that experience in a particular sport (*i.e.,* polo or soccer) led to more accurate perception abilities in the STB task. The study demonstrated that polo players were the most accurate in the polo images, and soccer players were the most accurate in soccer images These results were mostly as hypothesized, given the body of existing literature suggesting that experience plays an important role in SA and perception in sports-related tasks. However, importantly, there was no evidence of transfer in perception skills in the polo and soccer players' non-respective sport. In other words, whilst the polo players and soccer players were more accurate in their respective sport, they were no better than control participants in their non-respective sport.

Based on the existing literature, it can be suggested that the athletes in this study were more accurate than the controls in their overall predictions due to their prior experience and sport-specific memory—with this experience and memory, the athletes had likely created (and updated over time) mental models of situations common to their sports (Collins & Gentner, 1987; Filho et al., 2015). These mental models arguably allowed them to recognise the types of situations presented in the image based on their past experiences. In other words, the athletes could match the situation in the images to an existing mental model and make a decision on where the missing ball was located with relative success. Importantly, the lower Euclidean Distance Accuracies (EDAs) demonstrated by the athletes suggests that prior experience in a sport may play a role in acquiring SA. Sport experience has previously been shown to influence performance in sports-related cognitive tasks, particularly when experienced or skilled athletes are compared to inexperienced or less-skilled participants. For instance, Jin et al. (2011) demonstrated that badminton players made more accurate predictions than non-players when anticipating the landing position of a shuttlecock, and similarly, collegiate basketball players could more accurately predict the shot result compared to non- players (Li & Feng, 2020). In tennis, skilled players were more accurate in anticipating serves than beginner players (Singer et al., 1996). Potentially, the athletes of this study utilised their mental models gained through previous experience and situational knowledge to influence their recognition of situations and their perception in the STB task, thus suggesting that sport experience plays a role in acquiring Level I SA.

Transfer of perception abilities between sports was also investigated in this study; although the polo and soccer players performed better in their own sport, there was no evidence that cognitive and SA skills transferred to the other sport. There is evidence in the sporting literature that sports perceptual-cognitive abilities may be transferred between sports with similar styles and structures (Smeeton et al., 2004), however, the results of the study show no such evidence of transfer of SA skills between polo and soccer players. The athletes in the non-dominant sport condition (*e.g.,* polo players in soccer conditions and vice versa) were no more accurate than the control participants, suggesting that any benefits of sport-specific experience did not transfer to an unfamiliar sport. While some studies have suggested that transfer may occur between similarly structured sports (Causer & Ford, 2014; Smeeton et al., 2004), there is also evidence that transfer does not occur between different sports (Müller et al., 2015). For instance, Smeeton et al. (2004) showed that soccer and field hockey players were slower and less accurate when anticipating volleyball play outcomes, and Müller et al. (2015) found that cognitive skills were sports-specific, with rugby players failing to anticipate plays in baseball. However, soccer, field hockey, and volleyball (Smeeton et al., 2004) and rugby and baseball (Müller et al., 2015) are very differently structured sports, so it is possible that the lack of transfer of anticipation skills could be due to the dissimilar structure of the sports, as suggested by Causer & Williams (2015). However, polo and soccer are arguably similarly structured, so why would there be no evidence of skills transfer in this study?

A potential explanation for the lack of perception skills transfer between polo and soccer players may boil down to the theories of near-transfer and distant (far)-transfer (Gobet, 2016; Sala & Gobet, 2017; Seifert et al., 2019; Woltz et al., 2000). Here, the STB could be considered a distant-transfer, where the sports are loosely related to each other and the source (*e.g.,* polo) shares only a few elements and patterns with the target (*e.g.,* soccer) (see Sala & Gobet, 2017 for an explanation on near- and distant-transfer). Polo and soccer share similar elements at theoretical level; however, these elements are ultimately acquired through different perceptual patterns (Simon & Chase, 1973). Thus, because the perceptual patterns, which allow for athletes to gain domain-specific experience, are unique (Sala & Gobet, 2017), distant-transfer of SA skills may not have occurred.

Another reason for the lack of transfer effect in this study between soccer and polo is the very nature of the sport of polo itself. Polo is a very niche and underrepresented sport (Gilbert & Gillett, 2013), thus, many people outside the polo 'community' may be unfamiliar with it—even those who participate in other equestrian disciplines, such as jumping or dressage, often struggle to follow the game (Gilbert & Gillett, 2013). Additionally, the rules of polo (*i.e.,* the LOB and ROW), which are second nature to polo players, are all but guaranteed to be unknown to someone unfamiliar to the sport. In polo, a player cannot just see the ball and attack it as with other sports—there are strict rules on who has the legal play (Hurlingham Polo Association, 2019; United States Polo Association, 2020). The lack of rules knowledge could potentially have led to a detriment in the STB performance by the soccer players. There was no evidence of a transfer effect potentially because the unfamiliarity of the sport and the confusion of seeing such a sport for the first time may have created a higher cognitive load in the soccer players and non-athletes as they struggled to interpret the scene, thus reducing their ability to predict the location of the ball.

Similarly, the motor skills required for polo are vastly different than those required for soccer. When hitting a polo ball, polo players largely engage their upper body and trunk to swing the mallet (Brittain & Oliver, 2018; Oliver et al., 2017, 2018b); soccer players, however, largely engage their lower body to kick the ball (Lees & Owens, 2011; Savelsbergh et al., 2005). It is possible that the differing biomechanics required for polo and soccer may have provided enough of a barrier to prevent any transfer of prediction abilities. One who is unfamiliar with the biomechanics and kinematics necessary to drive the ball forward (or in any direction) may be less accurate in predicting shot locations, regardless of sport experience. For instance, in soccer players, it was found that players who fixated their gaze on less relevant body parts of a penalty kicker were ultimately less accurate in their predictions of where the shot would land (Savelsbergh et al., 2005). Thus, given the relative unfamiliarity of polo and differences in biomechanics and kinematics, soccer players may have struggled to utilise their developed visuo-cognitive skills during the polo STB task, reducing their accuracy. A better investigation into sports transfer effects should perhaps include sports which are similar in structure, widely available to watch in passing, and have relatively well-known rules; however, such a study is ultimately beyond the scope of this thesis.

3.1.4.3 The role of visual cues on a performance in a Situation Awareness sports task.

Visual cues have been suggested as a means towards gaining environmental information in which athletes may use to aid in prediction, anticipation, and decision-making (Lees & Owens, 2011; Sawyer et al., 2015), however, such cues have not been widely related to SA task performance despite the first level in SA being described as ‘perception’ (Endsley, 1995b).

Thus, an aim of this study was to investigate the gaze orientation of the photographed players and the player grouping on the SA abilities. The results showed that overall, participants (including control participants) were more accurate in the gaze-on conditions, suggesting that gaze and head orientation of players may be an important visual cue in SA acquisition. Additionally, the results showed that overall, participants were more accurate in the group conditions compared to the single conditions, suggesting that the more visual information provided by a group of players may be important in gaining lower-level SA.

The results suggest that the gaze (helmet, in polo images) orientation is possibly a driver of perception in sports; all participants, despite sports experience, were more accurate when the photographed athlete's gaze was directed towards the ball compared to when the gaze was not directed towards the ball or was not visible. In sports, it has been suggested that gaze cueing and head orientation were important visual cues in anticipating future outcomes (Greenlees et al., 2008; Polzien et al., 2021; Weigelt et al., 2020), and gaze cueing in target detection has been demonstrated in social psychology, with studies showing that participants were faster to attend to a stimulus if congruently cued (Driver et al., 1999; Frischen et al., 2007; Joyce et al., 2016). The results of the current study, though they did not present the speed of target location, demonstrate that congruent—or when the photographed athletes' gaze was on the ball—gaze orientation with the ball led to more accurate perception. This phenomenon has been shown in sports, where both higher- and lower-skilled soccer players were better at predicting a pass direction when the spatial cueing was congruent with the pass direction compared to an incongruent, deceptive pass manoeuvre (*i.e.,* a step-over; Wright & Jackson, 2014).

It has also been previously suggested that the direction of an individual's gaze may provide insight into their locus of attention (Böckler et al., 2011); indeed, Bukowski et al. (2015) demonstrated that participants automatically compute what is in the line-of-sight of a person. It would seem that the participants in the gaze-on conditions followed the direction of the photographed athletes' gazes to the ball with the assumption that the photographed athletes' gazes were indeed on the ball; this led to smaller EDAs and thus better performance in the STB task. The results of this study also suggest that the participants may have achieved joint attention with the photographed athletes (despite the athletes simply being presented as static images). As to be expected, then, in the gaze-off conditions, where the photographed athletes' gazes were not directed at the ball, the participants in this study, regardless of sport experience, were not quite as accurate, suggesting that gaze orientation of an athlete may be an important visual cue for acquiring SA in a sports setting.

The results also showed that the participants were more accurate when a group of athletes were shown compared to when only one was visible, which would suggest that a group of players provided more visual cues for which the participants could use to gain SA and make their decisions. In the literature, it has been suggested that in team open-style invasion sports (*i.e.,* equestrian polo and soccer), multiple players provide more visual information and visual cues in which an observer may use to aid in their anticipation abilities (Gredin et al., 2020; North et al., 2016). It has even been suggested that skilled players may be able to use field positioning of multiple players to anticipate future outcomes, as was shown in soccer by Roca et al. (2013) and North et al. (2016). The results of the current study showed that multiple players arguably provided more visual information than a single player, which led to more accurate location abilities, thus leading to lower EDAs. It is possible that the visual cues—although static—were useful to participants in acquiring SA, thus demonstrating that more visual cues provided by multiple players is important in gaining and maintaining SA in sports. Interestingly, there was no interaction between the gaze and group conditions; thus, a group of athletes did not compensate for a lack of gaze cueing. Ultimately, this suggests that of the visual cues investigated, the gaze and head orientation of the ball-handler was more important in locating the missing ball than the non-gaze visual information provided by several players. This will be further explored in the following study where the stimuli images will feature only single players, thus allowing for a potentially clearer analysis of gaze cueing without any potential confounds of extraneous information provided by multiple players. It is also important to acknowledge that gaze orientation and player grouping were just two visual cues elected to investigate for this study. As sporting research has shown, there are a plethora of visual cues that may be used when locating or tracking a ball. Therefore, it is not correct to extrapolate from this study the notion that gaze orientation is the *only* visual cue used when locating a ball. As discussed previously, visual cues in sports include postural cues (Abernethy, 1990; Lees & Owens, 2011; Savelsbergh et al., 2002; Smeeton & Huys, 2011; Runswick et al., 2020), kinematics (Alder et al., 2014; Mann et al., 2007; Williams & Jackson, 2019), player field positioning (Laakso et al., 2017), and ball trajectory (Chalkley et al., 2013). The following study therefore aims to experimentally test the role of additional polo-specific visual cues in a STB task.

3.1.4.4 No correlation between athlete experience levels and STB performance.

Perhaps an important facet to consider when gauging the role of sport-specific experience on sports cognitive tasks is to not only consider the effects of domain experience *across* sports (*i.e.,* polo players versus soccer players), but to also consider the effects of experience *within* a specific sport (*i.e.,* high-goal versus low-goal polo players). This distinction would ultimately show the tool's ability to effectively target higher-order cognitive skills which are associated with experience/expertise in a domain (Mackenzie et al., 2023). The current study found that in both polo and soccer players, there were no associations between level of experience and STB performance. This could potentially be a result of the clustering of similar experience levels (in both sports), where the vast majority of both the cohorts consisted of novice players. Whilst there were a handful of more experienced players, there were not enough to form even groups of 'novice' and 'expert' players. In the sporting literature, this was notably seen with the Ng et al. (2013) teenage basketball study which showed that SA, as measured through the SAGAT method, was not associated with basketball performance. That study, however, only tested basketball players of similar experience and playing levels, and thus, there was not an apparent novice versus expert spread of players. Other domains assessing SA, such as transportation (Kroll et al., 2020) and medicine (Mackenzie et al., 2023), have found experience differences within groups of participants (*e.g.,* novice versus experienced drivers, junior versus senior medical staff), thus lending support to idea that a SA assessment should also look at experience differences within groups, as well as across groups, to fully investigate the role of domain-specific experience on SA abilities.

3.1.5 Conclusion.

The aims of this study were to 1) to investigate if the STB methodology could discriminate sport experience when locating a missing ball, 2) to investigate potential sports perception transfer effects, and 3) to explore the role of visual cues, in particular gaze orientation and player grouping information, and how it may inform perception abilities in the STB task. The results demonstrated an experience effect, suggesting that sports experience may play a role in sports perception abilities; however, there was no evidence of a transfer effect between polo and soccer players. Additionally, the results suggested that player gaze orientation and multi-player visual information may be important in sports perception. The following study (Study 1.2) will continue to build upon the findings of this study with the aims to replicate the experience and gaze cueing effects with the addition of exploring the effects of a more polo-specific visual cue (*i.e.,* mallet presence) on perception in a polo task.

3.2 Study 1.2—The role of polo experience, gaze orientation, and mallet presence on perception accuracy in a polo static-image Level I Situation Awareness task

3.2.1 Introduction.

The previous study introduced the Spot the Ball (STB) tool as a potential objective assessment of perception skills (Level I SA) in sports; the results showed an experience effect, where athletes of their respective sports were more accurate in their predictions than athletes of a different sport and non-athletes. The results from Study 1.1 also showed a gaze cueing effect, suggesting that the gaze and head orientation is an important visual cue in sports prediction tasks. Because the results from the previous study demonstrated that gaze orientation was perhaps a more useful visual cue compared to the grouping of players, this study will focus solely on the visual cueing provided by gaze and head orientation and its effect on STB performance, and thus, Level I SA. However, it is likely that athletes, and polo players specifically, utilise more than just gaze cues and player grouping when looking for a ball on the field. Therefore, this study will investigate a polo-specific visual cue which might aid in perception abilities.

As discussed in the previous study, polo has very specific biomechanics and kinematics to hit the ball which are facilitated by the polo mallet—the long stick used to contact the ball. It has been demonstrated that the angle of the mallet head (Ewart et al., 2020) in conjunction with the player torso, arm, and shoulder kinematics determines the trajectory of the ball (Oliver et al., 2018b) and could thus potentially be used to predict the ball's flight path and landing spot. Therefore, the polo mallet should also be investigated as a relevant visual cue which may provide insight into the direction the ball will travel once it is hit, thus potentially providing information which players can use to 'spot' the ball. As such, the aims of the current study are to investigate the role of mallet presence and its effect on STB performance, and thus Level I SA, and to then replicate the experience and gaze cueing effects seen in the previous study.

3.2.1.1 The role of visual cueing on performance in a sports Situation Awareness task.

Visual cues have been explored in the sports realm as potential aids for anticipation and prediction skills (Jackson & Morgan, 2007; Lees & Owens, 2011; Sawyer et al., 2015; Stone et al., 2017). It has been reported that expert (elite) athletes are better at perceiving (Level I SA) and comprehending/interpreting (Level II SA) these visual cues, which allow them to perform at a higher level compared to novice athletes (Huys et al., 2009; Smeeton & Huys, 2011). Additionally, handheld striking equipment (*e.g.,* racquets, bats) have also been suggested as sources of visual cues to aid in anticipation (Alder et al., 2014; Huys et al., 2009; Ward et al., 2002). Based on previous research, it is possible that the polo mallet may provide visual cues which can be interpreted by polo players and subsequently used to gain information about their environment.

The role of the polo mallet on shot anticipation has not been investigated in sports visuo-cognitive studies, such as other striking sports that use a handheld tool to hit the ball (*i.e.,* tennis, badminton); however, results from comparative studies suggest that visual cues provided by racquets and connected body areas such as arms and trunks may be used to successfully predict the shot direction and location of the ball (Huys et al., 2009; Ward et al., 2002). Because the ball in these sports often moves at speeds greater than the eye can physically track (Morris-Binelli & Müller, 2017; Runswick et al., 2020), athletes in sports such as tennis and badminton must anticipate the flight path of the ball to successfully intercept it (Alder et al., 2014; Huys et al., 2009). To do so, the athletes must identify important visual cues and biomarkers which display relevant information about the ball's upcoming flight path.

For instance, Abernethy & Russell (1987) showed that badminton players fixated on the arm, wrist, and racquet during shot, suggesting that badminton shot information may be displayed in these areas. Alder et al. (2014) also showed that kinematic differences in shot length (*i.e.,* long and short serves) were observed in distal areas such as the arm, wrist, and racquet. Therefore, it can be inferred that the racquet, as well as the arm and wrist holding the racquet, may be an important source of visual information for players when anticipating a shot direction in badminton. In tennis, a similar phenomenon was observed; Huys et al. (2009) showed tennis players a variety of clips of a tennis shot with occlusions to the shoulders, hips, trunk, arm and racquet, legs, or no occlusions. The authors found that the occlusion of the arm and racquet negatively affected performance accuracy, even with skilled players, thus suggesting that these areas are important for anticipating shot location and direction in tennis.

It has been proposed that some areas of the body provide more relevant information than others, and that experienced/expert athletes will fixate on areas that supply richer information; in other words, the experienced players fixate on the most relevant locations to receive valuable information useful for anticipating the shot outcome (Runswick et al., 2020). Therefore, one could make an argument that this ultimately boils down to a higher level of SA in experienced players; those who perceive (Level I SA) greater intricacies of motion—whether it be biological (*e.g.,* arm, trunk kinematics) or mechanical (*e.g.,* racquet movement)—ultimately have a more accurate representation of the situation and can thus build their SA on a more informative base. Given the evidence from the current literature, it is possible that the polo mallet may provide visual cues and information useful to predicting the ball's trajectory and potential landing spot similar to a tennis or badminton racquet. Therefore, the effect of mallet presence, and specifically the role of individual parts of the mallet (whole mallet, cane, head), on STB performance will be investigated in the current study.

The polo mallet is what players use to hit the ball and is traditionally made of a flexible rattan cane (also called a shaft) attached to a hardwood head (Ewart et al., 2020); see Figure 3.11 for a diagram of a polo mallet.

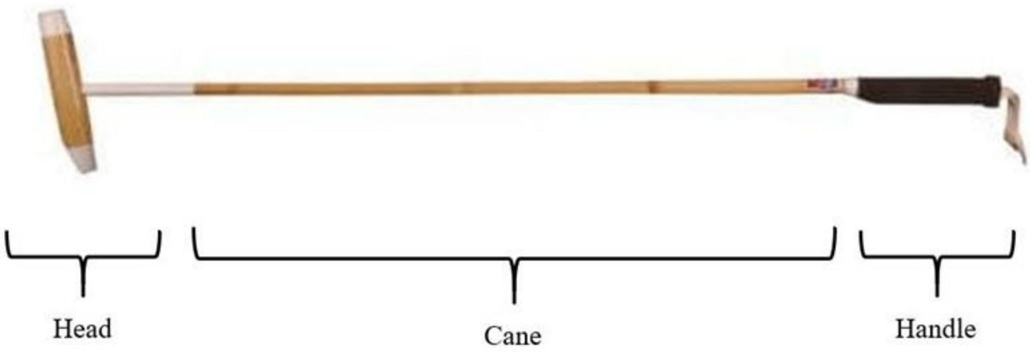

Figure 3.11 *Diagram of polo mallet showing the different parts (head, cane, handle).*

The mallet head is typically what makes direct contact with the ball, although there is no rule stating the ball cannot be hit with the cane. Players hit the ball with the planar (wide) face of the head and not the front, as in croquet (Ewart et al., 2020), and the typical polo swing can be compared to a pendulum, with the player's shoulder acting as a fulcrum, or pivot. Polo players can use a variety of swings to hit the ball in the desired direction (Grace, 1991); the four main swings are: 1) Offside-forehand, 2) Offside-backhand, 3) Nearside-forehand, and 4) Nearside-backhand. Offside refers to shots taken on the right side of the pony, and nearside refers to shots taken on the left side of the pony; forehand shots send the ball forward, and backhand shots send the ball backwards. Along with these four main shots, players may dribble the ball (keeping the ball close to their side), hit a neckshot (a shot taken under the pony's neck), an "open" or "tail" shot (a highly angled backshot depending on the direction), and a belly shot (a shot taken underneath the pony's belly). Naturally, each swing has different biomechanics, kinetics, angles, and speeds which allow the ball to travel in the desired direction and land at the desired location (Grace, 1991). Given these different swing biomechanics, it is not unreasonable to hypothesise that the mallet angle may contain important visual cues as to where the ball may be located.

The biomechanics and kinetics of a polo swing have been recently examined in both male and female polo players (Oliver et al., 2018b; Oliver et al., 2017). Oliver et al. (2019) found that during an offside forehand shot, male players exhibited a more efficient transfer of energy from their torso and upper extremities, through the mallet, and into the contact of the ball. Male players anecdotally produce longer shots, and it is now argued that their swing biomechanics (*i.e.*, longer arms and greater trunk flexion) is what drives their long shots (Oliver et al., 2019). However, it is not just the player's swing that gives direction to the ball. According to (Ewart et al., 2020), the angle of the mallet head is what determines the trajectory of the ball. When the mallet head is straight, the ball will travel straight, and when the mallet head is angled, the ball will travel on that angled trajectory. This is commonly seen in neckshots and angled backshots (Grace, 1991), which travel in sharp angles from the hitting player and pony. Because of the relationship between the angle of the mallet head and the ball trajectory, it is possible that the mallet head and cane angles may be used to help players anticipate and predict the location of a ball and the direction of a shot.

3.2.1.2 Replicating the experience and gaze cueing effects of Study 1.1.

A second aim of the current study is to replicate the findings of the previous study (Chapter 3: Study 1.1), namely replicating the experience effect seen with the STB tool and the gaze cueing effect in which participants were more accurate when the gaze was on the ball. It has long been reported that those with experience in a sport generally perform better on cognitive and physical tasks than novices, or those with little or no experience in that sport (Abernethy, 1990; del Campo et al., 2011; Mori & Shimada, 2013; Romeas & Faubert, 2015; Shih & Lin, 2016; Garland & Barry, 1990; McPherson, 1999; Memmert et al., 2009; Morris-Binelli & Müller, 2017; Savelsbergh et al., 2002; Williams & Ericsson, 2005; Wright et al., 2011). The previous study demonstrated that sports experience played a role in STB performance; polo players were more accurate than controls in the polo images, and likewise, soccer players were more accurate than controls in the soccer images. The current study, therefore, aims to replicate this experience effect to provide validation to the STB tool as an inference measure of Level I SA. The study also looks to replicate the findings of the gaze cueing effect seen in the previous study. The participants of Study 1.1 were overall more accurate when the photographed athlete's gaze (and head orientation) was directed towards the ball, suggesting that in sports, gaze orientation is an important visual cue for prediction. It is important to replicate findings of previous studies to provide additional validation, credibility, and support (Maxwell et al., 2015; Shrout & Rodgers, 2018) for the STB methodology for use as an assessment tool in sports SA, as well as to provide more evidence for the importance of experience and visual cues in sports prediction and SA tasks.

3.2.1.3 The current study, aims & objectives, and hypotheses.

From the literature above, the study has two aims: 1) to investigate the role of the polo mallet as a visual cue on STB performance, and 2) to attempt replicate the findings of the previous study which showed that sports experience and congruent gaze and head orientation may be important factors in predicting the location of a missing ball during a STB task. Importantly, this study will focus only on polo. The first hypothesis is that the participants will be most accurate (resulting from lower Euclidean Distance Accuracies) in conditions in which the whole mallet is present, followed by the cane, the head, and then no mallet visible; in other words, the more visual information is available, the more accurate participants will be. The second hypothesis is that polo players would be overall more accurate than control participants in the STB task, and the third hypothesis is that participants would be more accurate when the photographed athlete's gaze and head orientation are directed at the ball than when the gaze and head orientation are not directed at the ball or are not visible.

3.2.2 Methods.

3.2.2.1 Design.

To examine the role of mallet presence in STB performance and replicate the findings of Study 1.1, a 2 x 2 x 4 mixed factors design of sport experience (polo players, controls) by gaze type (gaze on, gaze off) by mallet occlusion condition (no occlusion, head occlusion, cane occlusion, whole mallet occlusion) was used. The sport experience was analysed as a between-subject variable, and the gaze condition and mallet occlusion condition were analysed as the within-subject variables. The Euclidean Distance Accuracy (EDA), or the distance between the *x, y* coordinates of where the participant clicked and the *x, y* coordinates of the centre of the ball, was analysed as the outcome variable.

3.2.2.2 Participants.

Participants were recruited online. Polo players were recruited through targeted advertisement posted in newsletters and on social media by the United States Polo Association (USPA), Hurlingham Polo Association (HPA), and the experimenter's personal social media.

Control participants were recruited through advertisement on the NTU SONA website and on the experimenter's personal social media. A sample size calculation was performed prior to recruiting participants using R (Version 3.6.3). Using the data from Study 1.1, a sport experience x image sport interaction yielded a partial η^2 of 0.245, which converted to an effect size (r) of 0.569. A sample size calculation using a three-way ANOVA design with $\alpha = 0.05$ and $\beta = 0.80$ (Banerjee et al., 2009) with six groups yielded a total sample size of 33 (17 polo players, 17 controls). Participants were excluded if they completed less than 80% of the study, answered in a systematic way (*i.e.*, clicking the same location repetitively clicking the same location for more than five images in a row), or were under the age of 18. Seventy-four participants took part, but 20 (14 polo players, 5 controls) were excluded based on incompletion of the study. In total, 54 participants (20 polo players, 34 controls) were included in the study.

Twenty polo players ranging in age between 18 – 64 (M = 36.60, SD = 15.95) completed the task. The players reported an outdoor handicap range between -1 to 1 goals (M = -0.29, SD = 0.91). The handicaps were: -1 (N = 8), 0 (N = 2), 1 (N = 4), Not Rated (NR) (N = 6). As clarification, NR does not necessarily equate to having no experience in polo. In polo, handicaps are awarded to actively playing members who participate in official tournaments. A player may still participate in practice events without being awarded a handicap, or a retired player may opt out of receiving a handicap if they are no longer playing. To better gauge player abilities, participants also completed an 11-Point Likert Scale to assess their self-rated polo abilities (0 = Novice and 10 = Expert). The players reported a range of Likert Self-Rated Polo Abilities scores between 1 – 6 (M = 3.00, SD = 1.52). Table 3.8 shows the polo player participant demographics.

Table 3.8 *Polo player demographics.*

	M	*SD*
Age (years)		
18—64	36.60	15.95
Handicap (goals)		
-1—1	-0.29	0.91
	N	%
NR	6	30.00
-1	8	40.00
0	2	10.00
1	4	20.00
Self-Rated Abilities	*M*	*SD*
1—6	3.00	1.52
	N	%
1	4	20.00
2	4	20.00
3	5	25.00
4	3	15.00
5	3	15.00
6	1	5.00

Note. N = 20.

Thirty-four control subjects with no sports experience ranging in age between 18 – 31 (*M* = 20.35, *SD* = 2.95) completed the task. The participants rated their watching involvement in polo and other sports through a 10-point Likert scale (1 = No Watching and 10 = Watching all the Time). The polo-watching Likert scores ranged between 1 – 6 (*M* = 1.27, *SD* = 0.89). The other sports-watching Likert scores ranged between 1 – 8 (*M* = 4.47, *SD* = 2.55). Table 3.9 shows the control participant demographics.

Table 3.9 *Control participant demographics.*

	M	*SD*
Age (years)		
18—31	20.35	2.95
Polo-Watching Levels	*M*	*SD*
1—6	1.27	0.89
	N	%
1	29	85.29
2	4	11.76
6	1	2.94
Other Sports-Watching Levels	*M*	*SD*
1—8	4.47	2.55
	N	%
1	3	8.82
2	6	17.65
3	10	29.41
5	1	8.82
6	3	8.82
8	7	20.59

Note. N = 34.

3.2.2.3 Materials.

3.2.2.3.1 Stimuli.

Participants viewed 80 still images of single polo players (only one player visible in each image), which were obtained from open-access internet sources, such as Google images and Shutterstock. The images were edited in the same way as the previous study. The stimuli (saved as JPEGs) were all high-resolution images (300 dpi) and were taken within the last 10 years. See Figure 3.12 for examples of the no mallet occlusion images before and after removing the ball, Figure 3.13 for examples of the mallet head occlusion images before and after removing the ball, Figure 3.14 for examples of the mallet cane occlusion images before and after removing the ball, and Figure 3.15 for examples of the whole mallet occlusion images before and after removing the ball. The images were selected based on their criteria to meet the following conditions: Gaze Type: The “Gaze-On” conditions showed the athlete (person in possession of the ball) directly looking at the ball. The “Gaze-Off” conditions showed the athlete (person in possession of the ball) looking away from the ball or images where the athletes’ gaze cannot be determined (*i.e.,* images from behind). Mallet Occlusion: The “No Occlusion” mallet condition showed the whole mallet. The “Head Occlusion” mallet condition occluded the mallet head, but the mallet cane was visible. The “Cane Occlusion” mallet condition occluded the mallet cane, but the mallet head was visible. The “Whole Mallet” mallet condition occluded the entire mallet.

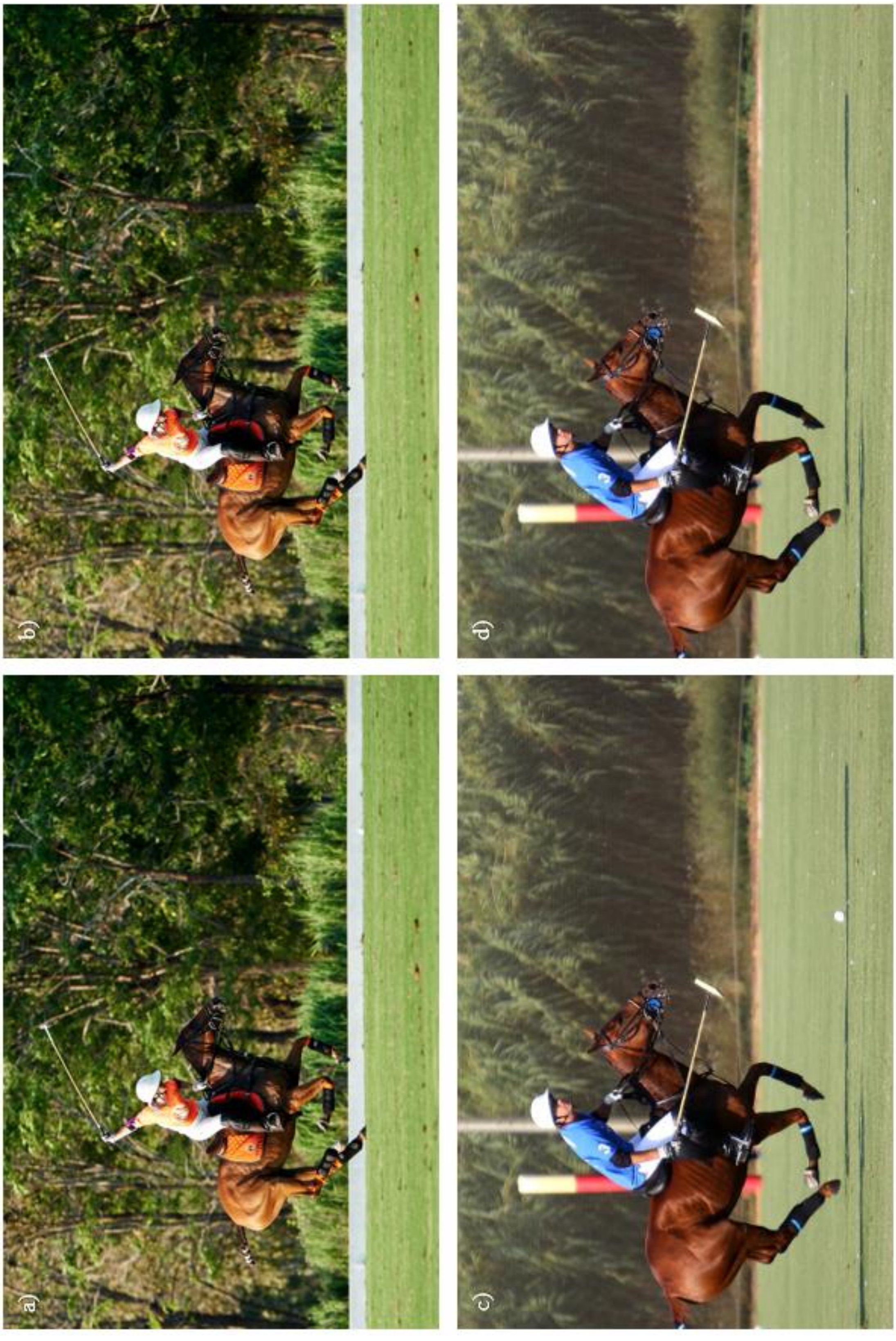

Figure 3.12 *Examples of no mallet occlusion image stimuli before and after removing the ball. Figure 3.12a—Before (gaze-on); Figure 3.12b—After (gaze on); Figure 3.12c—Before (gaze-off); Figure 3.12d—After (gaze-off).*

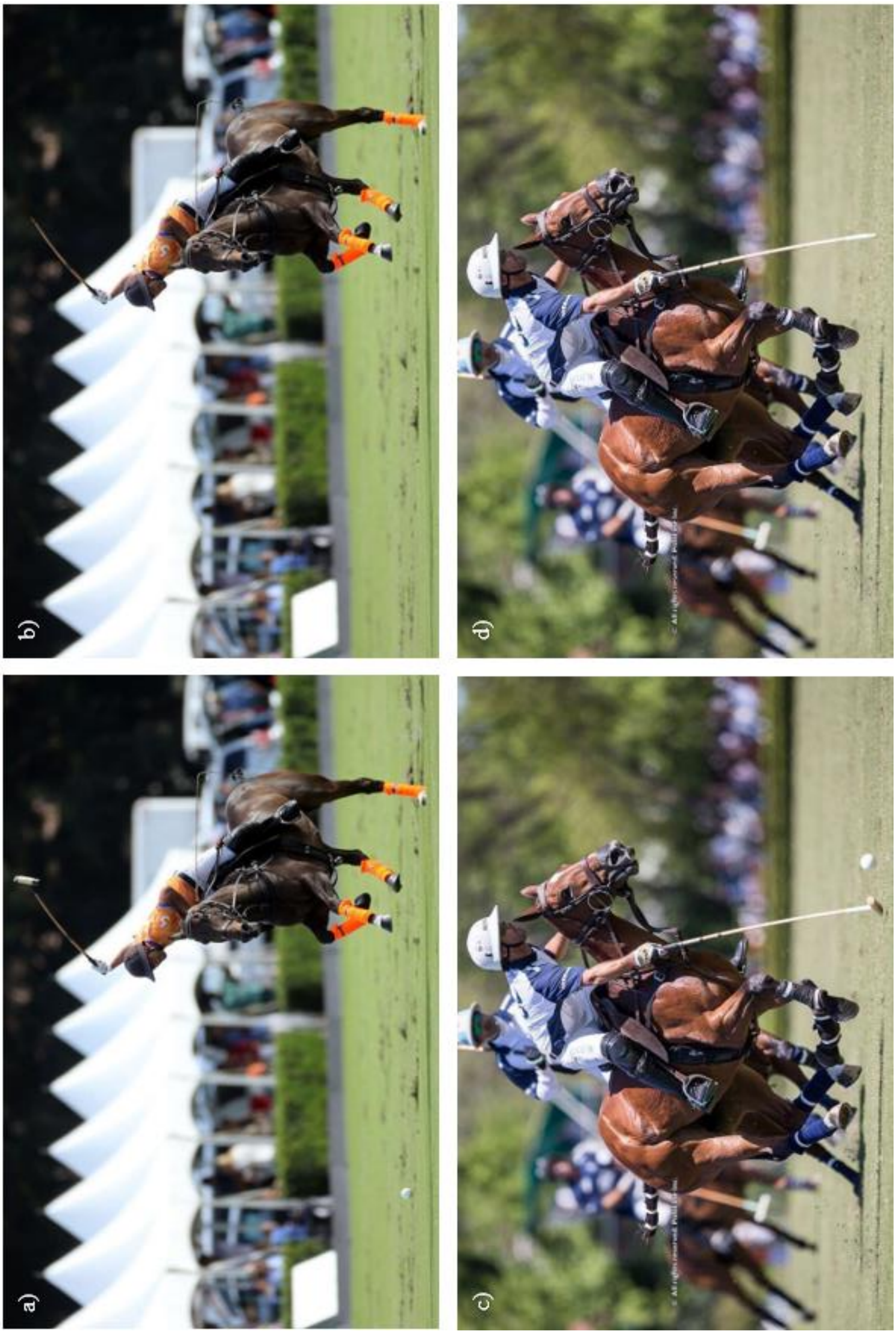

Figure 3.13 *Examples of mallet head occlusion image stimuli before and after removing the ball. Figure 3.13a—Before (gaze-on); Figure 3.13b—After (gaze on); Figure 3.13c—Before (gaze-off); Figure 3.13d—After (gaze-off).*

Figure 3.14 *Examples of mallet cane occlusion image stimuli before and after removing the ball. Figure 3.14a—Before (gaze-on); Figure 3.14b—After (gaze on); Figure 3.14c—Before (gaze-off); Figure 3.14d—After (gaze-off).*

Figure 3.15 *Examples of whole mallet occlusion image stimuli before and after removing the ball. Figure 3.15a—Before (gaze-on); Figure 3.15b—After (gaze on); Figure 3.15c—Before (gaze-off); Figure 3.15d—After (gaze-off).*

3.2.2.3.2 Apparatus.

3.2.2.3.2.1 Adobe® Photoshop®.

The polo video stimuli for this study were edited using Adobe® Photoshop® software (Version 22.1.0) licensed through Nottingham Trent University. A Think Centre computer and Samsung monitor were used during the editing process. The editing process is described in Chapter 2, Section 2.3.1.1.

3.2.2.3.2.2 Qualtrics.

This experiment was created and hosted online through Qualtrics Version 11.2020 (Qualtrics, Provo, UT). Data was collected between 2 March 2021 – 19 April 2021.

3.2.2.4 Procedure.

The procedure used for this study was the same as that used in Study 1.1. The only differences are that for this study, participants viewed three practice images to familiarize themselves with the apparatus and procedure, and that the 80 total images were separated into four blocks of 20 images. The blocks themselves were randomly ordered for each participant.

3.2.2.5 Data analysis.

The outcome variables used for this study were the same as that used in Study 1.1 (Chapter 3: Section 3.1.2.5): the Euclidean Distance Accuracy (EDA), or pixel distance between the participant's Cartesian (x, y) response and the correct Cartesian location of the centre of the ball for each image, determined by the Euclidean distance formula (Liberti et al., 2014). The main (fixed) effects predictor variables were the participant sport (polo player, control), the gaze type (gaze-on, gaze-off), and the mallet occlusion condition (no occlusion, head occlusion, cane occlusion, whole mallet occlusion). The random effects variables used for this study were the same as those used in Study 1.1: participant ID and image. These random effects were analysed with a fixed slope. The participant ID was analysed as a nested random effect, and the image was analysed as a crossed random effect. The data analysis used for this study was the same as that used in Study 1.1. Linear mixed effects modelling was used to determine the relationships between the EDA and several predictor variables. For the main effects models, all fixed effects were included for each model comparison. Interaction effects were also examined. Reduced-maximum likelihood ratios (REML) were used to compare the current model with the previous one to generate *p*-values (Luke, 2017), and any interaction was broken down using post-hoc Tukey tests. For the interaction effects, the fixed effects were modelled as a single three-way interaction model: sport experience x gaze type x mallet occlusion. The data analysis was performed using R (Version 3.6.3) (R Core Team, 2020) with the *lme4* package (Bates et al., 2020).

3.2.3 Results.

For the STB task, performance was measured as a function of Euclidean Distance Accuracy (EDA); the EDA was collected for each individual image (80 total images). As a reminder, a larger EDA represents a poorer performance in the task.

3.2.3.1 Main effects.

The mean Euclidean Distance Accuracies and standard deviations (in pixels) for each image condition (gaze type, mallet occlusion) by sport experience (polo player, control) are shown in Table 3.10. A linear mixed-effects model analysis examined the effects of the predictor variables, sport experience, gaze type, and mallet occlusion, on the outcome variable, or Euclidean Distance Accuracy (EDA). Fixed effects were added, one at a time, to models of increasing complexity and were compared, using likelihood ratio tests, to the model prior.

Table 3.10 *Mean Euclidean Distance Accuracy (EDA) and standard deviation (in pixels) for each image condition (gaze type, mallet occlusion) by sport experience (polo, control).*

	Gaze On				Gaze Off			
	None	Head	Cane	Mallet	None	Head	Cane	Mallet
Polo	129.73 (104.64)	173.12 (143.94)	102.36 (85.34)	125.92 (94.94)	299.85 (227.81)	261.55 (168.89)	197.91 (135.80)	247.55 (151.26)
Cont	208.43 (154.80)	216.26 (164.28)	174.48 (156.56)	203.26 (168.06)	289.03 (238.18)	271.98 (170.40)	204.54 (139.59)	305.85 (171.04)

Note. N = 54.

The mean Euclidean Distance Accuracies and standard deviations (in pixels) for each image condition (gaze type, mallet occlusion) by sport experience (polo player, control) are shown in Table 3.10. A linear mixed-effects model analysis examined the effects of the predictor variables, sport experience, gaze type, and mallet occlusion, on the outcome variable, or Euclidean Distance Accuracy (EDA). Fixed effects were added, one at a time, to models of increasing complexity and were compared, using likelihood ratio tests, to the model prior. See Table 3.11 for a list of the model comparisons. Results showed that the main effects model of sport experience + gaze type best fit the data ($\chi^2(1) = 11.80$, $p < 0.001$). Figure 3.16 shows the ranges, interquartile ranges, and medians of the EDA by sport experience. Paired comparisons with a Tukey correction revealed that polo players ($M = 191.77$, $SD = 159.78$) were more accurate than controls ($M = 234.21$, $SD = 178.09$; $p < 0.001$). Figure 3.17 shows the ranges, interquartile ranges, and medians of the EDA by gaze type. Overall, participants were more accurate in images when the gaze was on ($M = 175.14$, $SD = 148.70$) than when the gaze was off ($M = 261.81$, $SD = 183.89$; $p < 0.001$). Lastly, Figure 3.18 shows the ranges, interquartile ranges, and medians of the EDA by mallet occlusion condition. There were no differences between any of the mallet occlusion conditions ($p = 0.22$).

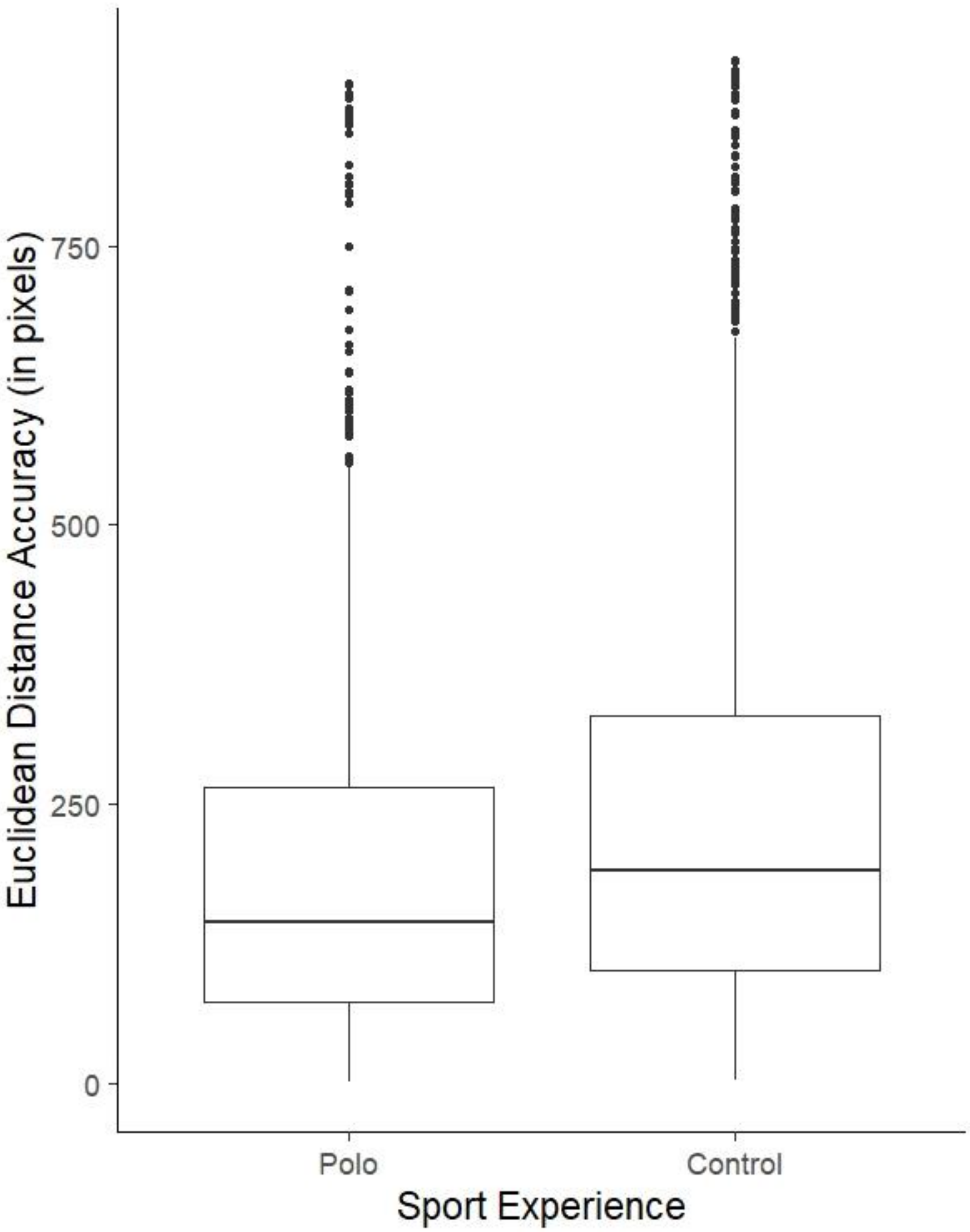

Figure 3.16 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) by sport experience.*

Note. N = 54.

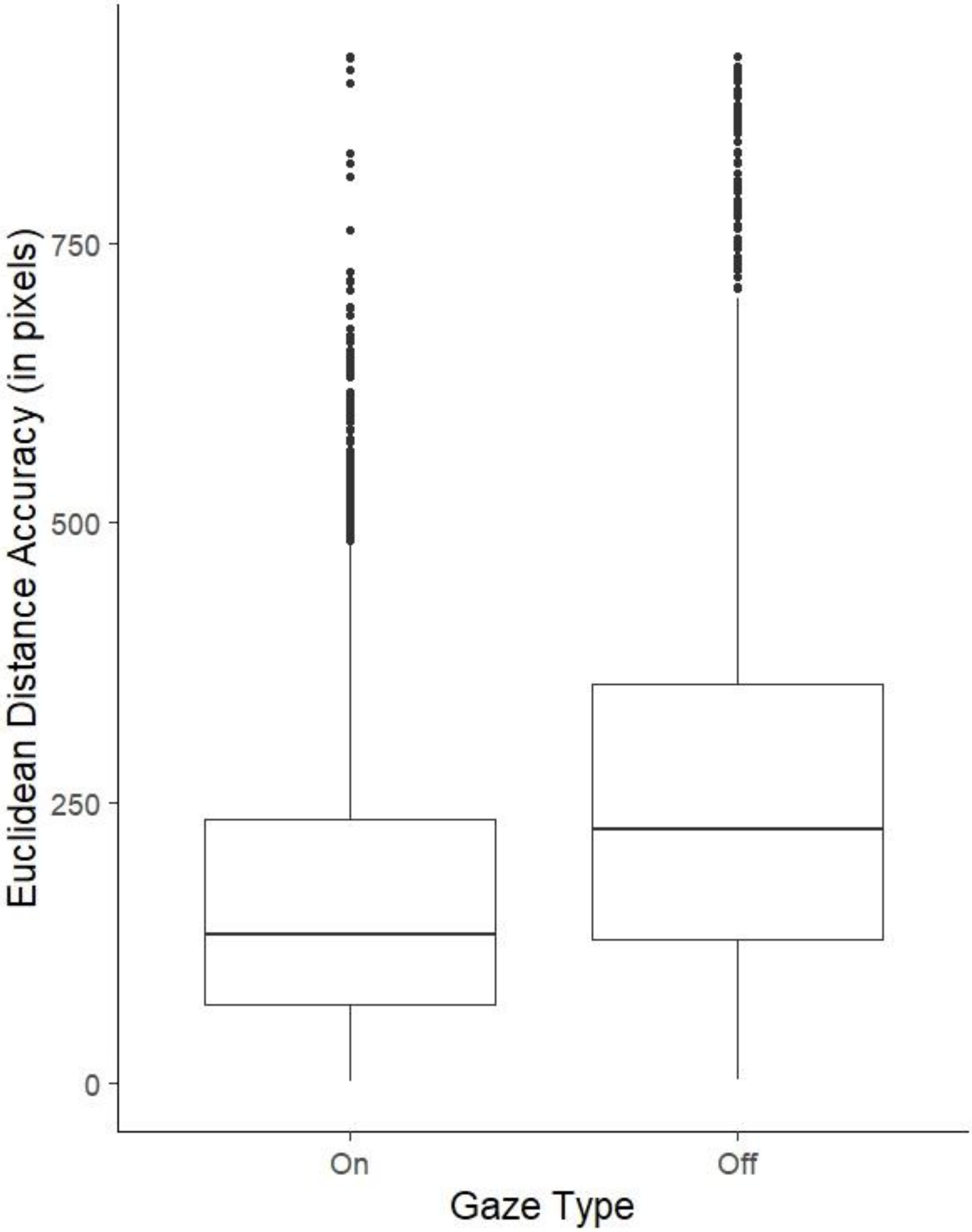

Figure 3.17 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) by gaze type.*

Note. N = 54.

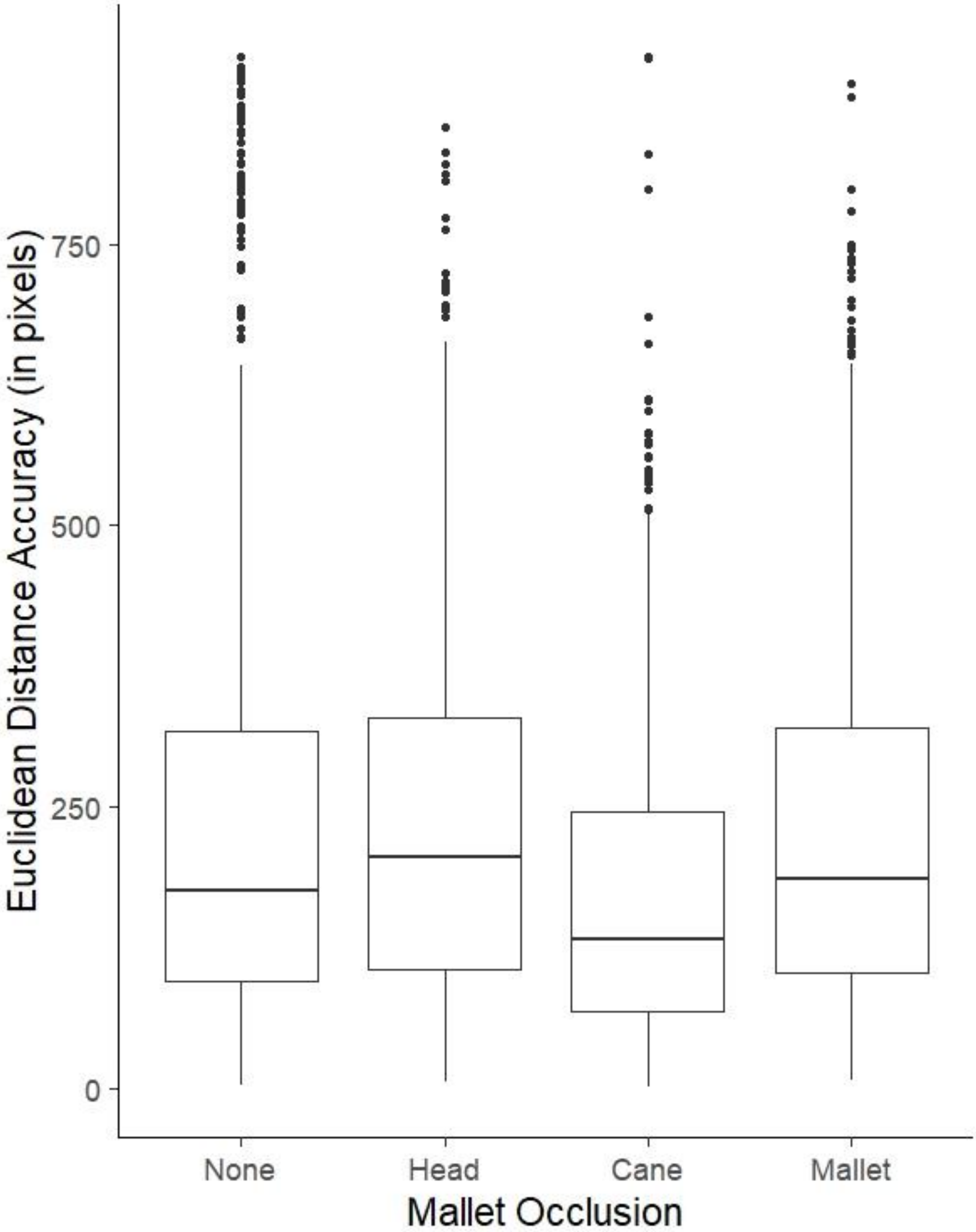

Figure 3.18 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) by mallet occlusion.*

Note. N = 54.

Table 3.11 *List of Euclidean Distance Accuracy main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	53323	-	-	-
ME1	Sport Experience	ME1 / Null	53310	14.88	1	< 0.001
ME2	Sport Experience + Gaze Type	ME2 / ME1	53300	11.80	1	< 0.001
ME3	Sport Experience + Gaze Type + Mallet Occlusion	ME3 / ME2	53301	4.44	3	0.22

Note. N = 54.

3.2.3.2 Interaction effects.

The second part of the analysis looked at the interaction effects models. A 2 x 2 x 4 linear mixed-effects model analysis examined the interaction effects of the predictor variables, sport experience, gaze type, and mallet occlusion, on the outcome variable, the Euclidean Distance Accuracy (EDA). Fixed effects were added, one at a time, to models of increasing complexity and were compared, using likelihood ratio tests, to the model prior. See Table 3.12 for a list of the model comparisons. Results showed the three-way interaction model (sport experience x gaze type x mallet occlusion) best fit the data (χ^2 (12) = 34.09, p < 0.001). Figure 3.19 shows the ranges, interquartile ranges, and medians of the EDA of mallet occlusion by sport experience and gaze type.

Paired comparisons with Tukey corrections revealed that in images with no mallet occlusion, polo players (*M* = 129.73, *SD* = 104.64) were more accurate than controls (*M* = 208.43, *SD* = 154.79) when the gaze was on (p < 0.001). There were no differences in polo players (*M* = 299.85, *SD* = 227.81) and controls (*M* = 289.03, *SD* = 238.18) when the gaze was off ($p = 1.00$). In images with the mallet head occluded, there were no differences between polo players (*M* = 173.12, *SD* = 143.94) and controls (*M* = 216.26, *SD* = 164.28) when the gaze was on ($p = 0.15$). There were no differences between polo players (*M* = 261.55, *SD* = 168.89) and controls (*M* = 271.98, *SD* = 170.40) when the gaze was off ($p = 0.99$). In images with the mallet cane occluded, polo players (*M* = 102.36, *SD* = 85.34) were more accurate than controls (*M* = 174.48, *SD* = 156.56) when the gaze was on ($p < 0.001$). There were no differences between polo players (*M* = 197.91, *SD* = 135.80) and controls (*M* = 204.54, *SD* = 139.59) when the gaze was off ($p = 1.00$). Lastly, in images where the whole mallet was occluded, polo players (*M* = 125.92, *SD* = 94.94) were more accurate than controls (*M* = 203.26, *SD* = 168.06) when the gaze was on ($p < 0.001$). Polo players (*M* = 247.55, *SD* = 151.26) were also more accurate than controls (*M* = 305.85, *SD* = 171.04) when the gaze was off ($p < 0.01$). Overall, the results showed that polo players were generally more accurate than the control participants when the gaze was on the ball, and the polo players and control participants were similar when the gaze was off the ball. However, there was an important experience effect when both the gaze was off the ball and the whole mallet was occluded.

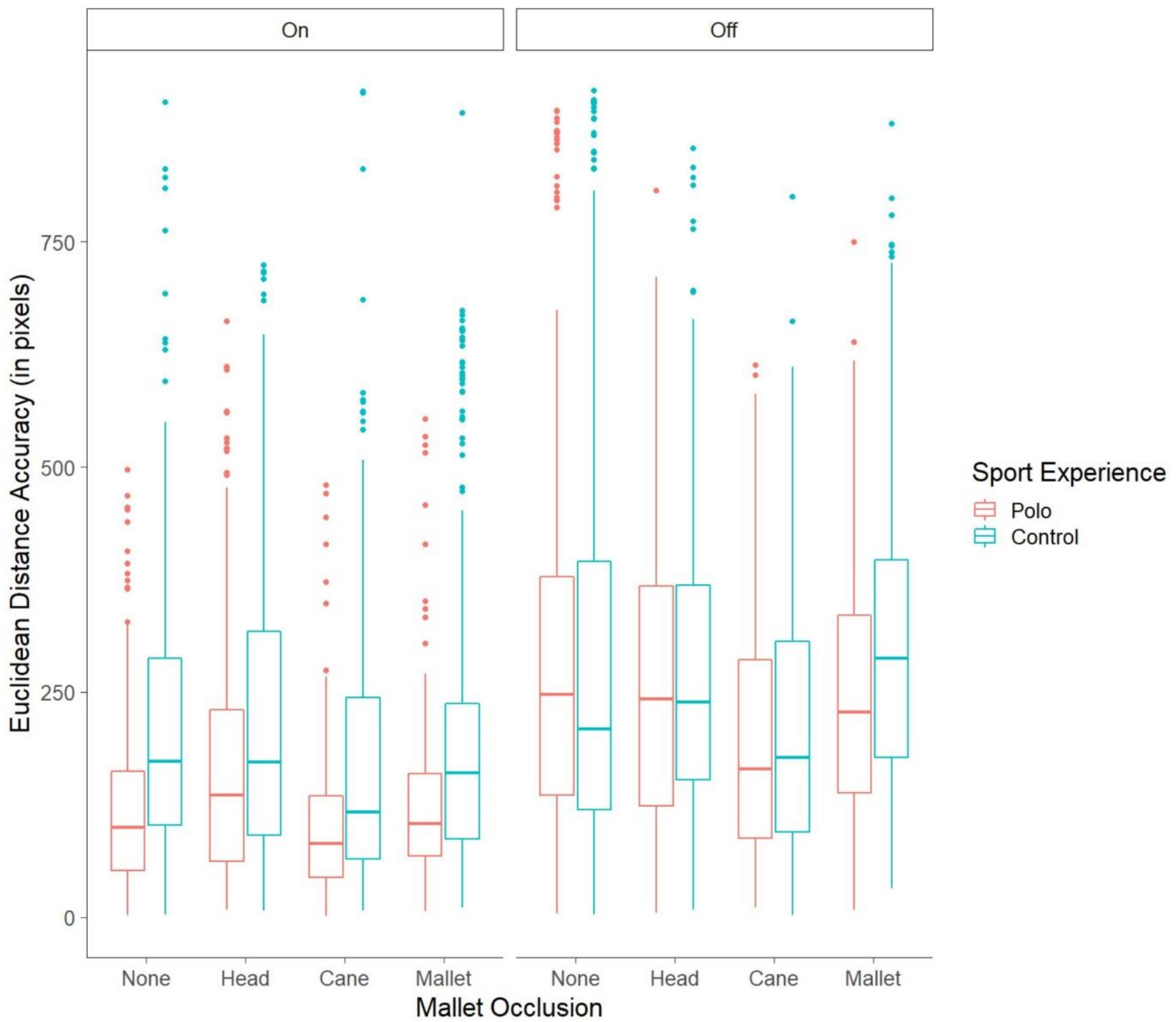

Figure 3.19 *The ranges, interquartile ranges, and medians of the Euclidean Distance Accuracy (in pixels) of mallet occlusion by sport experience and gaze type.*

Note. N = 54.

Table 3.12 *List of Euclidean Distance Accuracy interaction effects models comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
ME2	Sport Experience + Gaze Type	-	53300	11.80	1	< 0.001
INT1	Sport Experience x Gaze Type	INT1/ME2	53258	43.76	1	< 0.001
INT2	Sport Experience x Gaze Type x Mallet Occlusion	INT2/INT1	53248	34.09	12	< 0.001

Note. N = 54.

3.2.3.3 Sport experience and STB performance correlations.

To assess if the polo player handicap was associated with STB performance in polo images, a linear regression model was run with the outcome variable set as the Euclidean Distance Accuracy (EDA) and the predictor variable set as the handicap. The results indicated there was no significant effect of polo handicap on the polo image accuracy ($F(1, 11) = 0.02$, $p = 0.89$, $R^2 = 0.002$). To investigate if the self-rated abilities scores were associated with STB performance in polo images, a linear regression model was run with the outcome variable set as the Euclidean Distance Accuracy (EDA) and the predictor variable set as the self-rated scores. The results indicated there was no significant effect of self-rated polo abilities on the polo image accuracy ($F(1, 14) = 0.28$, $p = 0.60$, $R^2 = 0.02$).

3.2.4 Discussion.

The first aim of the study was to investigate the role of the polo mallet as a visual cue on STB performance. It was hypothesised that the participants would be most accurate (lower Euclidean Distance Accuracies) in conditions in which the whole mallet is present, followed by the cane, the head, and then no mallet visible. In other words, the more visual information was available, the more accurate participants would be. There was no evidence to support this, showing that overall participants were just as accurate across all mallet occlusion conditions. However, there was an experience effect shown where polo players were more accurate than controls when the whole mallet was occluded in both the gaze-on and gaze-off conditions. The second aim was to replicate the findings of the previous study which showed that sports experience and congruent gaze and head orientation may be important factors in predicting the location of a missing ball during a STB task. It was hypothesised that polo players would be overall more accurate than control participants in the STB task and that participants would be more accurate when the photographed athlete’s gaze and head orientation are directed at the ball than when the gaze and head orientation are not directed at the ball or are not visible. There was evidence to support these hypotheses, with the results showing that polo players were more accurate in the STB task compared to control participants, and overall, participants were more accurate when the gaze was on the ball. The results and theoretical implications will be further discussed below.

3.2.4.1 The role of polo mallet presence on performance in a polo Level I Situation Awareness task.

The first aim of the current study was to investigate the role of the polo mallet as a visual cue on STB performance. There was no main effect of mallet presence on the STB performance, thus not supporting the original hypothesis. Participants performed similarly in each mallet occlusion condition regardless of which part of the mallet was occluded. However, there was an experience effect in which polo players were more accurate in the no mallet occlusion, cane occlusion, and whole mallet occlusion conditions when the gaze was on the ball. This suggests that in conjunction with the gaze orientation being directed at the ball, polo players could utilise the mallet presence to predict the location of the missing ball more accurately. However, when the gaze was off, the experience effect became clearer as polo players were more accurate when there was no mallet present at all, suggesting that experience may lead to better understanding of off-ball game situations where players must look downfield for a play, and not directly at the ball. Importantly, the polo players were more accurate than the controls when the mallet was completely removed, suggesting that the controls struggled with its absence. This would indicate that the mallet was at least somewhat important, particularly to those with no previous experience, who may have relied on its angle to determine trajectory of the ball (Ewart et al, 2020) more so than the polo players.

Because the polo players were more accurate than controls when the whole mallet was removed, there is the possibility that the polo players used some other source of visual cues to make their prediction. One explanation may be that the polo mallet was not the important visual cue as was hypothesised, but rather that the player's body provided the most relevant information. The trunk, torso, shoulders, and arms have been shown to be important visual cues in predicting shot locations in tennis (Ward et al., 2002), badminton (Alder et al., 2014), and other striking sports (Runswick et al., 2020), with Huys et al. (2009) suggesting that athletes who were better at predicting tennis shot direction used a more global approach and did not focus as extensively on the racquet compared to the trunk. Additionally, Oliver et al. (2019) demonstrated that polo shot power ultimately comes from the trunk rotation of the player in conjunction with the shoulder and arm kinematics. Therefore, it is possible that the mallet presence was not as useful in locating the ball evidence that showed the mallet angle directly related to the ball trajectory (Ewart et al., 2020). This is logical, given that the mallet is ultimately an extension of the player's arm, and the player's body positioning must be correct to hit the ball with a high level of accuracy (Watson, 1989), and that each shot (*i.e.,* forehands, backshots, neckshots, *etc*.) has its own specific biomechanics. For instance, a nearside backshot has a distinctive wind-up where the player reaches over to left side of the pony's neck with the mallet at its highest at the pony's head, whereas an offside forehand starts with the player's mallet and arm raised high above the right side of the pony's hips. Perhaps, to an experienced player, these shot wind-ups are more salient and provide more (and perhaps more useful) visual information than the mallet alone—or even gaze cues. Therefore, future studies could investigate the role of body biomechanics in polo SA studies, potentially incorporating occlusion paradigms as have been used in tennis (Huys et al., 2009).

3.2.4.2 Replicating the experience and gaze cueing effects of Study 1.1.

The second aim of the study was to replicate the experience and gaze cueing effects of Study 1.1 to further validate the use of the STB method as an objective inference measure of Level I SA (perception) in sports. The results of the study show an experience effect, where polo players outperformed their control counterparts in the STB task, suggesting that there is a level of validity to the task because it is sensitive enough to target the perception skills possessed by athletes with sport-specific experience. This experience effect is in line with the results of Study 1.1 and numerous sports visuo-cognitive studies investigating anticipation (Loffing & Cañal-Bruland, 2017; Poulter et al., 2005; Singer et al., 1996; Suss & Ward, 2015; Wright et al., 2011) and decision-making (Afonso et al., 2012; Belling et al., 2015; Macquet & Fleurance, 2007; Silva et al., 2020) skills. Additionally, the results of the current study showed that overall, participants performed better in the STB task when the photographed athlete's gaze and head orientation were directed towards the ball. Once again, this is in line with the results of Study 1.1. The effectiveness (or lack thereof) of the gaze cueing suggests both experienced and inexperienced participants rely on it to gather information, thus showcasing its importance in perception skills in sports. Given the results of the two STB studies, it can be suggested that gaze cueing on the ball was crucial for accuracy in the task, even more so than the other visual cues.

Importantly, the results of Study 1.1 were replicated in the current study, providing a level of validation to the STB tool as an inference measure of Level I SA (perception) in sports. These replications, particularly where the experience effects are concerned, suggest that the tool may be accurate in its ability to discriminate sporting experience and tap into higher order cognitive skills. Ultimately, given the replication crisis reported within the psychology field (Maxwell et al., 2015; Shrout & Rodgers, 2018) and the lack of validated, objective SA assessment tools in sports, these results provide much-needed support for the STB tool as an inference measure of sports SA. Given its replicability, the tool could be applied to other team ball sports, such as soccer (as in Study 1.1), rugby, hockey, and basketball, to provide further evidence and empirical data for the STB method and sports SA as a whole.

3.2.4.3 No relationship between handicap level and STB performance.

As with the previous study, there was no relationship between polo player handicap level and STB performance, potentially once again as a result of the relative inexperience levels of the participants. The current study's polo player cohort were largely rated below 0-goals and would thus be classified as 'low-goal', which implies a lower level of experience in the sport. It is easy to say that a polo player has more polo experience than a non-polo player, but if their handicap is low (*i.e.,* -2 or -1), they are still relatively inexperienced in the grand scheme of things and may not have had the experience to fully develop mental models and prior knowledge as players with higher handicaps, which, as previously discussed, are important in top-down mechanisms such as perception, anticipation, decision-making, and SA. Therefore, as was done with the Chapter 3 (and continuing Chapter 4) studies, it is important to sample the experience and levels of play for the athletes to gain a better understanding of the participants' experiences. It is also important to understand that even within 'experienced' athletes, there are still differences in their visuo-cognitive skills, as is noted by Murray et al. (2018) suggesting that even "expert" versus "novice" athlete cohorts should take care to closely examine the experience beyond the surface level. These results ultimately suggest that studies investigating athletes in comparison to non-athletes in visuo-cognitive skills should not just classify participants as an all-or-nothing "expert" versus "control", but rather as a spectrum of players with differing levels of experience.

3.2.5 Conclusion.

The aims of the study were to 1) to investigate the role of the polo mallet as a visual cue on STB performance, and 2) to replicate the findings of the previous study which showed that sports experience and congruent gaze and head orientation may be important factors in locating a missing ball during a STB task. The mallet presence was shown to not be as relevant a source of visual information as was initially thought; it is perhaps the body positioning of the player that gives better visual cues. Thus, other sources of information, such as player trunk, torso, shoulders, and arms should be investigated for their role in STB perception and SA in polo. The results also replicated the experience and gaze cueing effects seen in Study 1.1 but were conditional based on the relative inexperience of the polo players in the current study.

This inexperience led to the experience effect observed in gaze-on conditions but only when the whole mallet was occluded in the gaze-off conditions. Lastly, when the entire mallet was occluded, an experience effect was shown when the gaze was off the ball, suggesting that polo players may have a better understanding of off-ball game situations, which will lead to Chapter 4, Study 2.1 and the ‘What Happens Next?’ (WHN) video prediction tasks.

3.3 Phase I General Discussion

The two studies presented in this chapter were aimed at investigating the veracity of the 'Spot the Ball' (STB) tool as an inference measure for Level I Situation Awareness (SA)—perception—performance, and investigating the roles of sports experience and visual cues, such as head and gaze orientation, player grouping, and polo mallet presence on STB performance. These studies were designed to remove the reactive responses and simply target the knowledge of where to look in sports images; by removing the ball in the images, the STB tool taps into top-down perception skills. Overall, the results demonstrated that the STB task was sensitive enough to target perception abilities which was seen through its ability to discriminate sports experience (experienced athletes from non-experienced athletes and control participants) in performance accuracy. Importantly, the STB task may be related to SA because it taps into the participants' perception abilities, which is the foundation for achieving a high level of SA based on the three-level framework by Endsley (1995b). Whilst it is easy to say that many tasks discriminate sports experience, such as naming players from each sport (it is expected that very few non-polo players could pick Adolfo Cambiaso out of a lineup, but polo players would more than likely be able to recognise him), tasks such as STB differ in fundamental ways. Whilst the STB task targets domain knowledge through a participant's ability to correctly look at the right object (even when it is not physically present), the task also requires participants to utilise a level of higher-order cognition; they must use their knowledge in a top-down approach to perceive the visual information provided in the photos and then comprehend the importance of information. It is these perception and comprehension skills that link the STB task to SA as a whole (Endsley, 1995b). Importantly, the STB paradigm is a visuo-cognitive task that hones in on a participant's perception skills, which are a pre-requisite for developing full SA.

Generally speaking, tools which have been validated as appropriate measures of SA, such as the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995a) and the What Happens Next? (WHN) (Jackson et al., 2009) methods, often show discrimination of domain experience (Crundall, 2016; Kroll et al., 2020; Mackenzie et al., 2023), which was seen in the two studies presented in this chapter. As was expected, athletes with specific sports experience performed better in the STB task than athletes with differing sport experience and control participants with no sports experience. Ultimately, this suggests that experience in a sport may play a role in SA performance, perhaps because of sport-specific memory allowing the experienced athletes to recall and utilise mental models and schema (Chase & Simon, 1973; Eccles, 2020). Research has shown that specific sports experience allows athletes to gain domain knowledge with which to build more accurate mental representations of play situations (Abernethy et al., 2005; Collins & Gentner, 1987; Filho et al., 2015), which in turn, may lead to better perception abilities as they are able to use that knowledge and mental model to match a 'new' situation with one they have already seen, and can therefore better direct their visual behaviours towards relevant areas the outcome (Collins & Gentner, 1987). It is possible that the athletes in these two studies drew upon their prior experience to make better use of the visual cues provided in the images, and thus pick more accurate locations. Importantly, as has been discussed in Chapter 1, comparing the experience levels of athletes in relation to visuo-cognitive skills across different studies is challenging as there is, as of yet, no standardisation of determining athlete level (Swann et al., 2015). Thus, whilst the referenced works may use different descriptions in regards to their participant cohort groups, there is a common theme that 'better' athletes typically outperform 'less-better' athletes or participants in visuo-cognitive tasks.

The visual cues (*i.e.*, gaze and head orientation, player grouping, polo mallet presence) investigated were found to also play a role in perception abilities, with the gaze and head orientation ultimately providing the most relevant information to participants across all experience levels. The results of both studies showed that participants were the most accurate when the photographed athlete's gaze was directed on the ball; this suggests that gaze (including head orientation) provided pertinent information useful in STB performance, and thus SA. The results of these two studies suggest that observers may be able to use gaze orientation of an athlete even in a static image to direct their attention towards the location of the ball. This is an important finding, as it demonstrates that, as has been shown in social psychology studies, observers may gain valuable information about an individual's intents (Baron-Cohen, 1994)—and importantly, locus of attention (Böckler et al., 2011)—in sports settings. This suggests that for those participating in sports—particularly inexperienced individuals—the gaze and head orientation of other players is perhaps one of the more salient and informative sources of visual cues which can be used to acquire lower levels of SA. Interestingly enough, the results showed that even though the polo (and soccer) players were mostly novice with small amounts of overall experience, there was still some level of expertise over control participants which occurred. Therefore, the results suggest that even small amounts of experience may still lead to a level of expertise over those with no experience.

The second study additionally showed that polo players were more accurate than non-experienced athletes and control participants when the gaze was off the ball, even with the entire mallet occluded. This ultimately suggests that experience in a sport allows for better perception in off-ball situations, whereas novices or non-experts rely on the ball to predict what may happen. For instance, Ryu et al. (2013) demonstrated that skilled basketball players spent less time than lesser-skilled players looking at the ball-handler, but were still able to make more accurate decisions, suggesting that there are off-ball cues which may provide information about what will happen next. This is important as sports such as polo and soccer require players to scan the field, look for teammates and opponents, and predict the movement of the players across the whole field (Goodspeed, 2005; McGuckian et al., 2020). Given this, there is a need to investigate players' SA across a more holistic play setting (*i.e.*, plays that involve passing and defensive manoeuvres off the ball), and not just situations that are ball-centric. Therefore, the studies in the next chapter (Chapter 4) will investigate SA using dynamic video stimuli and the What Happens Next? (WHN) method (Jackson et al., 2009).

The player grouping and polo mallet presence were ultimately found to not be as important as the gaze cueing when predicting STB performance. The player grouping on its own provided relevant information, but not enough to counteract a lack of gaze cueing, thus suggesting that gaze and head orientation were better sources of information. Interestingly, the mallet presence did not provide as useful information as was initially hypothesised. Previous studies have shown a link between mallet angle, player biomechanics and kinematics, and the ball trajectory (Brittain & Oliver, 2018; Ewart et al., 2020; Oliver et al., 2018a, 2018b); therefore, it was predicted that the mallet would be a source of polo-specific environmental information that polo players could use to aid in their perception abilities. However, the results showed no effect of the mallet on location accuracy, which contradicted the initial hypothesis. While it is possible that the lack of effect was due to the relative inexperience of the polo players sampled, it is also possible that the mallet was not the important source of visual information, but instead it was the player's posture and arm-shoulder-trunk positioning that provided the most information. In other striking sports, such as tennis and badminton, skilled players fixated more on an opponent's trunk, torso, shoulder, and arms rather than the racquet when predicting the landing shot of the ball (Alder et al., 2014; Huys et al., 2009; Runswick et al., 2020; Ward et al., 2002); thus, it is possible that the participants utilised the same sources of information, but without directly investigating eye movement behaviours during the STB task, it is impossible to tell.

Additionally, these studies hoped to address some of the shortcomings with the sports SA literature, namely that there are few objective, validated SA assessment tools utilised in sports studies, that of those assessment tools, the relation between sports experience and SA performance has not been examined, and that there are no studies (to date) that attempt to identify specifically how SA is acquired in sports. There are numerous studies that investigate visual search and scanning behaviours in sports (Abernethy, 1990; Aksum et al., 2021; Kato & Fukuda, 2002; Roca et al., 2018; Savelsbergh et al., 2002, 2005; Singer et al., 1996; Ward et al., 2002) and the links between those behaviours and anticipation and decision-making (Afonso, Garganta, & Mesquita, 2012; Causer & Ford, 2014; del Campo et al., 2011; Klostermann et al., 2015; Levi & Jackson, 2018; Silva et al., 2020; Travassos et al., 2013; van Maarseveen, Savelsbergh, et al., 2018), and one could make the argument that these behaviours may demonstrate how SA is acquired and utilised in sports. However, these studies overwhelmingly (see McGuckian et al. (2020) and Murray et al. (2018) for exceptions) do not explicitly relate these behaviours and skills to SA, therefore, it is hard to make any assumptions about the role these skills play in SA acquisition without exploring it experimentally. As was discussed in Chapter 1, this is a downfall of the sports and SA literature; it would perhaps be beneficial to explore any relations of scanning, anticipation, and decision-making in sports to SA in a more holistic way, and not just isolating certain skills.

3.3.1 Limitations.

The STB task has some limitations that should be addressed. The first limitation was the stimuli used for the task, namely static images with no prior context provided. One drawback of using still images is there is no way to determine precisely when the photo was taken. A polo ball, when hit with a full swing, can travel upwards of 160 km/h (100 mph)

(Watson, 1989), and a soccer ball can reach upwards of 129 km/h (80 mph) when kicked by professional players (Frechette, 2021). Research has shown that anticipation is necessary for tracking a fast-moving object (Brouwer et al., 2002), indicating that it is difficult to follow a fast-moving object directly. One could presume that a photo taken at the point of contact between the mallet/foot and ball could show a discrepancy between the ball location and the athlete's gaze due to the difficulty in tracking a fast-moving object. This could mean that the athlete's gaze being off the ball was due to a latency in object tracking and not an intentional decision (such as looking down-field away from the ball) that may be mirrored in posture and head tilt, which can be argued as important visual cues (Langton, 2000). This latency may have created a dissonance between gaze and posture which might make it harder to accurately locate the ball than if the posture and gaze orientation were congruent (Langton, 2000). This discrepancy can perhaps be remedied with video stimuli that shows the precise frame of ball contact and provide situational context, as will be investigated in Chapter 4. Videos may also provide better context for the situation displayed, as such, they are potentially better for capturing the dynamic nature of a scene and providing a more realistic task. Despite the aforementioned drawbacks of using static images, the STB task ultimately was designed to target the knowledge of where to look whilst removing reactive responses. Therefore, static images are good for Level I SA in that they allow for top-down perception and remove bottom-up reaction. By simply removing the ball, the task targets the top-down processes of perception, requiring participants to understand and utilise visual cues to make accurate responses. Thus, the results may still provide valuable information about the role of experience and visual cues in sports perception tasks, even when not performing in a dynamic task.

A second limitation was the Euclidean Distance Accuracy (EDA) did not discern the accuracy of the participant in relation to the ball trajectory. The EDA was merely an absolute value distance between the centre of the ball and the participant's response, and it did not distinguish whether or not a participant made an accurate click along the ball's actual trajectory. If a ball is traveling forward or in front of a player, and a participant clicks behind the player, they are not as accurate as a person who may have had a larger EDA but in the right direction. A possible suggestion to account for distance and direction would be to include an area of interest that is situated along the trajectory of the ball.

In a similar vein, there may be arguments that only measuring absolute distance away from the centre of the ball fails to define an acceptable measure of accuracy—in other words, at what distance would it be considered too far away from the centre of the ball to be truly 'accurate'? There are a few rebuttals for this argument, however, which should be addressed. Firstly, defining an acceptable accuracy distance would largely be subjective and would vary across sports, even if it were standardised. For example, setting an acceptable distance at +100% of the ball area would make it so that every sport (and study) could use a standardised method, however, this is still a subjective distance and would fail to account for different mechanisms for each sport. Converting a continuous variable (*i.e.,* the EDA) into a binary outcome (*e.g.,* hit/miss or accurate/inaccurate) would also remove the variability of the responses, which is ultimately what is being explored with the STB tool. The study design and statistical models used for the analyses also provides a level of standardisation to the paradigm. With the repeated measures, all participants saw the same images, including the size and placements of the balls, thus there were no differences in stimuli presentation based on participant groups. Lastly, by using mixed effect modelling, the results were not averaged as would be the case in a pooled statistical model (for instance, an ANOVA model), and thus the variation in stimuli (*e.g.,* ball sizes and placements) were accounted for as part of the mixed effects analyses.

Outside of an experimental setting, the results may have different implications for how accurate or precise one needs to be in a game setting. Here, the polo players may be a few pixels more accurate than controls, but how much would the difference in pixel distance affect a real-life sport? In a game setting, particularly when an athlete is not in possession or poised to hit the ball, it is perhaps only necessary to know the general location of the ball; that knowledge would then allow the athlete to make an appropriate play. In studies investigating Multiple Object Tracking (MOT), a key component in sports skills and performance (Howard et al., 2018), participants did not need to know the precise location of the objects but only the general spatial locations, which was achieved through covert attention and peripheral vision (Mackenzie et al., 2022). Thus, the implications of the results of the STB studies might be limited in scope when employed in a real-life setting. It is, therefore, important to explore how such a measure as STB correlates with sport performance, which is, ultimately a limitation of the studies and thesis overall.

Another limitation was the procedure of the study, which did not measure the response times of the participants because, a fast response time is meaningless if the accuracy is low. However, many sports anticipation studies measure response times, with experts often recording lower (faster) response times than novices (Afonso et al., 2012; Savelsbergh et al., 2005). Because response times were not measured, there were no instructions given to the participants to make quick responses; therefore, it could be argued that participants spent more time in their prediction than they would have in a real-world scenario. For future studies, measuring response time and accuracy would be beneficial to determine if there is a relationship between prediction, response time, and accuracy. A fourth limitation was the overall experience level of the participants sampled. These studies had a cohort of athletes (both polo and soccer) with low to medium abilities. In Study 1.2, the relative inexperience of the polo cohort could have been a reason for the contradictory results between 1.1 and 1.2. Notably, no correlation was found between athlete (either polo player or soccer player) handicap level/experience and STB performance, potentially because the cohorts were so clustered around inexperienced players. While the athletes had more experience when compared to the controls, they were still relatively novice in terms of player level within the sport. As a result of sampling less-experienced athletes, it becomes more difficult to compare the results of the STB studies with other sports cognitive studies that overwhelmingly sample highly experience or elite players as part of their cohorts. Future research should also aim to study how performance differs within sports, across different levels of players. Thus, recruiting athletes with more experience and better abilities may show a clearer relationship between experience and perception abilities.

3.3.2 Future directions.

The STB task has shown that still images can be used to assess athletes' perception abilities, and that the gaze direction of pictured athletes is important in sports perception. However, sports do not take place in still frames, but rather in a dynamic environment characterised by rapid changes. A future area of study could use video stimuli rather than still images. The video stimuli may provide dynamic cues that hold important information necessary for prediction, as has been demonstrated in sports anticipation (Loffing & Cañal-Bruland, 2017; Singer et al., 1996; Wright et al., 2011) and decision-making (Belling et al., 2015; Silva et al., 2020) studies. Video stimuli has also been frequently used in SA and hazard perception tasks in transportation (Kroll et al., 2020; Walker et al., 2009), aviation (Bolstad et al., 2010; Garland, 1991; Wickens, 2002), medicine (Chapman et al., 2020; Mackenzie et al., 2023), and other dynamic environments (Endsley, 1995b; Scialfa et al., 2013) and could potentially overcome some of limitations of still images. Therefore, in the following experimental chapter (Chapter 4), dynamic video stimuli will be used to assess SA in equestrian polo.

3.4 Conclusion

The sports SA literature is scarce with shortcomings surrounding the methodology and data. The literature reviewed ultimately suggests that more objective tools with empirical data are needed to further the sports SA domain and to explore the role of sports experience on SA performance, and to address the question of how SA is acquired in the first place by investigating the visual cues necessary for SA performance. This chapter introduced the 'Spot the Ball' (STB) tool as way to infer Level I SA (perception) skills in athletes by targeting the ability to detect the right thing even when it is not visible. Participants viewed sports (polo and soccer) photographs with various visual information provided and located a missing ball. The pixel distance between the participant's click and the actual centre of the ball was calculated to give a Euclidean Distance Accuracy (EDA), with lower EDAs representative of a more accurate prediction. The studies in this chapter investigated the validity of the STB tool as an inference measure of Level I SA in sports settings, the role of sports experience, and the roles of different visual cues (gaze cueing, player grouping, polo mallet presence) in STB performance, and thus SA in a static-image sports task. The two studies' results suggest that the STB tool discriminates sports experience, thus providing evidence that the STB tool may be used as an inference measure of perception skills in sports, which is a skill associated with SA. Additionally, the results showed that gaze cueing plays an important role in STB performance, with all participants regardless of sports experience performing better when the gaze was directed on the ball, suggesting that an individual's gaze provides a wealth of information about their locus of attention and future intentions. Athletes in invasion sports, such as polo or soccer, can possibly use this information to gain SA and make decisions on how to act on the play. Interestingly, the experience effects shown when the gaze was off the ball suggests that experience allows an individual to perform better in off-ball situations, or when the athlete's attention is not directed towards the ball, but downfield such as when looking for a pass to complete or intercept. Ultimately, this suggests that SA—especially for experienced athletes—is developed and maintained not just at the source of the ball, but also the entire playing field. Importantly, in polo, locating the players on the field and knowing their past, present, and future positioning is important to gaining and maintaining Field Awareness, or polo-specific SA (Goodspeed, 2005). The following chapter's (Chapter 4) experimental studies will explore off-ball polo SA in a video-based What Happens Next? (WHN) task.

Chapter 4 Phase II: Experience, expectation bias, and the potential for transfer in a dynamic polo Situation Awareness task

This experimental chapter aims to explore the validity of a dynamic video-based 'What Happens Next?' paradigm as an inference measure of SA in sports, the role of sports experience and situational context (offensive and defensive situations) on SA performance, and the transfer of prediction skills between sports of similar and dissimilar structures. The results show partial validity for the empirical, objective sports SA assessment tool. This study also shows the importance of situational context on SA, particularly with experienced athletes. Lastly, the results provide evidence that SA and anticipation skills are generally non-transferable to novel sports, suggesting that there are possible additional cognitive processes influencing SA in sports.

4.1 Study 2.1—Using the 'What Happens Next?' (WHN) paradigm to assess Situation Awareness in a polo task

4.1.1 Introduction.

The previous chapter introduced a novel inference measure of Situation Awareness (SA) in sports with the 'Spot the Ball' (STB) tool. The results of the experimental studies presented in the previous chapter showed that the STB tool discriminated sports experience with evidence to suggest that the tool was sensitive enough to target perception (Level I SA) skills. There was also evidence that those with specific sports experience were more accurate at locating 'off-ball' situations, where the photographed athletes' gazes were not directly looking at the ball but were looking downfield. This suggests that SA may be developed not just on or near the ball but across the entire field. Therefore, a more appropriate method of inferring SA in sports may be one that targets the prediction of off-ball play situations—in other words, a method that shows a more holistic picture of the field and developing plays. Thus, this chapter's experimental studies will investigate the What Happens Next? (WHN) paradigm for assessing SA in equestrian polo.

One of the main focuses of this thesis is investigating direct, objective methods of assessing SA in sports settings, and as discussed in Chapter 1, there are few objective SA tools used within a sports domain. Whilst there are many sports prediction tasks where athletes of varying experience or expertise level are asked to predict the outcome of a shot or play (Aglioti et al., 2018; Balser et al., 2014; Li & Feng, 2020; Mori & Shimada, 2013; Rowe et al., 2009), these studies do not explicitly link prediction skills with SA, despite SA encompassing the cognitive skills necessary for prediction in dynamic environments (Endsley, 1995b). Of the sports studies directly linking prediction to SA, only one employed a direct measure of SA using the Situation Awareness Global Assessment Technique (SAGAT) method (Ng et al., 2013). However, as was discussed previously in Chapter 1, this study failed to account for experience differences in the basketball players and did not show any relation of SA to game performance. Thus, there is a need for more research explicitly linking prediction skills to SA—research that ideally would employ direct, objective SA assessment methods, explore how experience drives SA performance, and ultimately, if SA performance relates to game performance. The current study aims to address the first two points, using the What Happens Next? (WHN) tool, derived from the SAGAT method, to investigate the role of sport experience on SA performance in a polo task.

The most widely used objective assessment method of SA is Endsley's (1995a) Situation Awareness Global Assessment Technique (SAGAT) (Salmon et al., 2009), with over 150 studies across various domains using this method (Endsley, 2021a). As discussed in Chapter 1, SAGAT is an offline, freeze-probe tool which presents participants with a video or simulation of a task. The simulation is then paused, and participants must answer queries regarding the three levels of SA (Endsley, 1995a) or how they are likely to act in the future (Orique & Despins, 2018). The SAGAT queries are generally scored discretely as correct or incorrect with a higher score indicating better SA (Endsley, 1995a). The queries can target individual levels of SA or a combination of SA requirements (Endsley, 2021a). Please see Chapter 1, Section 1.3.1.2 for an in-depth discussion of the SAGAT methods, including examples of potential polo queries as developed using a goal-directed task analysis (GDTA).

Generally, and across domains, more experienced operators perform better than novices in SAGAT tasks, with the suggestion that novice operators rely more on their working memory (Endsley, 2021a), whereas an experienced operator may circumvent this reliance on working memory by creating mental models through previous experience which permits them to perform a task with a certain amount of automaticity, thus allowing them focus more on their awareness and less on completing a task (Endsley, 1995b). It has been proposed that cognitively demanding tasks (such as driving or sports, for instance) may impair the executive functioning and ability to shift attention, which ultimately may result in stimulus—as opposed to goal—directed attention allocation (Broadbent et al., 2023; Eysenck et al., 2007), leading to poor task performance (Nieuwenhuys et al., 2008). In driving, it has been suggested that novice drivers allocate more attention to vehicle control tasks because the act of driving (*i.e.,* lane positioning, speed control) has not become automated (Mackenzie & Harris, 2017). Additionally, because of a lack of driving experience, novice drivers lack a developed mental model of potential roadway hazards (Underwood, 2007). The lack of automaticity and mental models in novice drivers has also been suggested to negatively impact their SA (Endsley & Garland, 2000) and Hazard Perception (HP) abilities on the road (Deery, 1999; Horswill & McKenna, 2004; Mackenzie & Harris, 2015; Ventsislavova et al., 2019; Wetton et al., 2010; Wood et al., 2016). Novice drivers also notably make more driving mistakes compared to experts when presented with external distractions, suggesting that their working memory is perhaps overloaded as a result of their cognitive resources (*e.g.,* attention) being devoted to simple vehicle control and not on scanning the road for potential hazards (Kass et al., 2007; Mackenzie & Harris, 2017). Simply put, experience may allow individuals to create detailed mental models of common situations, and therefore decrease the demand on the working memory so that the individual may employ a goal-driven task performance. This goal-driven task performance likely allows more experienced individuals to perform better in SAGAT tasks than inexperienced ones, thus inferring better SA.

The SAGAT method has been validated in different environments including aviation (Endsley, 1988b, 2000a; Endsley et al., 1998), driving (Jannat et al., 2018; Kaber et al., 2016), and medicine (Crozier et al., 2015; Dishman et al., 2020; Lavoie et al., 2016), but in sports it has only been used once to investigate the effect of SA on teenage basketball performance scores. As discussed previously in Chapter 1, Ng et al. (2013) tested 25 teenage (14 – 16 years) basketball players' level of anxiety, short-term memory, SA, knowledge of basketball rules and concepts, the ability to learn and set plays, and overall physical fitness level to investigate which cognitive skills influenced basketball performance. In addition to cognitive tests such as the Competitive State Anxiety Inventory-2 (CSAI-2) and Corsi block-tapping task, participants completed a basketball SAGAT task to assess their SA. The authors found that the players' SA was not a significant predictor of basketball performance (Ng et al., 2013), suggesting that SA may not directly relate to performance. Notably, there are several factors, such as technical motor skills, coaching, and experience (Burgess & Naughton, 2010) along with cognitive skills and SA (Hadlow et al., 2018) that have been suggested to affect sports performance, so while Ng et al. (2013) suggested that SA may not be as important to performance as initially suspected, it is possible there are more factors at play that have not been investigated in conjunction with SA. Additionally, there are no additional sports SA studies which specifically use the SAGAT tool with which to compare results; therefore, more research using the SAGAT tool in sports is warranted. One of the important findings within the sports SA literature search (Chapter 1) is the variability of SA assessment techniques used by researchers; overall, there have been numerous tools used to assess SA in sports settings, thus resulting in inconsistent findings across the domain. As such, sport SA research should be conducted using consistent methodologies so that results and patterns may become more apparently clear. The current study aims to provide an investigation into the relation of SA and experience using a similar method to Endsley's (1995b) SAGAT method: the What Happens Next? (WHN) paradigm.

4.1.1.1 'What Happens Next?' (WHN) paradigm as an inference measure of Situation Awareness.

A similar method of objectively assessing SA is the What Happens Next? (WHN) tool which presents participants with video stimuli of an environment, much like the SAGAT method; the video or simulation is paused during the task, and participants must answer the question, "What happens next?" (Jackson et al., 2009). The WHN tool specifically targets a participant's anticipation abilities, which corresponds to their Level III (projection) SA (Jackson et al., 2009). The WHN methodology has notably been used in transportation Hazard Perception (HP) and Hazard Prediction studies. Hazard Perception refers to simply identifying a dangerous situation on the road (Wetton et al., 2013), while Hazard Prediction targets an individual's prediction ability by asking, "What happens next?" (Ventsislavova et al., 2019).

Mckenna & Crick (1997) first used the SAGAT method for training drivers' Hazard Perception, where they instructed participants to answer the question of, "What might be about to happen?" when the training video was frozen. Participants were able to view the frame and process the environmental cues during the training session. Participants then completed a standard HP test, and their response times decreased following the training. Jackson et al. (2009) then used the WHN methodology for assessing individuals' HP abilities by asking them, "What happens next?" following a pause in the video. The pauses occurred prior to a hazard, with half the videos frozen (visual information still available) and half occluded (no visual information available). It was found that this methodology discriminated expert and novice drivers in the occlusion condition but not the freeze-frame condition (Jackson et al., 2009). It has been suggested that the discrimination ability of the occluded clips was due to the shorter processing time available with which to make a decision, whereas the freeze-frame would allow for longer processing time in which inexperienced drivers could achieve the same results as an experienced driver (Crundall, 2016). Importantly, the visual information and precursors must be apparent *prior* to the occlusion or freeze-frame in order for participants to be able to make an accurate prediction. Chapter 2, Section 2.3.2.1.1 discusses how occlusion and freeze-frame cut points were developed and which precursors were visible prior to the cuts. The specific precursors for the clips used in this study are shown in Table 4.4.

As the WHN method was validated for HP in driving, researchers then began to use it as a training tool. Wetton et al. (2013) used combinations of expert training commentary, self-generated training commentary, and WHN exercises to train HP in novice drivers, with the goal of reducing HP response times, indicating that drivers were faster to pick up on roadway hazards. They found that the WHN training was shown to significantly reduce the HP response times, suggesting it was a successful method of training. Additionally, the participants who received the full training package, which included WHN training plus expert and self-generated commentary, showed the most improvement in HP skills. The authors suggested that WHN training exercises may be beneficial to add to other exercises used for developing road SA (Wetton et al., 2013). Therefore, there is scope for using the WHN methodology for training, which is investigated further in Chapter 5: Study 3.

The WHN paradigm has also been applied in other domains, such as medicine. Recently, Mackenzie et al. (2023) investigated the usefulness of the WHN method in a medical trauma field. The authors created a 360-degree video continuous simulation of a medical emergency after paramedic handover, with the goal of stabilising the patient. Throughout the task, the simulation was paused, and participants answered several questions (“What happens next?” and “What should happen next?”) before the simulation resumed. The answers were scored as either correct or incorrect. Participants were categorised into three groups based on their trauma experience: Experienced Trauma, Inexperienced Trauma, and Non-Trauma Experience Control. The results showed that the WHN queries discriminated experience level, with the Experienced Trauma outperforming the Inexperienced Trauma and the Non-Trauma

Experience Control groups. The authors suggested that the WHN tool was sensitive enough to target the cognitive skills, such as anticipation and prediction, that experienced individuals possess (Mackenzie et al., 2023). Interestingly, in a pilot study, the authors found that simple decision-making, knowledge-based questions (perception and understanding probes; Level I and Level II SA) were not sensitive enough to discriminate experience, with the Experienced Trauma and Inexperienced Trauma groups performing similarly to each other. The results of the Mackenzie et al. (2023) studies suggest that while simple knowledge-based questions were not sensitive enough to target higher order cognitive skills and discriminate experience, the WHN questions were able to tap into the complex skills associated with SA.

In sports, there is limited studies which directly use a WHN paradigm, however, there has been use of similar methods which target prediction and decision-making of athletes. For instance, Berry et al. (2008) investigated the game perception and decision-making abilities of elite Australian Football League (AFL) players. Prior to the study, the players were ranked by their coaches by their overall decision-making abilities, with the players categorised as elite or less-skilled decision-makers. The players then participated in a task where AFL video clips were shown, with each video clip lasting roughly 15 seconds. The clips were occluded prior to a handball or kick pass. The participants were asked to first recall the positioning of the players on the field, and then were asked to predict the outcome of the play immediately after the occlusion point. It was shown that the elite decision-makers were significantly more accurate in both recalling the player positioning and predicting the outcome of the play (Berry et al., 2008).

The results of these studies suggest the WHN questions (and similar prediction paradigms) were able to tap into the complex skills associated with SA, thus making the WHN method appropriate for measuring SA beyond driving studies where it has been traditionally employed. This demonstrates that, whilst not directly referencing the WHN paradigm, the methodology of asking athletes to predict what will happen next is an appropriate method of targeting higher-level skills; therefore, the WHN paradigm may be suitable for measuring SA beyond driving studies where it has been traditionally employed. For the current study, the WHN method will be used as an inference measurement of SA, in a similar way that the 'Spot the Ball' (STB) tool was used in Chapter 3 (Studies 1.1 and 1.2). Ultimately, the WHN method was chosen over the SAGAT method due to its theoretical approach of assessing overall SA with one question (which targets the highest level of SA) and for its ease of creating probes. The WHN method has been shown to appropriately target Level III SA, in which Level I and II are important precedents, thus it is suggested to provide an inference of an individual's overall SA. As explained by Mackenzie et al. (2023), the knowledge-based questions (Level I and Level II SA) failed to discriminate experience in trauma team members, and it was only the WHN (targeting Level III SA) that showed discrimination. Thus, it is evident that the WHN paradigm successfully targets higher-order cognitive processes, such as anticipation. These cognitive processes are what allows more experienced individuals to outperform their less experienced counterparts in dynamic situations. Additionally, with the SAGAT probes, as opposed to WHN probes, lengthy and time-consuming GDTA's must be created to properly create questions that target the individual levels of SA. Whilst there is merit to assessing individual levels of SA, it is perhaps worth simply identifying if a person has an adequate level of SA first, then returning to assess where any deficiencies lie. Therefore, the WHN paradigm was chosen for the current study.

Because there was an experience effect in the STB studies seen in 'off-ball' situations, with polo players performing better than controls when the gaze was off the ball, the WHN method will include a more dynamic and holistic setting, allowing participants to see a play develop with the entire field in view, not just focusing on the ball. This may potentially be a more accurate exploration of SA in a sport setting when compared to the static STB task as it provides more realistic play scenarios. This study will therefore investigate the use of the WHN paradigm in a polo setting whilst also exploring the relationship between experience, situational contexts, and SA.

4.1.1.2 The role of experience on 'What Happens Next?' performance.

As has been discussed in the previous chapter, experience—specifically sporting experience—is believed to be a predictor in SA performance, given the results of the STB studies (Chapter 3: Studies 1.1 and 1.2) and the body of sports cognitive skills literature showing experience/expertise effects in anticipation (Causer & Williams, 2015; Gabbett et al., 2007; Loffing & Cañal-Bruland, 2017; Mori & Shimada, 2013; Nakamoto & Mori, 2012; Savelsbergh et al., 2005) and decision-making (Afonso et al., 2012; Catteeuw et al., 2010; Causer & Williams, 2015; del Campo et al., 2011; Hancock & Ste-Marie, 2013) studies. However, importantly, there is limited research into the role of experience on SA in sports, particularly using the WHN paradigm. Experience has been shown to positively affect SA and HP in driving studies using the WHN paradigm, with experienced drivers reporting faster HP response times and more accurate Hazard Prediction (anticipating what will happen next on the roadway) abilities compared to novice drivers (Crundall, 2016; Kroll et al., 2020; Ventsislavova et al., 2019). In medicine, it has also been shown that the WHN paradigm is sensitive enough to discriminate experience level in trauma teams, with more experienced individuals displaying higher WHN accuracy scores (Mackenzie et al., 2023). Therefore, based on the literature, it is plausible that the WHN paradigm may discriminate sports (polo) experience from general athletes and non-athletes, with the expectation that experienced polo players would have better accuracy scores when predicting what will happen next. It is important to investigate experience level differences as it is believed that domain experience allows individuals to develop higher order cognitive skills, such as anticipation and decision-making, which requires a certain level of awareness and knowledge of the domain; these skills and SA therefore may allow a person to perform at a high level (Mackenzie et al., 2023). The current study will therefore investigate the role of sports experience in SA performance using the WHN paradigm to gain a better understanding of if the tool can indeed target the higher-level cognitive skills possessed by polo players. For a more thorough description of sports experience and its role in cognitive skills—and SA—please refer to Chapter 1.

4.1.1.3 The role of situational context during sports prediction tasks.

As discussed, athletes are thought to construct mental models which help guide their task performance while playing (Abernethy et al, 2005), and these mental models may be created by past game situations and patterns detected during previous play experience (Eccles, 2020). Thus, it is possible that overall game situations and context may be important for sport performance and even SA. Elite athletes have been shown to use situational probabilities (Gray & Cañal-Bruland, 2018; Navia et al., 2013) and patterns of their opponents to aid in their anticipation (Loffing et al., 2015b). Overall, humans are very sensitive to finding patterns, and they generally use these patterns to help guide their actions (Oskarsson et al., 2009). In sports, patterns can be comprised of a multitude of actions, such as the steps in hitting a polo ball with an offside (right side of horse) forehand (*e.g.,* take-away, top of backswing, ball contact, follow-through) (Oliver et al., 2019). These patterns are then formed into probabilities of the event outcome by experts (Farrow & Reid, 2012; Loffing et al., 2015a; McPherson, 1999a), such as where the ball may end up based on the swing kinematics (Smeeton & Huys, 2011). It is believed that expert athletes use advanced cues (Gray & Cañal-Bruland, 2018), or a combination of kinematic cues such as body positioning or movement (Navia et al., 2013;

Smeeton & Huys, 2011) and contextual cues such as field/court positioning (Abernethy et al., 2001; Loffing & Hagemann, 2014b), action preferences of opponent (Farrow & Reid, 2012; Mann et al., 2014), or the game information (Runswick et al., 2019) to feed into their anticipation and decision-making. There have been investigations of sports situational context in relation to anticipation skills, and it has been suggested that knowledge of situational contexts can influence anticipation abilities (Loffing & Cañal-Bruland, 2017). It is also believed that patterns and situational contexts are used to create mental models, upon which experts may call to help plan a course of action for an event (Loffing et al., 2015b). For instance, Abernethy et al. (2001) demonstrated that expert squash players had superior anticipation abilities in part due to their utilization of situational probabilities, and Farrow & Reid (2012) showed that situational probabilities in addition to kinematics may be important for predicting the location of a tennis serve. In their research, older, more experienced players were able to integrate the situational cues and movement of the server to accurately make their predictions, whereas younger, less experienced players simply relied on the ball flight information, and therefore had lower prediction accuracy (Farrow & Reid, 2012). Elite tennis players were also shown to use the on-court positioning of their opponents to predict the shot direction (Loffing & Hagemann, 2014a), and Mann et al. (2014) demonstrated that handball players exposed to opponents with an action preference were more accurate in anticipating throw direction if the opponents used their preferred direction.

However, given that many of these situational context studies only examine one particular play/movement at a time (*i.e.,* tennis serve, volleyball lob, cricket bowl, baseball batting, *etc.*) (Abernethy et al., 2001; Farrow & Reid, 2012; Loffing & Hagemann, 2014a) and not a 'holistic' style of play where multiple events happen consecutively, it is worth investigating the role of situational context on SA and prediction (Level III SA) abilities in a more 'realistic' setting—in other words, can players use contextual cues throughout a game (or prolonged play) to build their SA, and thus, anticipation abilities? One such situational context that has not been explored in the literature is whether the play presented is of an offensive or defensive nature. The current study looks to explore whether participants can pick up the situational context (is the clip showing an offensive or defensive play?) and use that context to help them predict what will happen next. Situations such as an offensive or defensive play generally come with distinct patterns. If a team is on the offensive, they are playing with the goal to score points; therefore, the play(s) will be comprised of passing to teammates, carrying the ball downfield, and shooting at goal. These actions all come with specific biomechanics and patterns that may provide information as to what will happen next. Likewise, if a team is on the defensive, they are playing with the goal to prevent the other team from scoring points. Here, the play(s) will consist of defensive blocks, such as (in polo) hooking (striking an opponent's mallet to provide interference during a shot), bumping (laterally moving an opponent's horse off the ball), or intercepting a pass. Similarly, these actions also have specific biomechanics and patterns associated with them. Therefore, there is reason to suspect that knowing if an offensive or defensive play is unfolding may be important to predicting what will happen next. Additionally, knowing these types of plays feeds into overall 'game intelligence', which is how well players can read and understand the game (Lennartsson et al., 2015); this can relate to SA, or knowing what is going on around you. However, it should be noted that while there is literature analysing offensive and defensive strategies in a variety of team sports (Gómez et al., 2010; Lamas et al., 2014; Lennartsson et al., 2015; Rahimian & Toka, 2021), there is little investigation of the role these strategies play in overall sports SA.

4.1.1.4 The current study, aims & objectives, and hypotheses.

There is a paucity of sports studies directly assessing SA in athletes, therefore, there is significant room to extend the sporting literature by using the WHN paradigm to examine athlete SA. To date, no sports study has employed a WHN methodology in assessing SA, and only one sports study has used the related SAGAT method (Ng et al., 2013). However, given the success of the WHN tool in the transportation and medicine domains, where it generally discriminates experience (Crundall, 2016; Mackenzie et al., 2023), there is perhaps merit in using this method to assess the SA in athletes, particularly polo players. Polo is a highly dynamic open-style sport that requires awareness and forward-thinking to perform well and stay safe (Goodspeed, 2005), which makes it an excellent candidate for investigating SA using the WHN paradigm. The current study aims to investigate the veracity of the WHN tool for measuring SA and prediction in equestrian polo. Should the WHN tool discriminate sport experience, where polo players would outperform general athletes and control participants, it would suggest that the tool is sensitive enough to target the higher order cognitive skills, such as anticipation, which is associated with SA. With discrimination, the WHN task could be an inference measure of SA abilities.

From the literature above, the study has two aims: 1) to investigate if the WHN tool can be used to discriminate sport experience and thus provide evidence that the WHN tool may be an appropriate assessment of SA in sports by targeting anticipation skills, and 2) to investigate the role of situational context on SA and WHN performance. The first hypothesis of this study is that the WHN tool will discriminate polo experience from the polo players, sports players (athletes), and participants with no sports experience (controls), with polo players performing better at this task. Additionally, that within the non-polo participants, athletes will perform better than the control participants. The third hypothesis is exploratory in nature, and it is that all participants will be more accurate in offensive-based clips compared to defensive-based clips. It is believed that many sports participants and spectators play/watch with an offensive frame of mind and would thus be more accurate when viewing offensive play clips. Lastly, an interaction analysis was largely two-tailed; one prediction was made that the offensive and defensive performances would be larger in controls, where controls would be better in offensive conditions as they would potentially be more used to watching sports with an offensive frame of reference. Importantly, this interaction is exploratory in nature.

4.1.2 Methods.

This study was pre-registered and approved through OSF Registries on 9 November 2021 prior to any data collection taking place. The registration DOI is: https://doi.org/10.17605/OSF.IO/PZQ6J.

4.1.2.1 Design.

A 3 x 2 quasi-experimental mixed design of sport experience by clip type was used in this study. The sport experience (polo players, athletes, controls) was analysed as the between-subjects predictor variable, and the clip type (offensive, defensive) was analysed as the within-subjects predictor variable. The accuracy in the WHN task was analysed as the outcome variable. Participant ID and clip number were treated as random effects, and participant age was treated as a covariate.

4.1.2.2 Participants.

Participants were recruited online. Polo players were recruited through targeted advertisement posted in newsletters and on social media by the United States Polo Association (USPA), Hurlingham Polo Association (HPA), and the experimenter's personal social media. Athletes and control participants were recruited through advertisement on the NTU SONA website and on the experimenter's personal social media. Athletes were defined as participants who currently engaged in at least one sport, whereas controls were those who did not participate in any sports. Importantly, sports did not include general physical activities (non-specific gym training, leisure running/swimming/cycling, *etc*.); to be eligible as a sport, the activity must have a specific goal and performed whilst competing against other individuals or teams. Here, general athletes with participation in several different sports and types (individual, team, open-invasion, interceptive) were recruited to investigate if it is sport-specific or general sports experience that drives WHN performance. Controls were defined as participants who had never played a sport.

An *a priori* sample size calculation was performed using R (R Core Team, 2020) with the package 'pwr' (Champely et al., 2017). The effect size was based on previous polo situation awareness research with a ηp^2 = 0.245 which converted to an effect size (r) = 0.57. A conservative estimate of power at 0.95 and an alpha error probability of 0.05 was used for this calculation. A more conservative estimate was used for this study (compared with the 0.80 estimate of the previous studies) to ensure that the variability and complexities were more accurately accounted for (Kumle et al., 2021). This gave an overall sample size of 66 participants (22 in each group). Participants were excluded if they completed less than 80% of the study, answered in a systematic way (*i.e.,* answering all a, or a, b, c, d repetitively), or were under the age of 18. In total, 76 participants (48 female) ranging in age 18 – 74 years (M =

29.43 years, *SD* = 14.32) completed the WHN task. Four athletes were excluded from the study because they did not meet the athlete criteria. Therefore, 72 participants (45 female) ranging in age 18 – 74 years (*M* = 29.78 years, *SD* = 14.54) were included for analysis.

Twenty-eight polo players (13 female), ranging in age 20 – 74 years (*M* = 41.39 years, *SD* = 15.63) completed the task. The players had an outdoor polo handicap range of -1 – 3 goals (*M* = 0.07 goals, *SD* = 1.13). The handicaps were: -1 (*N* = 6), -0.5 (*N* = 3), 0 (*N* = 7), 1 (*N* = 2), 2 (*N* = 2), and 3 (*N* = 1), Not Rated (NR) (*N* = 7). The players reported 1 – 40 years of polo experience (*M* = 13.50 years, *SD* = 12.61), practiced 0 – 45 hours per week (*M* = 5.70 hours, *SD* = 8.89), and played 0 – 10 games per month (*M* = 2.77 games, *SD* = 2.96). Six players had been paid to play on a polo team, 21 had not been paid to play on a polo team, and one was unsure. See Table 4.1 for the polo player participant demographics.

Table 4.1 *Polo player participant demographics.*

Gender	*N*	%
Female	13	46.43
Male	15	53.57
Age (years)	*M*	*SD*
20—74	41.39	15.63
Experience (years)		
1—40	13.50	12.61
Hours Practiced/Week		
0—45	5.70	8.89
Games Played/Month		
0—10	2.77	2.96
Handicap (goals)		
-1—3	0.07	1.13
	N	%
NR	7	33.33
-1	6	28.57
-0.5	3	14.29
0	7	33.33
1	2	9.52
2	2	9.52
3	1	4.76
Paid Players	*N*	%
Yes	6	21.43
No	21	75.00
Unsure	1	3.57

Note. N = 28.

Twenty-five athletes (17 female), ranging in age 18 – 53 years (*M* = 24.60 years, *SD* = 9.55) completed the task. The athletes participated in the following sports: soccer (*N* = 5), netball (*N* = 4), basketball (*N* = 2), hockey (*N* = 2), running/track (*N* = 2), baseball (*N* = 1), cheerleading (*N* = 1), cycling/soccer (*N* = 1), dog agility (*N* = 1), ultimate frisbee (*N* = 1), golf (*N* = 1), kickboxing (*N* = 1), lacrosse (*N* = 1), martial arts (*N* = 1), and Thai boxing (*N* = 1). The athletes reported 1 – 35 years of sporting experience (*M* = 9.00 years, *SD* = 8.17), practiced 1 – 12 hours per week (*M* = 4.16 hours, *SD* = 2.90), and played 0 – 9 games per month (*M* = 2.32 games, *SD* = 2.30). Two athletes were paid to play on a team (1 soccer, 1 basketball), 22 were not paid to play on a team, and one was unsure. As can be seen, there was a broad mixture of sports represented in the study's cohort. Strategic sports, such as soccer, netball, basketball, hockey, *etc*. may be categorised as externally-paced and occur in noisy environments, where athletes must attend to multiple sources of visual information and make rapid decisions; conversely, sports such as golf, track (running), and cheerleading may be categorized as internally-paced where athletes' performances are not reliant on outside variables (such as multiple teammates and opponents potentially causing interference) (Mackenzie et al., 2021). Athletes who participate in strategic, team-ball sports have demonstrated better multiple-object tracking abilities (Howard et al., 2018), suggesting an increase in processing speed (Voss et al., 2010) which undoubtedly aids in externally-paced sports, such as polo. Because this type of processing may not be seen in internally-paced sports, it was decided to remove the athletes who participated in such sports to investigate the transfer of anticipation abilities between similarly paced sports.

Based on the above criteria for only including externally-paced sports, four athletes (running/track, N = 2; golf, cheerleading, N = 1 each, respectively) were removed from the current study's cohort. Therefore, 21 athletes (14 female) ranging in age 18 – 53 years (M = 24.86 years, SD = 9.90) completed the task. The athletes participated in the following sports: soccer (N = 5), netball (N = 4), basketball (N = 2), hockey (N = 2), baseball (N = 1), cycling/soccer (N = 1), dog agility (N = 1), ultimate frisbee (N = 1), golf (N = 1), kickboxing (N = 1), lacrosse (N = 1), martial arts (N = 1), and Thai boxing (N = 1). The athletes reported 1 – 35 years of sporting experience (M = 9.67 years, SD = 8.78), practiced 1 – 12 hours per week (M = 4.10 hours, SD = 2.79), and played 0 – 9 games per month (M = 2.19 games, SD = 2.38). Two athletes were paid to play on a team (1 soccer, 1 basketball), 18 were not paid to play on a team, and one was unsure. See Table 4.2 for the athlete participant demographics.

Table 4.2 *Athlete participant demographics.*

Gender	*N*	%
Female	14	66.66
Male	7	33.34
Age (years)	*M*	*SD*
18—53	24.86	9.90
Experience (years)		
1—35	9.67	8.78
Hours Practiced/Week		
1—12	4.10	2.79
Games Played/Month		
0—9	2.19	2.38
Sports Played	*N*	%
Soccer	5	23.81
Netball	4	19.05
Basketball	2	9.53
Hockey	2	9.53
Baseball	1	4.76
Football, Cycling	1	4.76
Dog Agility	1	4.76
Ultimate Frisbee	1	4.76
Kickboxing	1	4.76
Lacrosse	1	4.76
Martial Arts	1	4.76
Thai Boxing	1	4.76
Paid Players	*N*	%
Yes	2	9.53
No	18	85.71
Unsure	1	4.76

Note. N = 21.

Twenty-three control participants (18 female), ranging in age 18 – 22 years (*M* = 20.13 years, *SD* = 0.92) completed the task. The control participants did not participate in any sports but reported watching the following sports: soccer (*N* = 10), tennis (*N* = 2), Formula 1 (*N* = 1), soccer and Formula 1 (*N* = 1), and gymnastics (*N* = 1). Eight participants reported that they do not watch any sports. Using a slider scale from 0 (Never) – 10 (As much as possible), participants reported the frequency of watching sports ranging 0 – 10 (*M* = 2.96, *SD* = 3.01). See Table 4.3 for the control participant demographics.

Table 4.3 *Control participant demographics.*

Gender	*N*	%
Female	18	78.26
Male	5	21.74
Age (years)	*M*	*SD*
18—22	20.13	0.92
Watching Frequency		
0—10	2.96	3.01
Sports Watched	*N*	%
None	8	34.78
Soccer	10	43.48
Tennis	2	8.70
Formula 1	1	4.35
Soccer and Formula 1	1	4.35
Gymnastics	1	4.35

Note. N = 23.

It is important to note that there were age discrepancies in the three participant groups, particularly with the polo players reporting a mean age double that of the athletes and control groups. While it is important to have consistent age ranges between participant groups so that there is not an age-related confounding variable, the difficulty in sampling enough polo players who 1) completed the entire study and 2) were experienced enough (*i.e.*, were not complete novices to polo) meant that the recruitment efforts extended beyond the age range of the athletes and controls. To account for the age discrepancies, age was treated as a covariate in the data analysis.

4.1.2.3 Materials.

4.1.2.3.1 Stimuli.

The video stimuli were edited using Adobe® Premiere Pro® software (Version 13.1.5) on a Lenovo ThinkCentre computer. Participants viewed 18 polo video clips ranging in length from 3.06 – 29.07 seconds (*M* = 12.36s, *SD* = 6.90), with nine clips showing offensive plays (Range = 6.08 – 21.11s, *M* = 10.57s, *SD* = 4.73) and nine showing defensive plays (Range = 3.06 – 29.07s, *M* = 14.16s, *SD* = 8.45). Please refer to Appendix 7.3 for a complete description of the clips used for this study and Appendix 7.7 for the YouTube links of the clips.

The clip lengths provided enough information for the viewers to see the entire field of players (eight players total) and make any inferences about the play. In sports literature, Hancock & Ste-Marie (2013) suggested that video clips between 10 – 15 seconds were sufficient in length to contain enough visual information to make a decision but still remain somewhat ambiguous to discriminate expertise, so the video clips were edited to fit that time frame as best as possible. However, there were clips included that were shorter in length than the recommended time frame proposed by Hancock & Ste-Marie (2013); these clips were included because the temporal constraints posed by the shorter lengths more accurately represented the real-life constraints during a game. Polo plays, particularly in situations such as a knock-in from the goal line or opportunistic turnovers during field plays (a ball is redirected suddenly off a horse or divot in the ground), occur very rapidly; players often do not have the luxury of assessing a situation for more than a few seconds (sometimes less). For example, a knock-in from the goal line must be taken within five seconds of the umpire starting the clock, otherwise a delay of game penalty will be drawn (USPA, 2020). Thus, given the shot must be taken, and player's SA should reflect the temporal constraints of the plays. As a note, temporal occlusion paradigms used in sports studies have successfully demonstrated that experienced or more skilled athletes can successfully anticipate future outcomes in under one second. For example, tennis players have been shown to make accurate decisions in as little as 300—600ms (Abernethy & Russell, 1987; Farrow et al., 2005), and cricket batters have only approximately 900ms in preparation during a bowl (Müller & Abernethy, 2012). Additionally, Causer et al., (2017) demonstrated that skilled soccer goalkeepers could accurately predict the shot direction 80ms prior to ball contact by the shooter. In transportation WHN studies, Crundall (2016) even showed that longer clips led to a decrease in prediction accuracy amongst novice drivers, suggesting novices may lose awareness as the clips increase in length. Therefore, it is reasonable to expect that experienced polo players could also make accurate predictions in the shorter clips (under 10,000ms).

Each clip was examined for its overall accuracy and accuracy for each sporting group. It is to be expected that not all clips will have the same level of accuracy across sporting groups, and similarly, will not have the same level of accuracy within the same sporting groups. This variability is ultimately accounted for by using the binary logistic mixed effects modelling, which accounts for such variability in the random effects (here, the clip number) better than traditional ANOVA models because it does not aggregate data; such methods are less likely to therefore produce a Type I error when analysing hierarchal data structures with repeated measures.

To investigate if there was a relation between clip length and WHN accuracy, a linear regression model was used with average accuracy (across all participants and conditions) as the outcome variable and the length of clip (ms) as the predictor variable. The results showed that there was no relationship between length of clip and overall accuracy ($F(1,16) = 3.17$, $p = 0.09$, $R^2 = 0.17$, $R^2_{Adjusted} = 0.11$).

The video stimuli were created using footage from the 2021 USPA Gold Cup Final polo match between Scone Polo (red jerseys) and Tonkawa (green jerseys), which was played at the International Polo Club in Palm Beach, Florida on 28 March 2021. Both teams had cumulative 22-goal handicaps. Video footage was provided with permission from Global Polo TV®. The clips, filmed by a professional camera crew that was televised on Global Polo TV®, showed a mixture of aerial (bird's-eye view) footage where the field was viewed from above, and sideline footage where the field was viewed from the side, both of which are considered a 'third-person' viewpoint (Kittel et al., 2019). These views showcased the relevant actions to the play, with multiple viewing angles. Both views were included for this study to ensure the clips provided the appropriate visual information and precursors necessary for participants to anticipate the outcome of a play.

The third-person viewpoint for sports cognition studies is widely used and can include temporal occlusion paradigms (Farrow & Abernethy, 2002), spatial occlusion paradigms (Müller et al., 2006), and point-light displays (Williams et al., 2006). While there has been criticism of these viewpoints and paradigms for their lack of ecological validity (Farrow & Abernethy, 2003; Kredel et al., 2017), such third-person viewpoints persist in the literature. For instance, Farahani et al. (2020) used a third-person viewpoint of a soccer game where a camera was placed in the centre of the field at an angle looking down on the players. Participants with varying soccer experience were then asked to pick the best option for an attack; response times decreased with player experience, showing validity to the vantage point and task. It has also been proposed that a bird's-eye viewpoint (game viewed from above) allows athletes to approximate the spatial arrangement, angles, player field positioning, and the ball (Shimizu & Sumi, 2019; Williams et al., 2006), and according to a systematic review conducted by Kittel et al. (2019), third-person viewpoints were the most common viewing condition in research examining the decision-making of officials.

Conversely, Kredel et al. (2017) reported in a systematic review of eye tracking studies in sports since 1976 that 83.1% of the studies used a first-person viewpoint, whilst 11.9% used a 'behind the action' display, and 5.1% used a bird's-eye viewpoint. However, only 39.4% of gaze data was obtained in natural viewing conditions, whilst the remainder were obtained in lab settings. A majority of sports eye tracking studies asked participants to respond naturally to the stimuli (60.7%) compared to 39.3% using an 'artificial' response such as pressing a button or toggling a joystick (Kredel et al., 2017). Some researchers have also taken to realistic simulations as stimuli for sports cognitive skills studies. As an example, Gabbett & Abernethy (2013) used video taken from a first-person viewpoint of a rugby player which was then projected to a life-size scale on a wall. Participants were asked to react to the plays as they would in real life. Anticipatory skill and reaction times were increased with player experience level and age.

Whilst a first-person viewpoint (taken from a mounted helmet camera, for instance) would have provided a more ecologically valid viewing situation for the WHN task in the current study, such video clips were unavailable due to the constraints from the Covid-19 pandemic prohibiting in-person filming; thus, pre-filmed stimuli were acquired, and it is not yet industry standard to outfit players with helmet cameras during professional games, so such footage was not available. This is, without a doubt, a limitation to the study, which will be further discussed in Section 4.3.1. However, it should be noted that the WHN tasks employed in the current study were not designed to mimic real life, as many sports cognition studies have done. Instead, the WHN tasks were developed to study beyond the field, so to say, and examine the isolated decision-making approach as it relates to SA. Therefore, the viewing angle would not need to simulate a live polo game; however, that is an area for future endeavours.

4.1.2.3.1.1 WHN clip selection, identification of precursors, and creation of multiple-choice question (MCQ) distractors.

The selection of video clips used for the WHN task is important for the overall effectiveness of the WHN task. Ventsislavova et al. (2018) and Kroll et al. (2020) describe the importance of selecting clips for transportation hazard perception tasks. Clips should show natural hazards and contain precursors which allude to the upcoming hazard (Ventsislavova et al., 2018). In basketball, Aglioti et al. (2018) demonstrated the importance of visual cues in action prediction; elite athletes showed time-specific motor activation when anticipating shot outcomes, suggesting that visual cues and precursors allow elite athletes to accurately predict the outcome prior to the completion of the action.

Plays were chosen as the defining event, and precursors were defined as the visual information, including body and gaze positioning, player movements on the field, mallet direction, swing biomechanics, and the line of the ball (LOB) which would precede the completion of the play. As such, the precursors for each type of play (offensive or defensive) were carefully considered. In the current study, the clips all had differing freeze-frame cut points; in other words, the clip lengths varied. This was partially done to prevent participants from guessing when the freeze-frame point would be, but more importantly, the freeze-frame points were chosen based on the visual information available. Additionally in this study, to investigate situational context, the videos were separated into offensive and defensive play clips. Offensive clips showed plays which were offensive in nature (*i.e.,* the player/team in possession of the ball made offensive manoeuvres to maintain possession of the ball, pass to teammates, or score a goal). Defensive clips showed plays which were defensive in nature (*i.e.,* the player/team not in possession of the ball made defensive manoeuvres to gain possession of the ball or prevent the offense from scoring/passing). Table 4.4 shows the precursors available directly prior to the freeze frame, and Appendices 7.3 and 7.7 show the general clip descriptions and YouTube links, respectively.

Each video clip was edited to freeze prior to an offensive or defensive event (*e.g.,* a player passing the ball to a teammate or a player making a defensive hook on their opposition). Importantly, the freeze occurred when there was enough visual information (precursors) available to indicate how the play would progress, but not too much information that would allow anyone to guess what would happen, thus negating any experience effects. Many transportation Hazard Perception and Hazard Prediction tasks opt to completely occlude the video, as it has been shown that occlusion in WHN clips are discriminatory, whereas freeze-framing failed to show discrimination in levels of drivers (Crundall, 2016; Jackson et al., 2009; Lim et al., 2014). However, for the current study's freeze point, the screen was blurred so that minute details could not be seen (*i.e.*, a player's head positioning), but each player visible was labelled (*e.g.,* R1, G1). The screen was left blurred so that the general location of the players on the field could be recognised, but the player body positioning, mallet positioning, and ball details could not be made out, and the players were labelled to provide participants with the players' jersey colours and numbers. As this was only meant to be a prediction task, the goal was not to increase the participant's workload with a memory task as well (*i.e.*, remembering the players' numbers). While this goes against the procedure of a traditional WHN task, it is important to acknowledge that the WHN task, as it stands, was originally developed for use in the transportation field where there are limited interacting participants (cars typically do not interact with each other in the same fashion as athletes during field play) when compared to team sports. Currently, the WHN task must be adapted to fit the unique intricacies posed by dynamic team sports, such as polo; thus, procedural changes are made to better fit the task to the situation. Team sports have many more active participants with which to attend, and a blurred screen may allow for better memory trace that would allow for better recall in a WHN task. Additionally, a blurred screen may prevent a complete disconnect from the scene when answering a WHN probe, thus allowing participants to more easily maintain latent processing. Notably, a blurred screen with overlayed WHN probes has been used in a transportation WHN study; importantly, the experience effect was still seen, with emergency response drivers and experienced drivers outperformed novice drivers, suggesting a level of validity to the method (Kroll et al., 2020).

Figures 4.1 and 4.2 show WHN clip stimuli progression of one offensive and one defensive situation, respectively. The freeze-frame was visible for 20 seconds before auto-progressing to the next clip. The duration of the freeze-frame was chosen so that participants could have enough time to read the answer choices, but not so much time that they could potentially work backwards and guess the correct answer (which may result in false positives). Ideally, participants should already have an idea of what would happen next, and they would just need to find that answer from the given choices.

In accordance with the transportation hazard prediction studies (Ventsislavova et al., 2018), the multiple-choice questions (MCQs) and distractor choices were given appropriate attention. In the current study, during the freeze-frame, text would appear which asked the question, "What happens next?" followed by four multiple-choice answers (a, b, c, d). The multiple-choice answers contained an even mixture of offensively- or defensively-related choices. The distractor choices were chosen based on realistic possibilities for the play outcome, but importantly, were not evident based on the available precursors. For example, if the correct answer was Red 1 passes to Red 2, the precursors may show Red 1 look in Red 2's direction, Red 2 moving to get open for a pass, and Red 1's mallet swing trajectory aiming for Red 2. A distractor choice may be listed as Red 1 passes to Red 3. However, with the precursors available, there would be no indication that Red 3 was a target for a pass. Additionally, the visual information available may show Red 3 blocked by a defender or on the complete opposite side of the field as the intended passing target. Theoretically, an experienced participant would be able to read the precursors available and determine a pass to Red 3 is not likely, and thus would not choose that answer. Conversely, an inexperienced participant might not understand the visual cues and would thus be more apt to choose a distractor choice. For a complete list of MCQ distractors, refer to Appendix 7.3. Importantly, the distractor choices were not created using a ‘what should happen next?’ ideology, in which participants choose what they think the best play or course of action would be. In this study, the distractors and correct answers were chosen solely on what actually happened and the precursors available.

The WHN clips and MCQs were informally piloted to assess suitability of the clips, their length, and the language used for the MCQs. A participant with no polo experience viewed the clips, gave feedback, and the clips were revised to reflect such feedback. Whilst this pilot participant provided valuable information, a larger pilot sample would be beneficial to creating more robust WHN clips. This point is further discussed in the Chapter 4 General Discussion, Section 4.3.1.

Table 4.4 *List of precursors available immediately prior to the freeze-frame and WHN probe.*

Clip No.	Clip Type	Precursors Available	Play Outcome
1	Offensive	Green 4 looks to his right, towards the outside of the field. Green 3 begins to move his horse to the right to meet the pass.	Green 4 passes the ball to Green 3 on the outside of Red 3.
2	Offensive	Red 2 comes behind Red 4. Red 4 drops his mallet and begins to move towards Green 2 to the right.	Red 4 leaves the ball for Red 2.
3	Offensive	Green 3 begins his swing over his horse's right hip. Green 4 looks back at Green 3 and moves to get open.	Green 3 passes the ball to Green 4.
4	Offensive	Red 4 keeps the ball on his offside, begins to turn horse to the right. Green 2 fails to start turning to the right and continues straight.	Red 4 takes the ball to the right of Green 2.
5	Offensive	Green 3 moves to get open and looks over his left shoulder. Green 4 starts his swing at his horse's right hip with an angle to the left.	Green 4 passes to Green 3.
6	Offensive	Red 2 gets on LOB and raises mallet (signal for ROW).	Red 2 takes possession of the loose ball.
7	Offensive	Green 3 is defended. Green 4 swings around behind Green 3.	Green 3 leaves the ball for Green 4.
8	Offensive	Green 3 keeps the ball on his offside, begins to turn his horse to the right. Red 2 fails to start turning to the right and continues straight.	Green 3 turns the ball to the right.
9	Offensive	Green 3 moves parallel to the right to meet Red 4 and does not begin his swing. Green 4 is alone behind the ball and prepares for a swing.	Green 3 takes out Red 4 and leaves the ball for Green 4.
10	Defensive	Red 2 is on the nearside of Green 3, parallel to Green 3 (ball on offside). Red 2 moves his horse laterally toward Green 3.	Green 3 has possession of the ball. Red 2 bumps Green 3 to gain possession.
11	Defensive	Red 3 is on the nearside of Green 3. Green 3 hits the ball up (ball on offside). Red 3 begins to move horse laterally to Green 3.	Green 3 has possession of the ball. Red 3 bumps Green 3 to gain possession.

12	Defensive	Red 2 hits the ball (offside). Green 3 approaches on the offside of Red 2, looks to the ball, and begins his swing above his horse's left shoulder.	Red 2 has possession of the ball. Green 3 hits a backshot away from Red 2.
13	Defensive	Green 4 hits the ball up to the left. Red 4 approaches (ball on offside) and begins his swing above his horse's right shoulder.	Green 4 has possession of the ball. Red 4 hits a backshot away from Green 4.
14	Defensive	Red 4 hits ball the (on offside). Green 3 approaches with the ball on the nearside and begins his swing above his horse's left shoulder.	Red 4 has possession of the ball. Green 3 hits a backshot away from Red 4.
15	Defensive	Green 3 hits a long shot ahead. Red 3 is alone and makes his way to where shot is directed.	Green 3 has possession of the ball. Red 3 intercepts the ball.
16	Defensive	Green 3 hits a long shot ahead. Red 4 is alone and makes his way to where shot is directed.	Green 3 has possession of the ball. Red 4 intercepts the ball.
17	Defensive	Red 3 hits a long shot ahead. Green 4 looks over his right shoulder to where shot is directed.	Red 3 has possession of the ball. Green 4 intercepts the ball.
18	Defensive	Red 4 hits the ball (offside) directly down the centre. Green 4 looks back over his right shoulder and turns his horse to the right to meet the play on his offside.	Red 4 has possession of the ball. Green 4 intercepts the ball.

Figure 4.1 *Examples of the offensive WHN video stimuli progression. Figure 4.1a—The start of a play with the red player (far right) in possession of the ball; Figure 4.1b—The green player (centre) has intercepted the ball; Figure 4.1c—The frame before the occlusion showing the green player (far right) ready to make a pass; Figure 4.1d—The blurred freeze-frame screen and probe with the player labels, the "What happens next?" question, and the multiple-choice answers.*

Figure 4.2 *Examples of the defensive WHN progression. Figure 4.2a—The start of the play with the green player (top centre) in possession of the ball. Figure 4.2b—The green player (middle) is still in possession of the ball but is actively pressured by two red players (top and centre right). Figure 4.2c—The red player (bottom centre) is now in possession of the ball but is pressured by the green player (far left). Figure 4.2d—The blurred freeze-frame screen and probe with the player labels, the "What happens next?" question, and the multiple-choice answers.*

4.1.2.3.2 Apparatus.

4.1.2.3.2.1 Adobe® Premiere Pro®.

The polo video stimuli for this study were edited using Adobe® Premiere Pro® software (Version 13.1.5) licensed through Nottingham Trent University. A Think Centre computer and Samsung monitor were used during the editing process. The editing process is described in Chapter 2, Section 2.3.2.1.

4.1.2.3.2.2 Gorilla Experiment Builder.

The study was created and hosted online using Gorilla Experiment Builder (www.gorilla.sc). Data was collected between 12 November 2021 – 07 February 2022.

4.1.2.4 Procedure.

Participants completed the task online through Gorilla Experiment Builder using their mobile phone, personal laptop, or desktop computer. After giving informed consent, participants completed a set of general demographics questions that placed them in their specific sporting group (polo players, athletes, and controls). Once sorted into their sporting groups, participants answered a short series of sports-related demographics questions to determine sports experience (*e.g.*, "What is your outdoor polo handicap?" for polo players, “What sport do play, and how long have you played it?” for athletes, and “Do you watch any sports, and if so, which one do you watch the most?” for control participants).

Participants were instructed to view each video clip and answer the question of, “What happens next?” by clicking a button on the screen which corresponded to the letter choice (a, b, c, d). Participants were given a maximum of 20 seconds to choose their answer before the task would auto-progress to the next video. Participants viewed two practice polo clips (one offensive and one defensive) to familiarise themselves with the procedure that did not count towards their overall WHN accuracy. Upon completion of the practice clips, participants then viewed 18 polo clips (nine offensive and nine defensive) that counted towards their WHN accuracy score. Offensive and defensive clips were randomised throughout the task so that no participant saw the same order of clips. The participants were not told whether the clip was offensive or defensive. Each question was scored discretely with 1 = correct and 0 = incorrect. A 0 was scored for questions that were left blank. Following the completion of the task, each participant was awarded with an accuracy percentage, or the number of questions they got correct out of 18. At the end of the study, participants were thanked and debriefed. The task took approximately 15 – 20 minutes to complete.

4.1.2.5 Data analysis.

The outcome variable was the WHN accuracy score. Each individual trial was scored discretely, with 1 = Correct and 0 = Incorrect. Each participant was then awarded an overall accuracy score for the task based on the ratio of correct trials out of 18 (*e.g.,* 9 correct out of 18 would earn an accuracy score of 50). The higher the accuracy score, the better the participant’s SA. The first main effects predictor variable was sport experience, which was separated into three distinct groups: polo players, athletes, and controls. The second main effects predictor variable was the type of clip, which was separated into two types: offensive clips and defensive clips. Both main effects variables were analysed as fixed effects. The random effects variables were the participant ID and clip number (trial) and were analysed with a fixed slope. The participant ID was analysed as a nested random effect, and the clip number was analysed as a crossed random effect. Participant age was analysed as a covariate.

Binary logistic mixed effects modelling was used to determine the relationship between WHN accuracy and the predictor variables. The data analysis was performed using R (Version 3.6.3) (R Core Team, 2020) with the *lme4* package (Bates et al., 2020). Model comparisons were used to determine the overall best 'fit' of the data. Each model was run sequentially in order of increasing complexity, beginning with a null model (a model with constants instead of fixed effects). Each main (fixed) effect was added to the model and compared with the previous model. For the main effects models, all fixed effects were included for each model comparison. Interaction effects were also examined. Reduced-maximum likelihood ratios (REML) were used to compare the current model with the previous one to generate *p*-values (Luke, 2017), and any interaction was broken down using post-hoc Tukey tests. For the interaction effects, the fixed effects were modelled as a two-way model of sport experience x clip type.

4.1.3 Results.

The data was analysed as a 3 x 2 binary logistic mixed effects model with the sport experience (polo, athletes, controls) and clip type (offensive, defensive) measured as the predictor variables. For the outcome variable, performance was measured as accuracy in the WHN task. Participant ID and clip number were analysed as random effects. Participant age was analysed as a covariate. The accuracy percentages were collected over 18 video clips (9 offensive, 9 defensive). The mean accuracy scores (%) and standard deviations for the sport experience (polo, athlete, control), clip type (offensive, defensive), and sport experience by clip type are shown in Table 4.5.

Table 4.5 *Mean WHN accuracy scores (%), and standard deviations of sport experience (polo, athlete, control), clip type (offensive, defensive), and sport experience by clip type.*

	M	*SD*
Polo	32.20	46.77
Athlete	28.29	45.10
Control	29.49	45.65
Offensive	33.97	47.39
Defensive	26.38	44.12
	Offensive	Defensive
	M (SD)	*M (SD)*
Polo	48.86 (50.08)	15.73 (36.47)
Athlete	28.00 (45.01)	28.57 (45.29)
Control	21.62 (41.26)	37.73 (48.59)

Note. *N* = 72.

4.1.3.1 Main effects.

A binary logistic mixed effects model analysis was used to examine the effects of the predictor variables, sport experience and clip type, on the outcome variable, or WHN accuracy. Fixed effects were added, one at a time, to models of increasing complexity and were compared using likelihood ratio tests to the model prior. See Table 4.6 for a list of the main effects model comparisons. Results showed that there were no main effects of sport experience (χ^2 (2) = 1.79, *p* = 0.41) or clip type (χ^2 (1) = 1.38, *p* = 0.24).

Paired comparisons with a Tukey correction revealed that there were no differences between polo players (*M* = 32.20, *SD* = 46.77) and controls (*M* = 29.49, *SD* = 45.65; *p* = 0.61) and athletes (*M* = 28.29, *SD* = 45.10; *p* = 0.41) There were no overall differences in accuracy between athletes and controls (*p* = 0.94). Figure 4.3 shows the predicted (95%) confidence intervals for the overall WHN accuracy by sports experience, combining both offensive and defensive conditions. There were no significant differences between offensive clips (*M* = 33.97, *SD* = 47.39) and defensive clips (*M* = 26.39, *SD* = 44.10; *p* = 0.23). Figure 4.4 shows the predicted (95%) confidence intervals for the WHN accuracy by clip type.

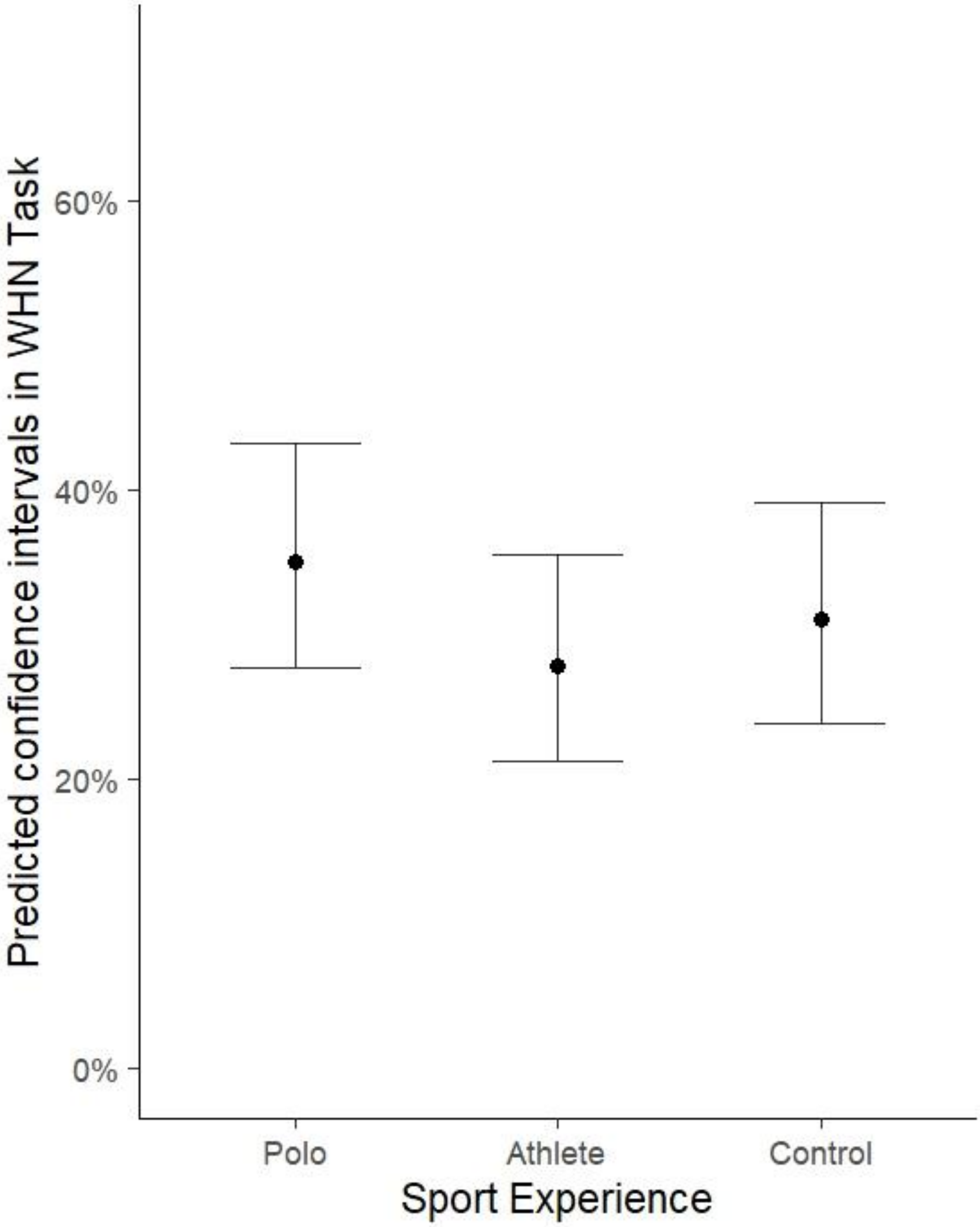

Figure 4.3 *Predicted (95%) confidence intervals of overall WHN accuracy by sport experience.*

Note. N = 72.

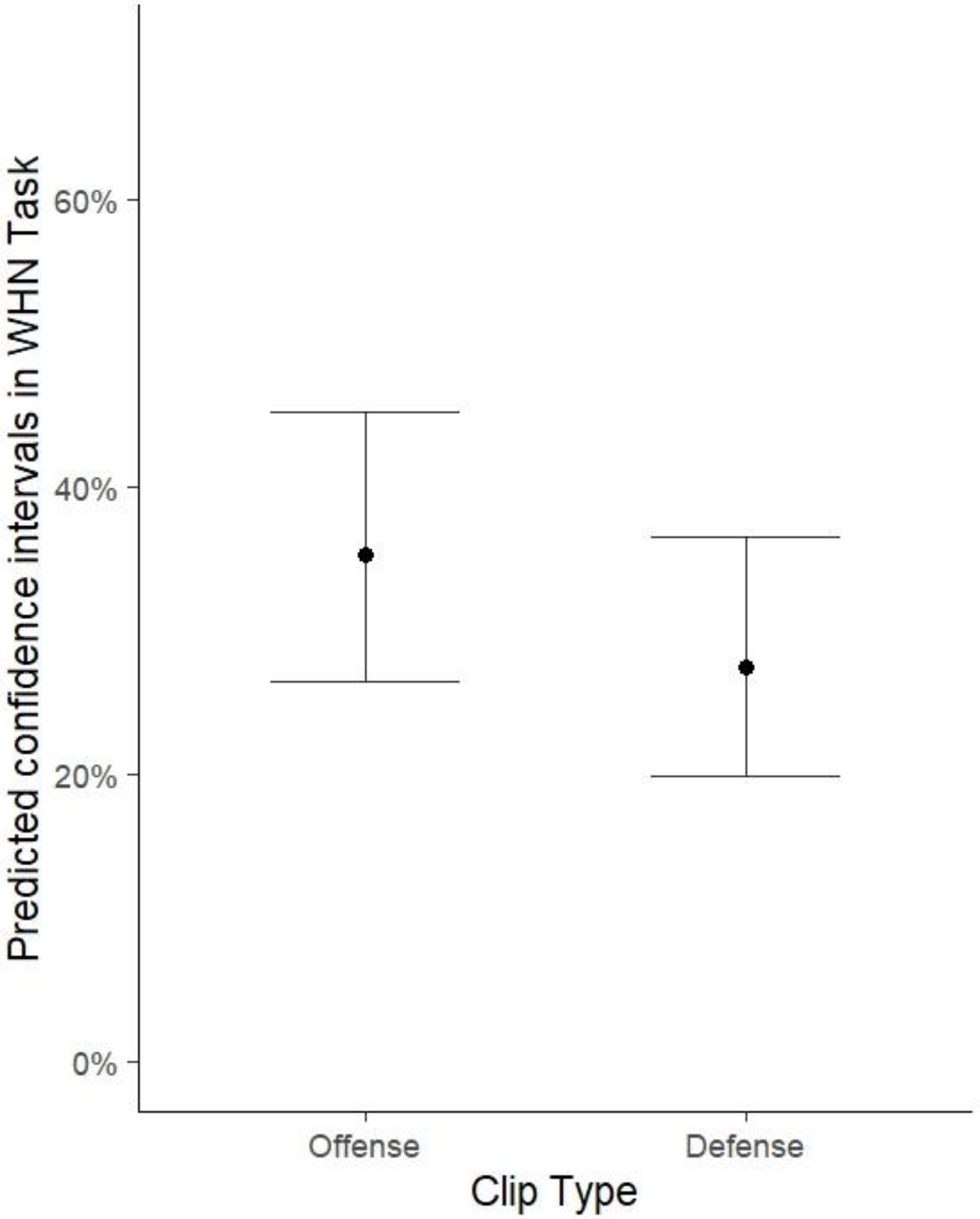

Figure 4.4 *Predicted (95%) confidence intervals of WHN accuracy by clip type.*

Note. N = 72.

Table 4.6 *List of main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	1619.8	-	-	-
ME1	Sport Experience	ME1 / Null	1622.0	1.79	2	0.41
ME2	Sport Experience + Clip Type	ME2 / ME1	1622.7	1.38	1	0.24

Note. *N* = 72.

4.1.3.2 Interaction effects.

Table 4.7 presents the list of interaction effects model comparisons. Results showed the two-way interaction model (sport experience x clip type) best fit the data (χ^2 (2) = 79.89, $p <$ 0.001). Paired comparisons with Tukey corrections revealed that for offensive clips, polo players (*M* = 48.86, *SD* = 50.08) were more accurate than athletes (*M* = 28.00, *SD* = 45.01; p < 0.001) and controls (*M* = 21.62, *SD* = 41.26; $p < 0.001$). There were no differences between athletes and controls ($p = 0.26$). For defensive clips, athletes (*M* = 28.57, *SD* = 45.29) were more accurate than polo players (*M* = 15.73, *SD* = 36.48; $p < 0.01$). Controls (*M* = 37.74, *SD* = 48.59) were more accurate than polo players ($p < 0.001$). There were no differences between athletes and controls ($p = 0.12$).

Within each sporting group, results showed that polo players were more accurate in the offensive clips compared to defensive clips ($p < 0.001$). Athletes did not differ in accuracy between offensive clips and defensive clips ($p = 0.88$). Controls were more accurate in defensive clips compared to offensive clips ($p = 0.02$). Figure 4.5 shows the predicted (95%) confidence intervals of each sporting group by clip type.

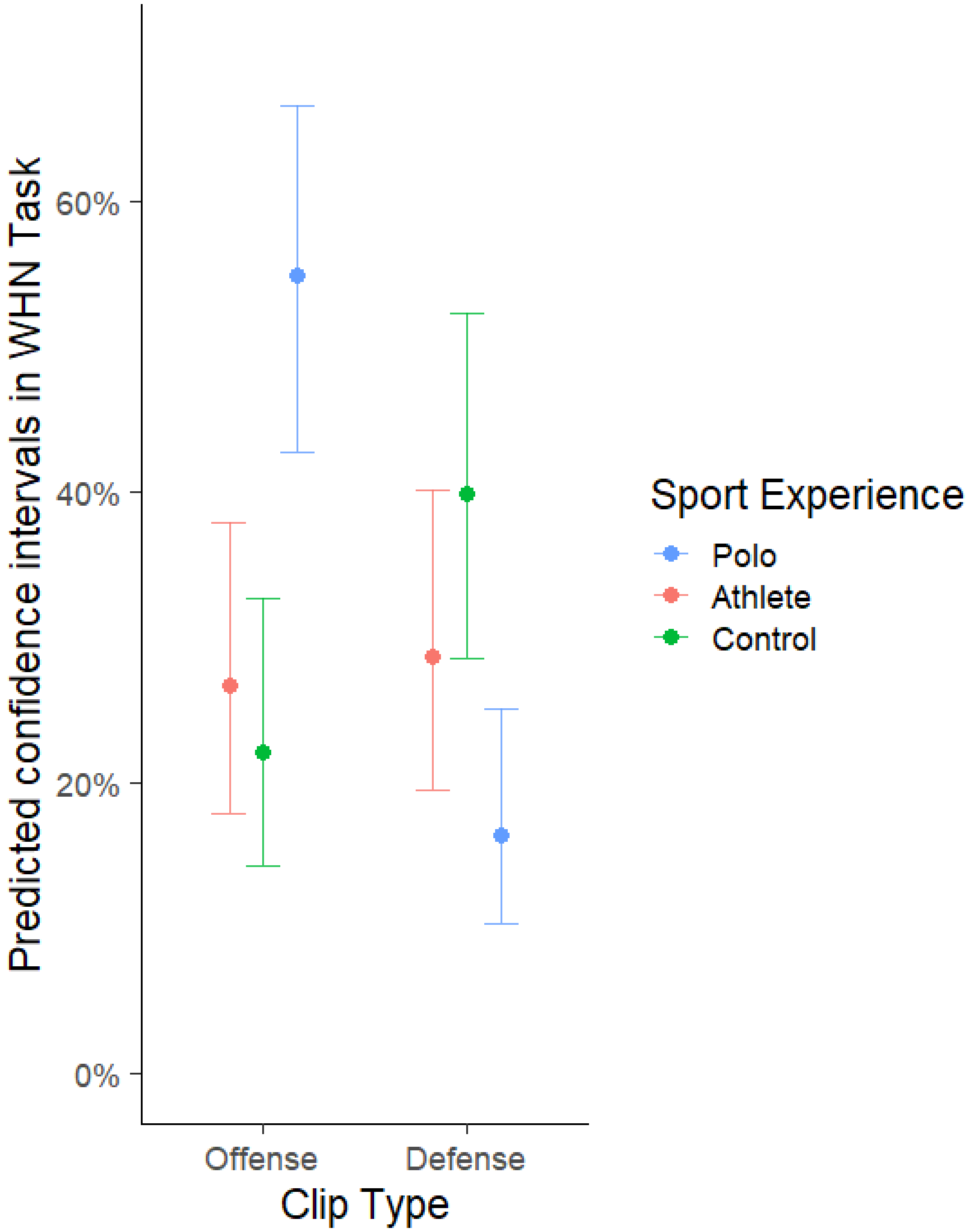

Figure 4.5 *Predicted (95%) confidence intervals of the sport experience in the WHN task by clip type.*

Note. N = 72.

Table 4.7 *List of interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	1619.8	-	-	-
ME1	Sport Experience	ME1 / Null	1622.0	1.79	2	0.41
ME2	Sport Experience + Clip Type	ME2 / ME1	1622.7	1.38	1	0.24
INT1	Sport Experience x Clip Type	INT1 / ME2	1546.8	80.15	2	< 0.001

Note. $N = 72$.

4.1.3.3 Exploratory data analyses.

As can be seen in the data visualisations of the interactions (Fig. 4.5), there was a large discrepancy between the polo players' offensive and defensive condition scores, where the polo players were better in the offensive condition but were worse in the defensive condition. The scores in these conditions were better than chance (over 25% correct) in the offensive condition, however, were *worse* than chance (less than 25% correct) in the defensive condition, suggesting that the polo players were not simply guessing answers, but instead had a strategy of answering the WHN probes, albeit incorrectly in the defensive condition. Mathematically, if the scores were around the 25% mark, it would suggest that the participants were simply guessing—with four answer choices, they had a one-in-four (25%) chance of guessing right. However, with scores significantly higher (or lower) than the 25% mark, it is possible that the polo players were using a specific, higher-level strategy. To test whether the participants performed differently than chance levels (25%), suggesting a strategy, a one-sampled *t*-test was performed for each group, with $\mu = 0.25$. As a whole, participants performed differently than chance ($M = 30.19$; $SD = 45.93$; $t(1367) = 4.18$, $p < 0.001$). Polo players performed differently than chance (*M* = 32.30; *SD* = 46.77; $t(530) = 3.55$, $p < 0.001$), and when broken down into clip type, polo players performed better than chance in offensive clips (*M* = 48.86; *SD* = 50.08; $t(263) = 7.74$, $p < 0.001$) but worse than chance in defensive clips (*M* = 15.73; *SD* = 36.48; $t(266) = -4.15$, $p < 0.001$). Athletes performed no differently than chance (*M* = 28.29; *SD* = 45.10; $t(402) = 1.46$, $p = 0.14$), and when broken down into clip type, athletes did not perform different than chance in offensive clips (*M* = 28.00; *SD* = 45.01; $t(199) = 0.94$, $p = 0.35$), or in defensive clips (*M* = 28.57; *SD* = 45.29; $t(202) = 1.12$, $p = 0.27$. Controls performed differently than chance (*M* = 29.49; *SD* = 45.65; $t(433) = 2.05$, $p = 0.04$), and when broken down into clip type, controls were no different than chance in offensive clips (*M* = 21.62; *SD* = 41.26; $t(221) = -1.22$, $p = 0.22$) but were better than chance in defensive clips (*M* = 37.74; *SD* = 48.59; $t(211) = 3.82$, $p < 0.001$).

With evidence that the polo players performed worse than chance in the defensive condition (while the controls performed better than chance in the same condition), it can be suggested that these groups had a specific strategy towards viewing the clips and answering the WHN questions. As a reminder, the answer choices were an even mixture of offensive- and defensive-related choices, giving the participants no inclination as to the type of situation they were viewing (offensive or defensive clip). Therefore, with the discrepancies of the polo players' and control participants' accuracies between offensive and defensive clips, there may have been unintended biases towards viewing the clips with an offensive or defensive frame of mind which might have affected how the participants answered the questions. If such a phenomenon existed, the participants might have been more likely to choose a certain type of answer choice (offensive or defensive) regardless of the actual play being presented. To examine if participants in each sporting group were biased towards answering the questions offensively or defensively, Chi-Squared tests of association were run to investigate if the type of answer (offensive answer or defensive answer) was related to the sporting group (polo players, athletes, or controls). Pearson residuals were used to make inferences about the associations between answer types and sporting groups. Larger, positive Pearson residual values indicated a stronger relationship, whereas smaller or negative values indicated a weaker association or no association. Figure 4.6 shows the overall percentage of observations of offensive answers selected and defensive answers selected by sport experience.

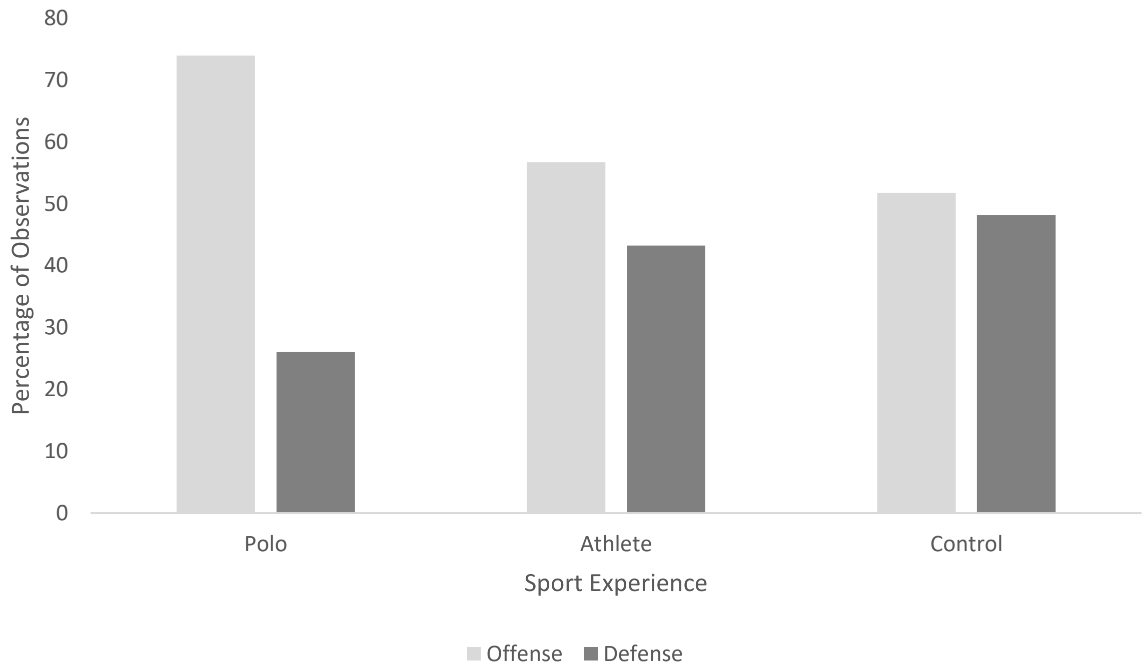

Figure 4.6 *The percentage of overall observations of offensive and defensive answers by sport experience.*

Note. N = 72.

A 3 x 2 Chi-Squared test of associations (sport experience x answer type) was performed to investigate if the answer type (offensive or defensive) was associated with the sport experience (polo players, athletes, controls). The test showed that the answer type was associated with the sport experience (χ^2 (2) = 50.19, p < 0.001). After inspecting the observed and expected counts plus the Pearson residuals, shown in Table 4.8, it was found that there was a stronger association between a polo player choosing an offensive answer (3.38) compared to an athlete (1.48) or control participant (-2.51). There was a weaker association between a polo player choosing a defensive answer (-4.29) compared to an athlete (2.39) or control participant (3.19). This indicates that polo players had a bias towards choosing offensive answers, even in defensive conditions, while athletes and control participants had a bias towards choosing defensive answers, even in offensive conditions.

Table 4.8 *Observed and expected counts plus Pearson Residuals of the answer types by sport experience.*

	Offensive Clips			Defensive Clips		
	Observed	Expected	Residual	Observed	Expected	Residual
Polo	349	291.30	3.38	123	180.70	-4.29
Athlete	210	228.41	1.48	160	141.59	2.39
Control	204	243.16	-2.51	190	150.84	3.19

Note. N = 72.

4.1.4 Discussion.

The first aim of the study was to investigate if the WHN tool could be used to discriminate sport experience and thus provide evidence that the WHN tool may be an appropriate assessment of SA in sports by targeting higher order cognitive skills. It was hypothesised that the WHN tool would discriminate polo experience from the polo players, sports players (athletes), and participants with no sports experience (controls), with polo players performing better at this task. Additionally, that within the non-polo participants, athletes would perform better than the control participants. There were no main effects of sport experience, thus the original hypothesis was unsupported. However, there were interaction effects which were not originally hypothesised. Polo players were more accurate than athletes and control participants in this task, but only in the offensive situations. They were, however, worse than athletes and controls in the defensive situations. Within the non-polo participants, there was no evidence to support the original hypothesis of athletes outperforming controls, as athletes and control participants performed similarly in the WHN task. The second aim of the study was to investigate the role of situational context on SA acquisition and WHN performance. It was hypothesised that all participants would be more accurate in offensive-based clips compared to defensive-based clips. There was no support for this hypothesis either, given that there were no differences in WHN accuracy scores between the offensive and defensive conditions. Lastly, it was hypothesised that the offensive and defensive performances would be larger in controls, where controls would be better in offensive conditions as they would potentially be more used to watching sports with an offensive frame of reference. Importantly, this interaction is exploratory in nature. There was no support for this hypothesis, with results showing that the controls actually performed significantly better in the defensive conditions. The results and theoretical implications are further discussed below.

4.1.4.1 The 'What Happens Next?' paradigm showed a nuanced experience effect, but no evidence of a transfer effect.

Whilst there were no main effects of sporting group with WHN performance, the results did show an interaction effect where polo players were more accurate in the offensive condition, as was to be expected. This suggests that in offensive conditions, sport-specific experience allowed participants to perform better than those with no sport-specific experience in WHN tasks; importantly, as has been discussed in Chapter 1, there are currently no WHN studies within a sport setting, thus making it difficult to compare the results of this study with the sporting literature. However, the results are supported by non-sporting domains WHN studies which have demonstrated that experience generally leads to better prediction abilities (Crundall, 2016; Kroll et al., 2020; Mackenzie et al., 2023). The lack of a main effect where polo players were better in the task may have been due to their low scores in the defensive conditions dragging their average scores down, thus making it appear they were not as accurate overall. This is discussed in Section 4.1.4.2.

The athletes and control participants performed similarly to each other, which was not as hypothesised. It was believed that athletes who participated in sports would be able to use their sporting knowledge of general plays, plus their anticipation and decision-making skills in their respective sports to predict the outcomes of polo, which has similar flow and movements as other open-style sports (Dale, 2015). However, that was not the case. This is interesting given that previous literature has shown evidence of athletes transferring cognitive skills to non-domain tasks, such as pattern recall and recognition (Abernethy et al., 2005; Allard & Starkes, 1992; Causer & Williams, 2015; Smeeton et al., 2004), particularly when those athletes were exposed to a variety of sports at a young age (Abernethy et al., 2005). Importantly, however, much of the literature investigating transfer effects in athletes sample highly experienced/elite/near-elite athletes. The current study's cohort of athletes were largely recreational, which could also explain a lack of transfer of anticipation abilities. It is possible that at their level of performance, regardless of sport, they had not had enough experience or training, and thus, their mental models may not have been developed to the point where it would aid in novel situations.

As discussed in Chapter 3, it appears, however, that polo is different enough to other open-style team sports that it prohibited athletes from transferring their sporting cognitive skills to help them answer the WHN questions. Therefore, the lack of any transfer effect in the athletes could also potentially be explained by the sports the athletes participated in. A little over half of the athletes participated in externally-directed team strategic sports (*e.g.,* football, netball, basketball, hockey, lacrosse) while the rest participated in internally-directed individual sports (*e.g.*, running/track, cheerleading, cycling, golf). Even with the internally-directed athletes removed from analysis, the remaining athletes still participated in a wide variety of sports, some of which included ultimate frisbee, martial arts, and baseball. It is possible that those who did not participate in team strategic sports had vastly different mental models stored, thus preventing any transfer (Kalén et al., 2021). An athlete who only participates in individual sports, such as martial arts, or non-invasion team sports (*e.g.,* ultimate frisbee or baseball) will not be as familiar or well-trained in anticipating a teammate's or opponent's movement, the trajectory of a ball, or the general flow of a strategic open-style game under heavy time pressure. Even individual sports which do require anticipation and decision-making abilities, such as martial arts (in this study's cohort), will require vastly different mental models as well. They may be attuned towards anticipating their opponent's movements, but these are often in close-contact, and they still do not necessitate awareness of other teammates or the trajectory of a flying ball. It would then be reasonable to suggest that the general unfamiliarity and confusion caused from watching an novel sport nullified any prior sports-knowledge advantage athletes had over control participants.

It is important to discuss that overall and across all groups of participants, the WHN accuracy scores failed to reach the 50 percent mark, suggesting that perhaps the clips were too difficult. One other possibility, particularly when examining the polo participants, is that the polo players themselves were less experienced as determined by their handicaps. The polo players sampled were largely 'low-goal' players, with the highest handicap rating listed as 3-goals, and the majority of the players listed below 0-goals. It is possible that the discrepancy between the level of players sampled and level of players viewed in the clips may have been the cause of the lower overall accuracy scores. The video clips showed elite players (high-goal) engaged in a much different style of game than low-goal, novice players would be familiar with. Goodspeed (2006) notes that high-goal polo games consist of long passes, open plays, high speeds, and substantial mallet control, whilst low-goal games are slower, and players tend to be clustered together, constantly rotating through, and possessing poorer ball control. It can be proposed that the low-goal players, despite having polo experience, may have not had the developed mental models to successfully predict the outcomes of an elite-level game, thus rendering them, in a sense, on a similar level as those without polo experience. For this reason, future research should perhaps also delve into the level of play showcased during WHN tasks and evaluate it against the level of experience the participants possess.

4.1.4.2 Evidence of a clear strategy and possible case of expectation bias.

There is an interesting caveat that showed the control participants were more accurate than polo players in the defensive clip conditions. This was unexpected because the control participants did not have any previous polo—or sporting—knowledge to draw upon when predicting what would happen next. This would, at face value, suggest that the polo players sampled were not as good at reading defensive situations and manoeuvres compared to offensive ones, suggesting the appropriate precursors were not visible or were incorrect. However, the precursors were identified *a priori*, and the freeze-frame cut points were chosen carefully to reflect the available precursors. It is likely that, rather than the precursors being absent, the polo players who participated in this study may have had an offensive bias where they incorrectly interpreted each clip as showing offensive plays, and therefore misinterpreted the advanced contextual cues provided by the players, thus leading to a misrepresentation of the situation. Such a bias may have led to the participants choosing offensive-related answers even in situations that showed defensive plays.

A post-hoc exploratory analysis was conducted to offer some support for the possibility of this explanation. The results of a one-sampled *t*-test showed that polo players performed better than chance in the offensive condition, but worse than chance in the defensive condition. On the other hand, control participants did not perform differently than chance in the offensive condition, but they were better in the defensive condition. That the polo players were better than chance in the offensive condition and worse than chance in the defensive condition suggests that they had a clear strategy of viewing and answering the clips, which could indicate that polo players viewed the clips with an offensive-related mental model, regardless of whether the clip showed an offensive or defensive play. While this strategy was successful when viewing offensive situations, it was detrimental to the polo players' accuracy when their mental model was incongruent to the play situation, as discussed previously. This suggests that the polo players may have had an offensive bias, one where they were more likely to view the clips with an offensive frame of mind and then pick offensive-related answer choices. Importantly, an expectation bias does not necessarily mean they are bad at a certain task, such as predicting the outcome of a defensive play. Instead, the bias may have led to the polo players having an inaccurate mental representative of the situation which resulted in poor performance.

Additionally, it is also possible that, due to an offensive bias, polo players viewed situations where the precursors were ambiguous enough that the play could go either way (in an offensive or defensive direction), and they consciously chose the offensive direction. An example of this would be when a red player is preparing to take an offside forehand shot (thus, an offensive play) at the same time a green player goes to make a nearside hook (thus, a defensive play). Because precursors (the body positioning to make a shot) for both types of plays are visible, it would be difficult to choose offensive versus defensive plays without some sort of additional information, such as 1) what team I am playing on, or 2) what type of play is this specific situation meant to showcase? Thus, without this information, the offensive bias may have been the ultimate deciding factor in ambiguous clips. This offensive bias is experimentally explored in the following study by providing contextual cues about the play, priming the participants to view the play as offensive or defensive.

In the sports literature, such a preconceived notion is generally termed ‘expectation bias’ (Loffing et al., 2015b). Research has shown that if the expert athlete relies too heavily on the probabilities extracted from the contextual cues, their anticipation performance may suffer. This has been found in sporting situations in athletes (Loffing et al., 2015b; Mori & Shimada, 2013) and even officials (Findlay & Ste-Marie, 2004; Plessner, 1999). Essentially, information that is incongruent with the play outcome hinders anticipation abilities in skilled athletes more than novice athletes (Loffing et al., 2015b; Mori & Shimada, 2013; Runswick et al., 2019). Therefore, pattern expectation may affect anticipation performance, particularly in experienced athletes, when the outcome is incongruent with the expectation, such as when the polo players mistook a defensive situation for an offensive one. The incongruence between what the polo players thought would happen versus what actually happened may have hindered their anticipation abilities in the defensive clip conditions. It is perhaps possible that the polo players were expecting an offensive play, not a defensive one, and thus were negatively affected when presented with a defensive play, which was reflected by their accuracy in the defensive clips.

A second post-hoc exploratory analysis was conducted to investigate the likelihood of participants choosing offensive or defensive answer choice, thus suggesting they viewed clips with a certain bias. To examine if polo players, and athletes and controls, were biased towards choosing a certain type of answer choice (offensive or defensive), a Chi-squared test of associations was conducted, along with Pearson Residuals for each sporting group. The results showed that polo players had the strongest association with offensive answer choices amongst athletes and controls. Likewise, polo players had the weakest association with defensive answer choices. Interestingly, control participants had stronger associations towards defensive answer choices and weaker associations with offensive answer choices. The results suggest that overall, polo players were biased towards choosing offensive answer choices for each clip, while control participants were biased towards choosing defensive answer choices. This suggests that when viewing the offensive clips, the polo players may have had a specific strategy to help them answer the questions and successfully predict what would happen next. Polo players potentially relied on mental models created from experience and prior knowledge of the game to aid in their SA and anticipation abilities, which has been suggested as a factor for expert performance in SA studies (Endsley, 1995b, 2021a). However, it is possible that these mental models may have been of offensive plays, rather than defensive. Therefore, the polo players chose how to act based on an incorrect mental model of the situation. This could potentially explain polo players' suboptimal performance in the defensive conditions and the control participants' higher accuracy in the defensive conditions. This strategy, which biased them towards choosing offensive-related answer choices, was successful in congruent (offensive) conditions but unsuccessful in incongruent (defensive) strategies. The following study will experimentally test for evidence of a polo player expectation bias by priming the participants to the type of clip they are about to view. If the results show that priming the participants nullifies the discrepancy between the offensive and defensive accuracy scores, there would be evidence that the polo players indeed had an offensive expectation bias. If there is still a discrepancy in offensive and defensive accuracy scores, there would be evidence that there was not an offensive bias, and instead the polo players are just bad at predicting defensive situations.

4.1.5 Conclusion.

The aims of the current study were to 1) investigate if the WHN tool can be used to discriminate sporting experience and thus provide evidence that the WHN tool is an appropriate assessment of SA in sports by targeting anticipation skills, and 2) investigate the role of situational context on SA acquisition and WHN performance. There were no main effects seen, but the results did show a partial experience effect, in that polo players were more accurate in the offensive condition, which was not initially hypothesised. Here, polo players were more accurate in the offensive condition, but less accurate in the defensive condition. The results also showed polo players had a clear strategy for answering the questions, but an expectation bias where they viewed the clips as mostly offensive (despite an even mixture of offensive and defensive situations) hindered their performance. This suggests that situational contexts play a role in SA acquisition, but if the contextual priors are incongruent with what is expected, there may be a decrement in performance, particularly amongst experienced players. Overall, this study provided information on the potential use of the WHN paradigm as an SA inference measurement in sports, whilst also suggesting that situational context may be an important component for gathering SA. The following study will experimentally explore the expectation bias hypotheses proposed in this study by priming the participants to the type of clip they are viewing.

4.2 Study 2.2—Exploring the offensive expectation bias of polo players in a polo 'What Happens Next?' (WHN) study

4.2.1 Introduction.

The previous study introduced the What Happens Next? (WHN) paradigm as a sports Situation Awareness (SA) assessment tool. The results of the study showed that, whilst there were no main effects of sport experience on WHN performance, there was an interaction effected noted. However, this interaction effect, where polo players were more accurate than general athletes and control participants, was only seen in offensive situations; in defensive situations, the opposite effect was observed such that polo players were actually worse than the athletes and control participants. To gain better insight into the results, post-hoc analyses were performed. The results of these analyses showed that, by performing differently than chance-levels, polo players had a strategy for answering the WHN questions; importantly, the results also showed that polo players were more likely to choose an offensive-based answer choice regardless of the type of situation, suggesting that the polo players had an offensive expectation bias when viewing the clips and were not just simply bad at predicting defensive plays. Therefore, one goal of this experimental study is to further explore the offensive expectation bias hypothesis proposed in the previous study with the aim of investigating how priming may influence such bias. If there truly was a polo player offensive expectation bias in the previous study, priming should theoretically eliminate the discrepancy in accuracy scores between the offensive and defensive situations. Of course, if the polo players just had poor defensive performance, there should still be that same discrepancy in this study.

Notably, there was no evidence of a transfer effect in the previous study's athlete cohort; the athletes, which comprised of general athletes who participated in a wide variety of both individual and team sports, were no better than the control participants in the WHN task despite having sports experience. It was believed that this experience would benefit the athletes and allow them to better predict the outcome of a situation when compared to control participants with no previous sporting experience. However, this was not the case. The lack of a transfer effect may have been due to the types of athletes sampled because the cohort consisted of athletes of a variety of sports, and not just team invasion sports (which have a closer structure to polo than, say, martial arts). Therefore, this study will also investigate the transfer of sports cognitive skills, including prediction, using a cohort of athletes who only participate in team sports with similar structures to polo, such as football, rugby, hockey, *etc.*

4.2.1.1 Exploring the role of priming on experts' expectation biases in sports.

The sporting literature shows that experienced athletes are more accurate than novice or inexperienced athletes about anticipating where the ball will land (Alder et al., 2014b; De Waelle et al., 2022) or predicting how an opponent will react (Jackson et al., 2006; Loffing et al., 2015a; Mori & Shimada, 2013) during lab studies and *in situ* play. It has been demonstrated that expert athletes are more accurate than novices in anticipation abilities in a variety of sports situations (Loffing & Cañal-Bruland, 2017), and one possible explanation is that expert athletes are better at reading situational contexts and using prior information with which they use to predict potential outcomes (Gredin et al., 2018; Huesmann & Loffing, 2019; McRobert et al., 2011; De Waelle et al., 2022). Therefore, in sports WHN tasks, it may be beneficial—and potentially more realistic—to provide some prior information about the video clips used as stimuli. For instance, priming the participants that the clip will show an offensive (or defensive) situation may provide enough context for an athlete to make a prediction more accurately. An athlete should know whether they are on offense or defence, and that knowledge alone should provide information useful for predicting the outcome of a play. Situational context is believed to influence athletes' anticipation, and perhaps SA, during sport cognitive tasks (De Waelle et al., 2022; Gredin et al., 2018, 2020; Huesmann & Loffing, 2019; Levi & Jackson, 2018; McRobert et al., 2011). The previous study hypothesised that polo players likely misinterpreted the type of WHN clip shown (offensive or defensive), and their accuracy scores—particularly with the defensive conditions—reflected such confusion. One potential way to experimentally investigate such a hypothesis is to alert the participants as to the type of clip they are about to view—in other words, to prime the participants with potentially useful information such as whether the play will be offensive or defensive in nature.

Priming, described as helpful effects on responses to a subsequent event or action (Tulving & Schacter, 1990), is thought to be the non-conscious activation of mental representatives through the environmental context (Chartrand & Bargh, 1996). Priming occurs because something—whether it be verbal or nonverbal—gives a person information about an upcoming situation (Ramscar, 2016). Priming effects have been studied in lab-based social psychology situations (Molden, 2014), cognitive psychology (Doyen et al., 2014), and in real-world situations requiring the use of advanced knowledge and contextual cues (Verkoeijen, 2005). In traditional priming studies, the priming generally occurs outside of the participant's awareness of its effect or with the objective to utilise the representations created during an action (Loersch & Payne, 2011). For instance, in social psychology, priming may take many forms depending on the situation and stimuli used (Loersch & Payne, 2011); repetition priming improves stimulus processing speed, semantic priming improves the identification of related concepts, and goal priming initiates a related goal (Doyen et al., 2014); behavioural priming leads to related behaviour, and construal priming can alter how individuals perceive others (Loersch & Payne, 2011). For example, Chartrand & Bargh (1996) showed in two separate experiments that 1) participants primed for rudeness interrupted the experimenters more often than those primed for politeness, and 2) participants primed with a stereotype of an elderly person walked slower than the control participants. This suggests that even implicit priming may have an effect on real-world outcomes.

In sports, it is thought that priming with contextual information may help elite athletes make correct decisions and actions when experiencing a heavy time pressure (Kibele, 2006). For instance, Crognier & Fery (2005) showed that tennis players were more accurate in anticipating the volley stroke from an opponent if they (the participants) were in control of the rally (*i.e.,* on the offensive) and thus were more likely to reduce the potential outcomes of their opponent. Similarly, McRobert et al. (2011) demonstrated that cricket batters improved their accuracy during a simulated cricket-batting test when they viewed the bowler multiple times and were thus provided with contextual information about the bowler's style and bowling tendencies. A meta-analysis of the priming effect in sports has found that overall, elite athletes were more sensitive towards sport-specific visual information when compared to novice athletes; the authors of the meta-analysis also found that images used for priming stimuli triggered a behavioural preparation in the athletes which lowered the response time in similar targets (Jiang et al., 2021). Interestingly, interceptive sports such as tennis and badminton showed a significant priming effect between elites and novices, but individual sports such as swimming or gymnastics failed to show such an effect (Jiang et al., 2021). This is potentially due to individual sports athletes not needing to predict behaviours of opponents or shot trajectories, as in interceptive sports, such as in tennis or badminton.

Perhaps one of the more relevant studies examining the effects of priming athletes for an event was conducted by Navia et al. (2013), who showed that soccer goalkeepers' save performance improved on trials where the experimenters informed the goalkeepers that there was a high probability the penalty kick would occur in the left (or right) direction. Nine soccer goalkeepers were positioned in the goalmouth on a soccer pitch and were presented with four trials of 12 penalty kicks, plus an additional five kicks for familiarisation. In each of the four trials, the probabilities of the direction of the penalty kick (left or right) and whether the keepers were told of these probabilities were altered: In the equal-probability conditions, there was a 50/50 chance the kick would go left or right—participants were not informed of this probability. However, in the high-probability conditions where there was an 80% chance the ball would go left (80/20 left/right) in one trial and vice-versa in the other trial (80/20 right/left), participants were informed of these probabilities. Navia et al. (2013) found that the goalkeepers' performances benefitted from the high-probability conditions (which were primed) with goalkeepers performing saving dives significantly more often to the correct side compared with the equal-probability conditions. The goalkeepers also initiated their dives earlier in the high-probability conditions as well. The authors argued that the goalkeepers were able to use the knowledge of the kicker's probabilities regarding the direction of the kick to successfully perform a saving dive, thus improving their anticipation performance (Navia et al., 2013). In other words, providing the athletes with probable event outcomes may improve their anticipation abilities in certain sports situations.

The previous study hypothesised that the polo players may have fallen victim to an expectation bias where they perhaps viewed the WHN clips with an offensive frame of mind more frequently; this was evidenced by their likelihood of choosing an offensive answer choice (from an even mixture of offensive and defensive choices) regardless of whether the situation was offensive or defensive. The current study aims to explore the expectation bias hypothesis proposed in the previous study by priming participants to the type of situation (offensive or defensive) they are about to see. It is thought that priming information may eliminate the discrepancy in accuracy scores between the offensive and defensive situations, indicating that the polo players in the previous study did in fact have an offensive expectation bias, and were not just simply bad at predicting what happens next in defensive situations.

4.2.1.2 Exploring the effect of cognitive skill transfer in team sport athletes.

A second aim of the study is to investigate if previous experience in sports with similar play structures to polo would result in a transfer of sports cognitive skills, such as prediction ability in a WHN task. Importantly, this study will only employ athletes who play a team, open-style sport; athletes who play individual sports, such as tennis or swimming, will be excluded from this cohort because individual sports have such a vastly different structure compared to team sports. As has been discussed previously, athletes have been shown to transfer cognitive skills between familiar and unfamiliar sports, provided that the sports are of similar structure (Abernethy et al., 2005; Allard & Starkes, 1992; Smeeton et al., 2004). This is believed to be because engaging in several types of sports at an early age helps to develop perceptual-motor skills (Côté et al., 2007), which may then benefit sports performance at an older age, evidenced by athletes displaying 'talent transfer' when they switch from one sport to another (Bullock et al., 2009). Additionally, it has been shown that athletes who have participated in a variety of sports of similar structures (*e.g.,* different types of invasion sports) are generally better decision-makers (Berry et al., 2008). Berry et al. (2008) sampled elite members of Australian Football League (AFL) teams, who were ranked by their coaches based on their decision-making and game perception abilities. Each player then participated in an AFL video-based task where they were asked to recall the positioning of the players and then predict the outcome of the next sequence following a pause. (Notably, whilst this study did not use the name 'What Happens Next?', this is essentially the same concept and described more in depth in the previous study, Chapter 4: Study 2.1, Section 4.1.1.1). The players also gave information regarding their practice habits, and whether they participated in other sports, and whether the 'different' sports were invasion, or non-invasion (*e.g.,* net/wall games, field/running, target, or other). The results showed that the expert decision-makers participated in more non-AFL invasion activities than non-experts. The authors argued that the elite decision-makers' participation in a variety of invasion activities likely benefitted their performance, suggesting a level of learning transfer from sports of similar structures (Berry et al., 2008). In the previous study, the athlete cohort was no more successful than the control participants, suggesting that there was no transfer of prediction skills in the athletes. However, the athlete cohort in Chapter 4: Study 2.1 was comprised of athletes who participated in a variety of sports, not just sports with similar styles as polo. This may have played a role in the lack of transfer effect. The current study will investigate if targeting athletes who specifically play a team, open-style sport, such as football, netball, hockey, *etc*., will demonstrate a transfer effect to equestrian polo WHN tasks.

4.2.1.3 The current study, aims & objectives, and hypotheses.

From the literature above, the current study has two aims: 1) to experimentally test the offensive expectation bias hypothesis presented in the previous study by priming participants about the type of clip (or situation) they were about to view, and 2) to investigate the role of sports structure on prediction skills transfer with team sport athletes. The first hypothesis is that for polo players, priming for the type of clip will eliminate the discrepancy between offensive and defensive situation accuracy scores, thus suggesting that the previous study's polo players did indeed have an expectation bias, and were not just simply poor at predicting defensive situations. The second hypothesis was that with the priming, the polo players will show an experience effect over the athletes and control participants. The third hypothesis is that team sport athletes will show some level of transfer in the polo WHN task and will be more accurate than control participants.

4.2.2 Methods.

This study was pre-registered and approved through OSF Registries on 1 March 2022 prior to any data collection taking place. The registration DOI is: https://doi.org/10.17605/OSF.IO/RB3T9.

4.2.2.1 Design.

A 3 x 2 quasi-experimental mixed design of sport experience by clip type was used. The sport experience (polo players, athletes, controls) was analysed as the between-subjects predictor variable, and the clip type (offensive, defensive) was analysed as the within-subjects predictor variables. The WHN percentage accuracy score was analysed as the outcome variable.

4.2.2.2 Participants.

Participants were recruited online. Polo players were recruited through targeted advertisement posted in newsletters and on social media by the United States Polo Association (USPA), Hurlingham Polo Association (HPA), and the experimenter's personal social media. Athletes and control participants were recruited through advertisement on the NTU SONA website and on the experimenter's personal social media. An *a priori* sample size calculation was conducted using R (R Core Team, 2020) with the package 'pwr' (Champley et al., 2017). The effect size (*r)* = 0.26 was based on the data from the previous WHN study. A conservative 0.95 power with a 0.05 alpha error probability was used. This gave a sample size of 62 participants (21 per group). Participants were excluded if they completed less than 80% of the study, answered in a systematic way (*i.e.*, answering all a, or a, b, c, d repetitively), or were under the age of 18. Athletes were excluded if they did not play a team open-style sport. In total, 43 participants (23 female) ranging in age 18 – 63 years (*M* = 29.51 years, *SD* = 11.31) completed the WHN task, but due to four athletes not meeting the requirement of 'team' athletes, the sample size was reduced to 39 participants (22 female) ranging in age 18 – 63 years (*M* = 30.00 years, *SD* = 11.68). It is important to note that due to time and cost constraints, the required sample size of 62 participants was ultimately not met, therefore, this study is underpowered.

Sixteen polo players (8 female), ranging in age 18 – 63 years (*M* = 31.12 years, *SD* = 13.87) completed the task. The players had an outdoor polo handicap range of -2 – 1 goal (*M* = -0.29 goals, *SD* = 0.96). The handicaps were: -2 (*N* = 1), -1 (*N* = 4), -0.5 (*N* = 1), 0 (*N* = 3), 1 (*N* = 3), Not Rated (NR) (*N* = 4). The players reported 2 – 20 years of polo experience (*M* = 6.72 years, *SD* = 4.82), practiced 0 – 10 hours per week (*M* = 3.84 hours, *SD* = 2.95), and played 0 – 10 games per month (*M* = 2.56 games, *SD* = 3.39). Two players had been paid to play on a polo team, and 14 had not been paid to play on a polo team. Table 4.9 shows the polo player participant demographics.

Table 4.9 *Polo player participant demographics.*

Gender	*N*	%
Female	8	50.00
Male	8	50.00
Age (years)	*M*	*SD*
18—63	31.12	13.87
Experience (years)		
2—20	6.72	4.82
Hours Practiced/Week		
0—10	3.84	2.95
Games Played/Month		
0—10	2.56	3.39
Handicap (goals)		
-2—1	-0.29	0.96
	N	%
NR	4	25.00
-2	1	6.25
-1	4	25.00
-0.5	1	6.25
0	3	18.75
1	3	18.75
Paid Players	*N*	%
Yes	2	12.50
No	14	87.50

Note. N = 16.

Fourteen athletes (6 female), ranging in age 19 – 44 years (*M* = 27.29 years, *SD* = 7.38) completed the task. The athletes participated in the following sports: soccer (*N* = 4), basketball (*N* = 2), netball (*N* = 2), cricket (*N* = 1), lacrosse and softball (*N* = 1), ice hockey (*N* = 1), Brazilian Jiu Jitsu (*N* = 2), and horse riding (*N* = 1). Four athletes (2 Brazilian Jiu Jitsu, 1 cricket, 1 horse riding) were removed as they did not fit the criteria for team sport athletes but were also not able to be considered 'control participants' due to their previous sporting experience. Therefore, ten athletes (5 female), ranging in age 19 – 44 years (*M* = 28.30 years, *SD* = 8.03) were included in the study. The athletes reported 1 – 23 years of sporting experience (*M* = 10.70 years, *SD* = 8.65), practiced 1 – 6 hours per week (*M* = 1.90 hours, *SD* = 1.52), and played 0 – 4 games per month (*M* = 1.70 games, *SD* = 1.77). All 10 athletes were not paid to play on a team. See Table 4.10 for the athlete participant demographics.

Table 4.10 *Athlete participant demographics.*

Gender	*N*	%
Female	5	50.00
Male	5	50.00
Age (years)	*M*	*SD*
19—44	28.30	8.06
Experience (years)		
1—23	10.70	8.65
Hours Practiced/Week		
1—6	1.90	1.52
Games Played/Month		
0—4	1.70	1.77
Sports Played	*N*	%
Soccer	4	40.00
Basketball	2	20.00
Netball	2	20.00
Lacross and Softball	1	10.00
Ice Hockey	1	10.00
Paid Players	*N*	%
Yes	0	0.00
No	10	100.00

Note. N = 10.

Thirteen control participants (9 female), ranging in age 18 – 61 years (*M* = 29.92 years, *SD* = 11.79) completed the task. The control participants reported watching the following sports: soccer (*N* = 4), basketball (*N* = 1), cricket 1 (*N* = 1), figure skating (*N* = 1), and ice hockey (*N* = 1). Five participants reported that they do not watch any sports. Using a slider scale from 0 (Never) – 10 (As much as possible), participants reported the frequency of watching sports, ranging 0 – 5 (*M* = 1.93, *SD* = 1.71). See Table 4.11 for the control participant demographics.

Table 4.11 *Control participant demographics.*

Gender	*N*	%
Female	9	69.23
Male	4	30.77
Age (years)	*M*	*SD*
18—61	29.92	11.79
Watching Frequency		
0—5	1.93	1.71
Sports Watched	*N*	%
None	5	38.47
Soccer	4	30.77
Basketball	1	7.69
Cricket	1	7.69
Figure Skating	1	7.69
Ice Hockey	1	7.69

Note. N = 13.

4.2.2.3 Materials.

4.2.2.3.1 Stimuli.

The stimuli video clips were the same used in the previous study with one distinct difference: the answer choices were not a mix of offensive or defensive choices as in the previous study, but instead were all offensively-related in offensive clips or all defensively-related in defensive clips. Additionally, the freeze-frames with the WHN probe and answer choices were shown for only 10 seconds in an attempt to mitigate participants having enough time to work backwards from the answer choices to find the correct answer. Ideally, the participants should already know the answer and simply find the answer in the given choices. The stimuli video clips were created following the same format as the previous study. Please refer to Table 4.4 for a description of the clips and precursors present, Appendix 7.4 for a general description of the clips, and Appendix 7.8 for a list of YouTube links for the clips.

Figures 4.7 and 4.8 show WHN clip stimuli progression of one offensive and one defensive situation, respectively. The freeze-frame was visible for 10 seconds before auto-progressing to the next clip.

Figure 4.7 *Examples of the offensive WHN video stimuli progression. Figure 4.7a—The start of a play with the red player (far right) in possession of the ball; Figure 4.7b—The green player (centre) has intercepted the ball; Figure 4.7c—The frame before the occlusion showing the green player (far right) ready to make a pass; Figure 4.7d—The blurred freeze-frame screen and probe with the player labels, the "What happens next?" question, and the multiple-choice answers.*

Figure 4.8 *Examples of the defensive WHN progression. Figure 4.8a—The start of the play with the green player (top centre) in possession of the ball. Figure 4.8b—The green player (middle) is still in possession of the ball but is actively pressured by two red players (top and centre right). Figure 4.8c—The red player (bottom centre) is now in possession of the ball but is pressured by the green player (far left). Figure 4.8d—The blurred freeze-frame screen and probe with the player labels, the "What happens next?" question, and the multiple-choice answers.*

4.2.2.3.2 Apparatus.

4.2.2.3.2.1 Adobe® Premiere Pro®.

The polo video stimuli for this study were edited using Adobe® Premiere Pro® software (Version 13.1.5) licensed through Nottingham Trent University. A Think Centre computer and Samsung monitor were used during the editing process. The editing process is described in Chapter 2, Section 2.3.2.1.

4.2.2.3.2.2 Gorilla Experiment Builder.

The study was created and hosted online using Gorilla Experiment Builder (www.gorilla.sc). Data was collected between 01 March 2022 – 24 August 2022.

4.2.2.4 Procedure.

Participants completed the task online through Gorilla Experiment Builder using their mobile phone, personal laptop, or desktop computer. After giving informed consent, participants completed a set of general demographics questions that placed them in their specific sporting group (polo players, athletes, and controls). Once sorted into their sporting groups, participants answered a short series of sports-related demographics questions to determine sports expertise (*e.g.,* “What is your outdoor polo handicap?” for polo players, "What sport do play, and how long have you played it?" for athletes, and "Do you watch any sports, and if so, which one do you watch the most?" for control participants).

Participants were instructed to view each video clip and answer the question of, "What happens next?" by clicking a button on the screen which corresponded to the letter choice (a, b, c, d). Participants were given a maximum of 10 seconds to choose their answer before the task would auto-progress to the next video. The amount of time to answer the probes was reduced from the previous study's 20 seconds to discourage participants from working backwards from the answer choices to make their decision.

Participants viewed two practice polo clips (one offensive and one defensive) to familiarise themselves with the procedure that did not count towards their overall WHN accuracy. Upon completion of the practice clips, participants then viewed 18 polo clips (nine offensive and nine defensive) that counted towards their WHN accuracy score. The videos were grouped into offensive and defensive blocks based on their content. Participants viewed two separate blocks of 18 polo clips (Block A consisted of nine offensive clips, and Block B consisted of nine defensive clips). Participants were primed by informing them of the type of clips they would be seeing prior to viewing each block, thus allowing them to view the clips with a correct frame of reference. The videos within each block were randomised, and the blocks themselves were randomised for each participant so that no participant viewed the same order of clips. Each question was scored discretely with 1 = correct and 0 = incorrect. A 0 was scored for questions that were left blank. Following the completion of the task, each participant was awarded with an accuracy percentage, or the number of questions they got correct out of 18. At the end of the study, participants were thanked and debriefed. The task took approximately 15 – 20 minutes to complete.

4.2.2.5 Data analysis.

The data analysis for the current study is the same as that used in the previous study, Chapter 4: Study 2.1. The outcome variable was the WHN accuracy score. Each individual trial was scored discretely, with 1 = Correct and 0 = Incorrect. Each participant was then awarded an overall accuracy score for the task based on the ratio of correct trials out of 18 (*e.g.*, 9 correct out of 18 would earn an accuracy score of 50). The higher the accuracy score, the better the participant's SA. The first main effects predictor variable was sport experience, which was separated into three distinct groups: polo players, athletes, and controls. The second main effects predictor variable was the type of clip, which was separated into two types: offensive clips and defensive clips. Both main effects variables were analysed as fixed effects. The random effects variables were the participant ID and clip number (trial) and were analysed with a fixed slope. The participant ID was analysed as a nested random effect, and the clip number was analysed as a crossed random effect.

Binary logistic mixed effects modelling was used to determine the relationship between WHN accuracy and the predictor variables. The data analysis was performed using R (Version 3.6.3) (R Core Team, 2020) with the *lme4* package (Bates et al., 2020). Model comparisons were used to determine the overall best 'fit' of the data. Each model was run sequentially in order of increasing complexity, beginning with a null model (a model with constants instead of fixed effects). Each main (fixed) effect was added to the model and compared with the previous model. For the main effects models, all fixed effects were included for each model comparison. Interaction effects were also examined. Reduced-maximum likelihood ratios (REML) were used to compare the current model with the previous one to generate *p*-values (Luke, 2017), and any interaction was broken down using post-hoc Tukey tests. For the interaction effects, the fixed effects were modelled as a two-way model of sport experience x clip type.

4.2.3 Results.

The data was analysed as a 3 x 2 binary logistic mixed effects model with the sport experience (polo, athletes, controls) and clip type (offensive, defensive) measured as the predictor variables. For the outcome variable, performance was measured as accuracy in the WHN task. Participant ID and clip number were analysed as random effects. The accuracy percentages were collected over 18 video clips (9 offensive, 9 defensive). The mean accuracy scores and standard deviations for the sport experience (polo, athlete, control), clip type (offensive, defensive), and sport experience by clip type are shown in Table 4.12.

Table 4.12 *Mean WHN accuracy scores (%) and standard deviations of sport experience (polo, athlete, control), clip type (offensive, defensive), and sport experience by clip type.*

	M	*SD*
Polo	45.29	49.87
Athlete	32.95	47.14
Control	21.12	40.90
Offensive	33.24	47.17
Defensive	34.61	47.64
	Offensive	Defensive
	M (SD)	*M (SD)*
Polo	50.35 (50.17)	40.00 (49.17)
Athlete	20.93 (40.92)	44.83 (50.02)
Control	21.55 (41.30)	20.69 (40.68)

Note. N = 39.

4.2.3.1 Main effects.

A binary logistic mixed effects model analysis was used to examine the effects of the predictor variables, sport experience and clip type, on the outcome variable, or WHN accuracy. Fixed effects were added, one at a time, to models of increasing complexity and were compared using likelihood ratio tests to the model prior. See Table 4.13 for a list of the main effects model comparisons. Results showed that there was a main effect of sport experience (χ^2 (2) = 18.12, $p < 0.001$), but not one of clip type (χ^2 (1) = 0.08, $p = 0.78$). Therefore, the main effects model with just the sport experience best fit the data.

Paired comparisons with a Tukey correction revealed that polo players (*M* = 45.29, *SD* = 49.87) were more accurate than controls (*M* = 21.12, *SD* = 40.90; $p < 0.001$), but were similar to athletes (*M* = 32.95, *SD* = 47.14; $p = 0.11$). There were no differences in athletes and controls ($p = 0.06$). Figure 4.9 shows the predicted (95%) confidence intervals for the WHN accuracy by sports experience. There were no differences between offensive clips (*M* = 32.24, *SD* = 47.17) and defensive clips (*M* = 34.61, *SD* = 47.64; $p = 0.78$). Figure 4.10 shows the predicted (95%) confidence intervals for the WHN accuracy by clip type.

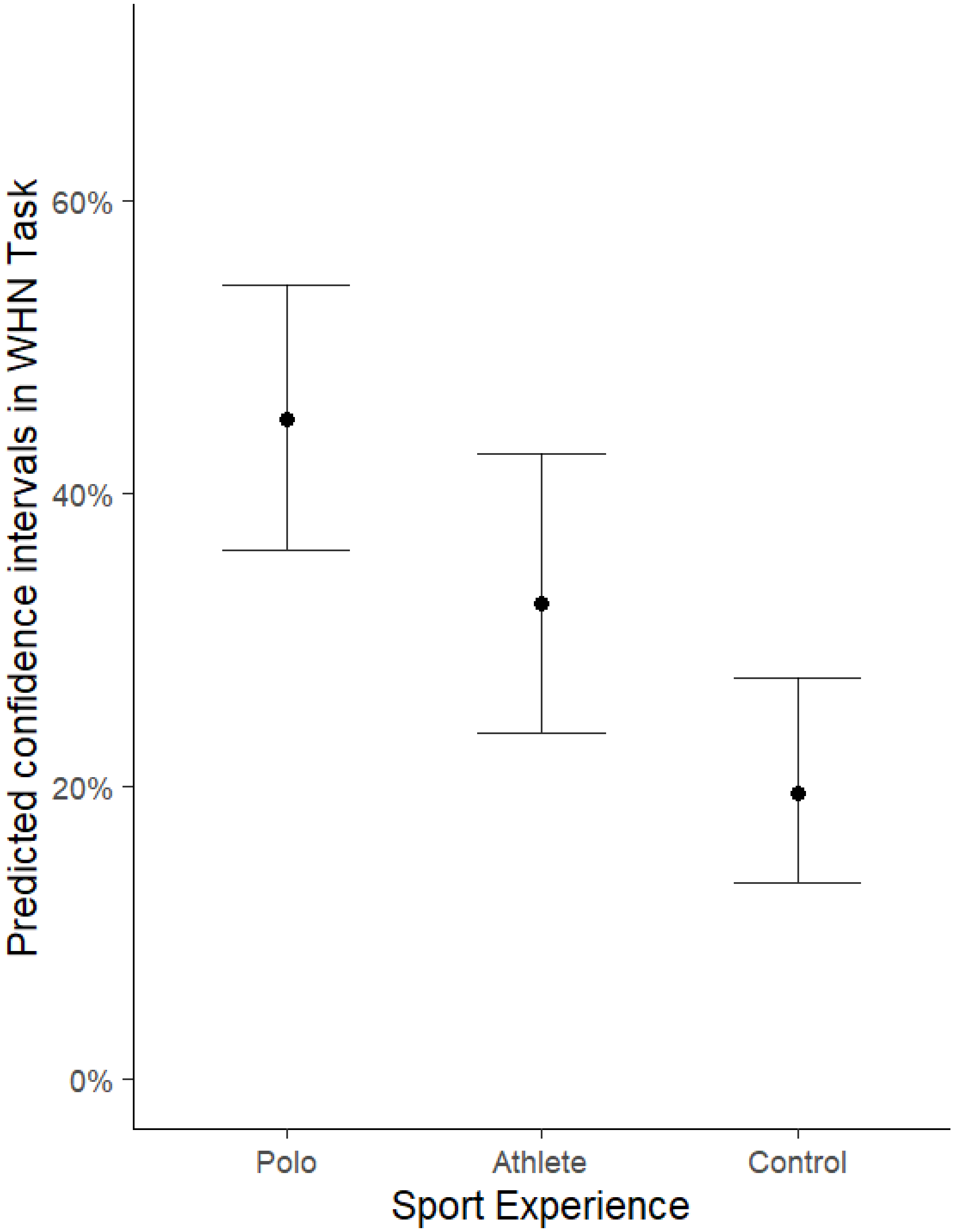

Figure 4.9 *Predicted (95%) confidence intervals of WHN accuracy by sport experience.*

Note. N = 39.

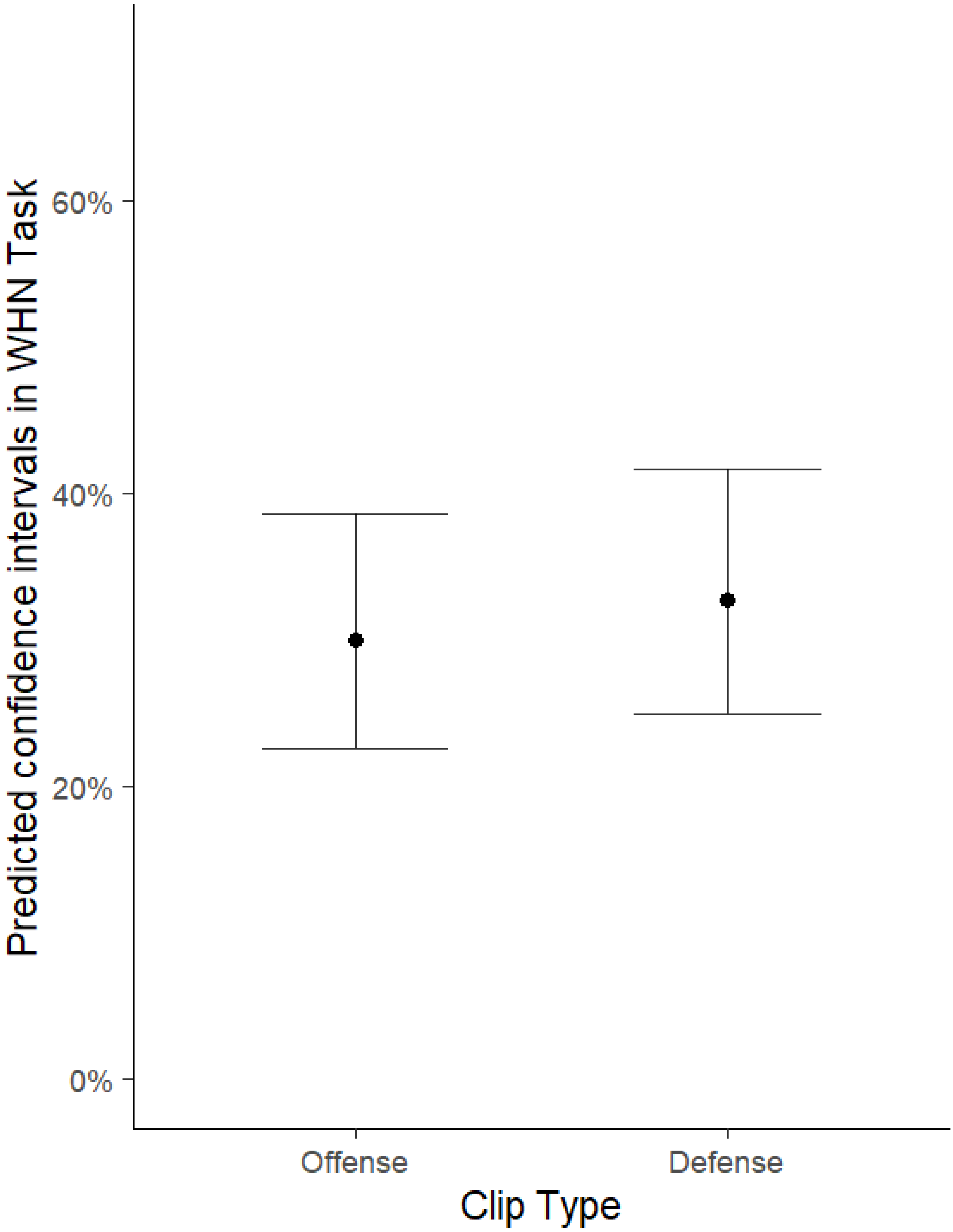

Figure 4.10 *Predicted (95%) confidence intervals of WHN accuracy by clip type.*

Note. N = 39.

Table 4.13 *List of main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	848.57	-	-	-
ME1	Sport Experience	ME1 / Null	834.44	18.12	2	< 0.001
ME2	Sport Experience + Clip Type	ME2 / ME1	836.36	0.07	1	0.78

Note. N = 39.

4.2.3.2 Interaction effects.

Table 4.14 presents the list of interaction effects model comparisons. Results showed the two-way interaction model (sport experience x clip type) best fit the data (χ^2 (2) = 15.05, $p < 0.001$). Paired comparisons with Tukey corrections revealed that for offensive clips, polo players (*M* = 50.35, *SD* = 50.18) were more accurate than athletes (*M* = 20.93, *SD* = 40.92; $p < 0.001$) and controls (*M* = 21.55, *SD* = 41.30; $p < 0.001$). There were no differences between athletes and controls ($p = 0.99$). For defensive clips, there were no differences between polo players (*M* = 40.00, *SD* = 49.17) and athletes (*M* = 44.83, *SD* = 50.02; $p = 0.79$). Polo players were more accurate than controls (*M* = 20.69, *SD* = 40.68; $p = 0.01$). Athletes were more accurate than controls ($p < 0.01$).

Within each sporting group, results showed that polo players did not differ in accuracy between offensive clips and defensive clips ($p = 0.16$). Athletes were more accurate in defensive clips compared to offensive clips ($p < 0.01$). Controls did not differ in accuracy between offensive clips and defensive clips ($p = 0.94$). Figure 4.11 shows the predicted (95%) confidence intervals of sport experience by clip type.

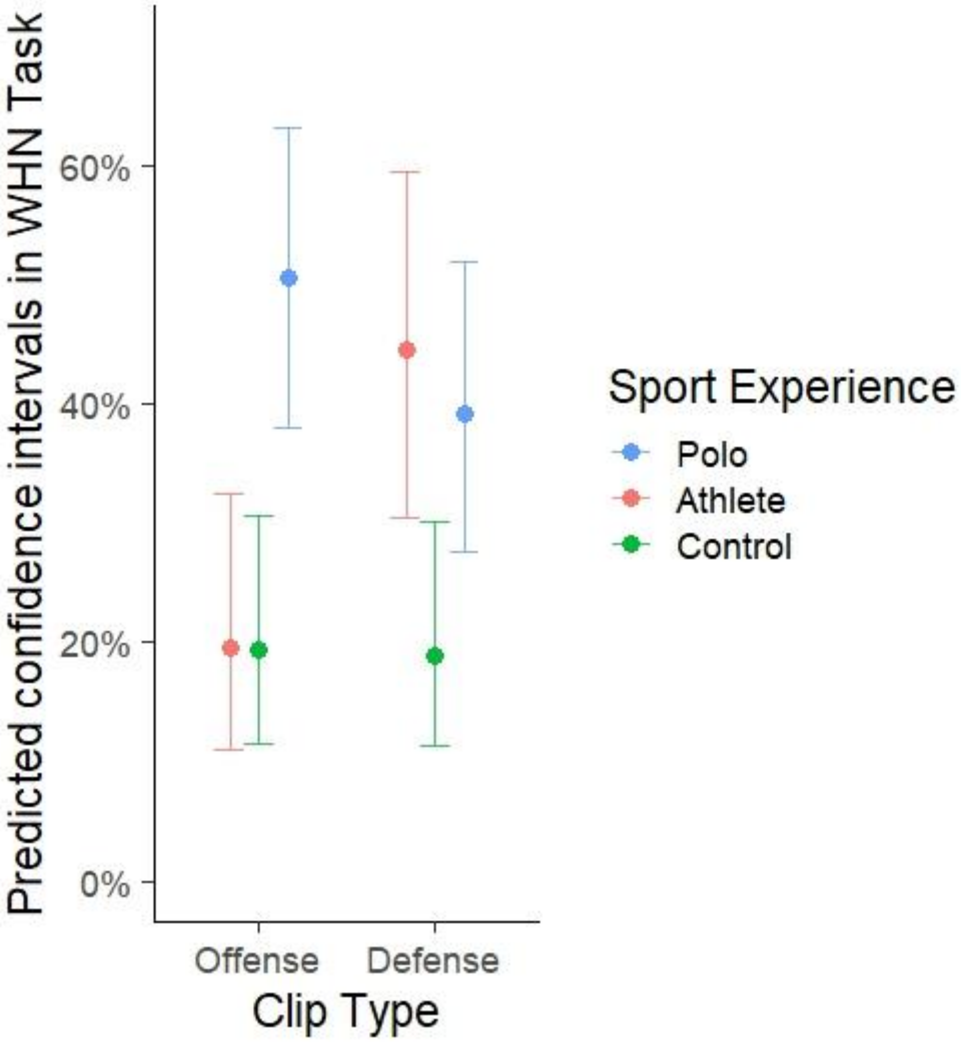

Figure 4.11 *Predicted (95%) confidence intervals of sport experience in the WHN task by clip type.*

Note. N = 39.

Table 4.14 *List of interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	848.57	-	-	-
ME1	Sport Experience	ME1 / Null	834.44	18.12	2	< 0.001
ME2	Sport Experience + Clip Type	ME2 / ME1	836.36	0.07	1	0.78
INT1	Sport Experience x Clip Type	INT1/ME2	825.31	15.05	2	< 0.001

Note. N = 39.

4.2.4 Discussion.

The first aim of the study was to experimentally test the offensive expectation bias hypothesis presented in the previous study by priming the type of clip (or situation). It was hypothesised that for polo players, priming for the type of clip would eliminate the discrepancy between offensive and defensive situation accuracy scores, thus suggesting that the previous study's polo players did indeed have an expectation bias, and were not just simply poor at predicting defensive situations. There was evidence to support this hypothesis, with polo players having similar WHN accuracies in the offensive and defensive clips. It was also hypothesised that with the priming, the polo players would show an experience effect over the athletes and control participants. There was also evidence to partially support this hypothesis. Whilst there was a main effect of sport experience on WHN performance, it was only seen when comparing polo players to controls. However, there was also an interaction effect noted which was not originally hypothesised. Polo players were undoubtedly better than the control participants in both offensive and defensive situations, and they were more accurate than the athletes in the offensive situations. The polo players performed similarly to the athletes in the defensive situations. Importantly, the polo players did not perform worse than chance in the defensive conditions as in the previous study. The second aim of the study was to investigate the role of sports structure on prediction skills transfer with team sport athletes. It was hypothesised that team sport athletes would show some level of transfer in the polo WHN task and would therefore be more accurate than control participants. As stated, there were no main effects showing athletes to be overall more accurate than control participants, however, there was, again, an interaction effect. Athletes were more accurate than controls in the defensive condition but performed similarly to controls in the offensive condition. This is in contrast to the results of the previous study which showed no transfer effect between general athletes. The following sections will discuss the results, the theoretical rationale, and the implications of the study.

4.2.4.1 Priming may eliminate expectation biases in experienced athletes.

The first aim was to experimentally test the offensive expectation bias hypothesis presented in the previous study by priming participants about the type of clip (or situation) they were about to view. As a reminder, in the previous study, polo players were shown to be more likely to choose an offensive answer choice from a mixture of offensive and defensive choices, regardless of whether the play showed an offensive or defensive play. Those results suggested that the polo players had an offensive expectation bias and offensive-minded strategy for viewing and answering the WHN probes. This study designed an experiment to test that offensive expectation bias theory and gain evidence that the polo players weren't simply bad in the defensive situations, they were merely viewing the clips with an incorrect frame of mind. To test this theory, the same WHN clips were used as in the previous study, but participants were informed whether the clips were offensive or defensive, and the answer choices were either all offensive or all defensive—there was no mixture of the two. If the polo players were less accurate in the defensive situations with the priming, there would be evidence to suggest that polo players were simply bad at predicting defensive plays. However, if—with priming—the polo players' accuracies were similar in the defensive situations compared to the offensive situations, there would be evidence that polo players actually succumbed to an offensive expectation bias in the previous study. The results of the current study showed that with priming, there were no significant differences between the offensive and defensive situations, thus supporting the theory that the polo players had an offensive expectation bias in the previous study that was rectified in the current study. Simply put, polo players are just as accurate in both the offensive and defensive conditions, provided they are viewing each situation with a correct mental model or frame of reference.

By providing the participants with situational and contextual information (*i.e.,* priming), the polo players were able to have a clearer picture and mental model of the play situation, and thus were more accurate in their predictions. This has been evidenced in the literature, with athletes who were given additional advanced information in the forms of opponent action preferences (McRobert et al., 2011) or probabilities of shot direction (Navia et al., 2013) performed better than those without that information. This is likely because the athletes were able to create a more accurate mental model with more information, and thus, they were able to use that mental model aid in their anticipation abilities (Farrow & Reid, 2012). Of course, during a real-life game, athletes are generally not given more advanced information on top of the information they have already gathered, such as postural cues (Smeeton & Huys, 2011), kinematic changes (Cañal-Bruland et al., 2011), and even body language (Bijlstra et al., 2020), however, they will undoubtedly know whether they are on offense or defence based on which team is in possession of the ball and their location on the field. Thus, providing the simple information of whether the play in the video clip is offensive or defensive would not be providing more information than would be gathered during a real game, and the results of the study could be taken at face-value without the assumption that the anticipation abilities were artificially raised due to extraneous information.

In future studies, another way to address any offensive or defensive expectation biases would be to instead inform participants which team they are 'on' (*e.g.,* "Pretend you are playing for the Red team"). This may provide a more ecologically sound approach as it more closely resembles a realistic game setting, and offensive or defensive plays may be clearer to participants. By knowing which team to view as their own, participants may also be able to emerge themselves better in the situation and gain a better understanding of their overall surroundings. Experimentally testing situational context using this method in sports WHN and SA tasks is thus, warranted.

4.2.4.2 Team sport experience may allow for transfer of cognitive skills between sports of similar structures.

The second aim of the study was to investigate the structure of sports on the transfer of prediction skills in a WHN task. Athletes, who all participated in team open-style, invasion sports with similar play structures to polo (Dale, 2015) served as the current study's athlete cohort. There was evidence of some transfer of prediction ability that was not seen in the previous study. The athletes were overall more accurate than the control participants, which suggests that team sports athletes (as opposed to the general athletes inclusive of team and individual sports of the previous study) were able to transfer some of their prior sports knowledge to the current task, despite it being in a sport they were unfamiliar with. It was believed that the experience gained from participating in sports with similar structures would aid in a polo WHN task because the athletes would be able to draw upon their prior sports experience and match novel situations (*i.e.,* those seen in polo, an unfamiliar sport) to similar situations that they have encountered before (Abernethy et al., 2005; Berry et al., 2008; Smeeton et al., 2004). This has been seen in the sports literature, where athletes of different sports are able to transfer cognitive skills developed through experience in their chosen sport to other sports, thus out-performing non-athletes in perceptual-cognitive tasks (Abernethy et al., 2005; Allard & Starkes, 1992; Smeeton et al., 2004). It has been noted by Berry et al. (2008) that athletes who engaged in more invasion sports compared to non-invasion sports were better decision-makers in Australian football. Additionally, because sports of a comparable style share similar perception and decision-making requirements, experience in different invasion sports benefits the development of those cognitive skills (Berry et al., 2008). Thus, it can be suggested that the team sport athletes in the current study had developed prediction abilities through prior sports experience. This was not seen in the previous study, and an explanation for the transferability of cognitive skills in the current study may in fact come down to the cohort of athletes sampled. The current study only sampled athletes who played a team, strategic sport—all other athletes were excluded. Presumably, the team athletes had experience in reading plays and teammate/opponent movements, as well as tracking ball trajectories, which may have given them an advantage over the athlete cohort in the previous study that included athletes of team and individual sports. In the literature, athletes who demonstrated cognitive skills transfer were those who played sports with similar flows and styles of play (*i.e.,* soccer, basketball, ice hockey, field hockey) (Abernethy et al., 2005; Berry et al., 2008; Côté et al., 2007; Smeeton et al., 2004), therefore, targeting athletes who participate in sports somewhat similar to polo may have been a reason for this transfer of skills.

Interestingly, the athletes were only just as accurate as the polo players in the defensive condition, but not the offensive condition, suggesting that the athletes may not have been as proficient in their offensive play-making abilities when transferring to an unfamiliar sport.

Because this transferability appeared to only benefit the athletes during the defensive condition, it is possible that the athletes may have been going off of rudimentary sports tactics (*i.e.,* in defensive plays, the ball must be intercepted or stopped, and in offensive plays, the ball must be moved forward) and not advanced play-making strategies. Therefore, the defensive polo conditions, which gave answer choices such as 'the ball is intercepted…,' or 'Player X hooks Player Y…,' may have appealed to the athletes more than the offensive conditions, which gave answer choices such as 'Player X passes to Player Y on the outside…,' or 'Player X carries the ball to the right…', because of their, for lack of a better word, vagueness. Athletes possibly knew that in a defensive condition, a defensive manoeuvre must be made, and thus they were more accurate because the answer choices were worded in a more general manner than the offensive answer choices which became very specific and may have created confusion. (For example: 'I know that Player X needs to pass the ball, but does he pass to Player Y on the inside of Player Z or outside of Player Z?'). Thus, in future studies investigating the transfer of prediction skills from different sports, the wording of the answer choices or tasks should be carefully evaluated to ensure equal complexity so that one type of answer choice isn't easier or more obvious to work out than the others.

4.2.5 Conclusion.

The aims of the current study were 1) to experimentally test the offensive expectation bias hypothesis presented in the previous study by priming participants about the type of clip (or situation) they were about to view, and 2) to investigate the role of sports structure on prediction skills transfer with team sport athletes. The results showed that with priming, polo players had similar accuracy scores in both the offensive and defensive conditions, suggesting that the polo players in the previous study were actually experiencing an offensive expectation bias and were not, in fact, just poor performers in defensive situations. The results also suggest that priming for situational context may be beneficial for overcoming expectation biases as it may allow experienced participants to gain a better understanding of the situation and use more accurate mental models. A main effect was seen where polo players were overall more accurate than control participants, as was expected, but they were not more accurate than athletes. Similarly, there was no main effect showing athletes to be better than controls. However, an interaction effect showed that in the defensive condition, athletes were superior to their control counterparts. Thus, there is partial evidence of a transfer of prediction abilities in team sports athletes, with the athletes performing better than control participants. This suggests that transfer of sports cognitive skills, such as prediction, may occur when the sports are of similar structures. Overall, this study also provides evidence some, albeit weak, evidence that the WHN paradigm can discriminate experience, provided that the video clips are accompanied by relevant situational context through priming. The WHN paradigm then will be used to assess the effectiveness of different SA training techniques in the following chapter (Chapter 5: Study 3).

4.3 Phase II General Discussion

The two studies presented in this chapter were aimed at investigating the usefulness of the What Happens Next? (WHN) paradigm as an inference measure of sports Situation Awareness (SA) performance, exploring the offensive expectation bias in polo players hypothesis through priming for situational context, and investigating the role of sports structure on the transfer of prediction abilities of athletes to a novel sport. Overall, the results of the two studies showed weak evidence of the ability of the WHN task to discriminate experience. The first study showed no main effects of sport experience on WHN performance; however, the second study demonstrated an experience effect where polo players were overall more accurate than control participants, but not athletes. These results, particularly when referring to the second study, demonstrated that the WHN paradigm may be sensitive enough to target the prediction abilities associated with sports SA performance, providing enough contextual information is supplied prior to viewing the WHN clips. This suggests that the WHN paradigm may be related to SA because it specifically targets an individual's prediction abilities, which is generally considered to be the highest level of SA (Level III Projection) in the three-level framework (Endsley, 1995b). Interestingly, the results initially showed that polo players were only better during offensive situations, and were, based on their scores, significantly worse in defensive situations. Taken at face-value, this would suggest that polo players were simply bad at reading and predicting the outcomes of defensive situations. However, separate analyses showed evidence of an offensive expectation bias where polo players likely viewed the clips with an offensive frame of reference, regardless of what the actual clip was showing. Therefore, it was hypothesised that this offensive expectation bias hindered the polo players' performance, rather than the polo players simply performing poorly in defensive situations.

To explore this hypothesis, an experiment was devised so that participants were primed as to the type of clip they were about to view. The results showed that, with priming, the discrepancy between the polo players' offensive and defensive accuracy scores was removed, thus providing evidence that there was indeed an offensive expectation bias that was mitigated with priming. Additionally, the results showed that sports structure may play a role in the transfer of prediction abilities to a novel sport. General athletes who participated in a variety of individual and team, invasion and non-invasion sports showed no evidence of transfer during a WHN task, but athletes who only participated in team, invasion sports with similar structures to polo demonstrated some level of transfer. This indicated that the team sport athletes may have been able to draw upon their previous sports experience by matching novel polo situations to mental models made of their familiar sport.

The results of the two studies, which showed an experience effect where polo players performed better, particularly with the priming, are supported by a body of WHN literature which has been pulled from transportation studies, with the general consensus being that the WHN paradigm is discriminatory towards driving experience and is indicative of overall Hazard Perception and Hazard Prediction abilities (Jackson et al., 2009; Kroll et al., 2020; Wetton et al., 2013), and thus SA on the road (Horswill & McKenna, 2004). In medicine, the WHN paradigm was shown to discriminate trauma experience, whilst simple knowledge-based questions had no such discrimination (Mackenzie et al., 2023), suggesting that the WHN paradigm is an appropriate tool for assessing SA outside of the traditional transportation studies. Importantly, this paradigm, which encompasses cognitive skills such as visual search, anticipation, and subsequent decision-making—important for SA (Hadlow et al., 2018)—has not yet been employed in the sports literature by name. There have been studies which use a similar approach towards assessing perception and decision-making in athletes (Berry et al., 2008), but the name, 'What Happens Next?' was not used, thus making it difficult to search for using that term. In Chapter 1, it was discussed that there is a lack of quantifiable links between SA, experience, and performance in the sports SA and perceptual-cognitive field, which is an area that should be addressed in the future. One way to potentially address this problem is to explicitly use the three-level SA framework (Endsley) and employ direct methods of assessing SA, such as the WHN paradigm, and refer to them directly by name.

Therefore, it is notably difficult to discuss the results of the current chapter's WHN studies in comparison to the existing body of sports cognitive skills literature. While a majority of sports anticipation studies rely on occlusion paradigms where visual information is removed (Jackson et al., 2006), similar to the occlusion in the WHN paradigm, these studies often focus on specific movements such as ball flight information (Savelsbergh et al., 2002; Smeeton & Huys, 2011), body movements (Wright et al., 2011), or deceptive manoeuvres (Jackson et al., 2006; Mori & Shimada, 2013), and not the outcome of a play which could have many options and include multiple actors (teammates and opponents). The WHN task does not focus on one type of outcome but instead forces participants to choose from a variety of different outcomes relating to different movements, actors, and teams as a whole. This makes the WHN task more difficult—as it requires participants to examine and anticipate the big-picture as opposed to a specific area—but it also provides valuable information that is more similar to how sports are played in situ. In other words, an athlete would not just be anticipating the ball flight, but also their teammates' and opponents' movements simultaneously; they would then use that information to create a course of action for their best performance option. The WHN task allows for a more accurate representation of anticipation skills, and thus a better assessment of an individual's SA in sports compared to studies that isolate different cognitive skills.

Perhaps a better comparison of studies would be the SAGAT and WHN tasks employed in the transportation field. The results of Study 2.2 showed that polo players were more accurate than the control group, which is supported by the driving and transportation literature that shows experienced drivers perform better than novice drivers in WHN tasks (Crundall, 2016; Kroll et al., 2020; Ventsislavova et al., 2016). For instance, Crundall (2016) showed that during a driving WHN task, occluded clips successfully discriminated experience, with experienced drivers recording higher accuracies than novices. Similarly, Ventsislavova et al. (2016) reported that experienced drivers had better SA (through higher accuracies) when completing a WHN Hazard Perception and Hazard Prediction test. Recently, Kroll et al. (2020) showed that emergency response drivers (ERD's) were more accurate in multiple-choice questions targeting hazard prediction than the control drivers, despite both groups having considerable driving experience. Likewise in medicine, the use of the WHN paradigm was shown to discriminate experience, with more experienced trauma personnel reporting higher accuracies and better decision-making than less experienced personnel (Mackenzie et al., 2023). Thus, the results of the two studies and the previous literature suggest that experience in a domain allows for better anticipation abilities, perhaps due to detailed mental models developed over time within a domain (Walker et al., 2009). Therefore, the polo players in these two studies may have relied on domain-specific memory (Eccles, 2020) which allowed for the creation and recall of mental models, or a mental representation used to predict outcomes in different situations (Collins & Gentner, 1987), created through their experiences on the polo field to answer the WHN questions.

The second aim of the studies in this chapter was to experimentally explore the offensive expectation bias seen in Study 2.1, where there was a significant discrepancy between the polo players' offensive and defensive scores. There was evidence that showed that polo players were more likely to choose an offensive-related answer choice from a mixture of offensive and defensive choices, thus suggesting that the polo players in Study 2.1 had an offensive expectation bias where they viewed the clips with an offensive frame of mind. In Study 2.2, an experiment was developed to test this offensive expectation bias theory by priming the participants for the type of clip they would view. With priming, there was no statistical difference between the polo players' offensive and defensive accuracy scores, suggesting that the polo players of Study 2.1 indeed did have an offensive expectation bias, which was removed through priming. It can be suggested that priming provided important information about the play, and polo players were able to interpret that information in an accurate manner which may have allowed them to create a clearer mental model of the situation.

These priming effects have been noted in the sporting literature, with studies showing higher prediction abilities when given information about opponents' action preferences (McRobert et al., 2011) or probabilities of shot direction (Navia et al., 2013). However, these studies generally look at one specific movement, such as a cricket bat soccer penalty kick, respectively, whereas priming for a broad type of play (offensive or defensive) can be applied to a more holistic setting that encompasses multiple play situations. For instance, an 'offensive' play could include anything from shooting the ball, passing to a teammate, scoring a goal, or simply maintaining possession; a 'defensive' play could include hooking, bumping, intercepting, or preventing the progression of a play in any way. Therefore, there are several types of plays the participants in the two studies would have to predict, thus making the WHN paradigm closer to how open, invasion team sports are actually played, and could therefore give a better indication of overall SA abilities.

A final aim of the two studies in this chapter was to investigate the transfer of prediction abilities of athletes of different sports. Both general athletes (consisting of team and individual sports participants) and team-sport only athletes took part in the WHN task. The results showed that general athletes were no better than control participants in Study 2.1, suggesting that there was no transfer of prediction abilities to a polo task. A potential explanation for this is that the athletes, having only sport-specific memory and mental models (Eccles, 2020; Kalén et al., 2021), were under a higher cognitive load form the newness of the task, and were therefore unable to devote cognitive resources towards SA and prediction (Sweller & Chandler, 1991). However, in Study 2.2, the team-sport athletes did show an experience effect over the control participants in the defensive condition, which suggests there was some level of transfer taking place. This has been shown in the literature, where athletes were more accurate in pattern-recall and recognition tasks of unfamiliar sports with similar structures (Oppici & Panchuk, 2022; Smeeton et al., 2004). For instance, Smeeton et al. (2004) showed that soccer and field hockey players could recognise action sequences of the non-dominant sport but struggled to recognise volleyball sequences due to its dissimilarity in structure. Berry et al. (2008) demonstrated that even in elite Australian Football League players, perception and decision-making abilities were influenced by the participation in different types of invasion sports; better decision-makers were shown to play more (different) invasion sports. The authors, therefore, suggested that transfer of perception and decision-making abilities in sports may be due to the exposure of more situations which helps to build perceptual-cognitive skills (Berry et al., 2008). Additionally, Causer & Ford (2014) demonstrated that decision-making abilities transferred between sports of similar structures, such as in hockey, soccer, basketball, and rugby, but did not transfer between sports of dissimilar structures, such as with tennis or golf. Equestrian polo has many similarities with other team, invasion, open-style sports such as hockey, soccer, and basketball (Dale, 2015), so perhaps the team-sport athletes were able to pick up and interpret the action sequences of polo using their prior experience in similarly structured sports. Importantly, though, the transfer effect by team sport athletes was only seen in the defensive condition, suggesting that even athletes with team open-style invasion sport experience were not able to transfer offensive play-making prediction abilities from their familiar sport to a non-familiar (polo) sport. That the athletes were just as accurate as the polo players in the defensive condition is an interesting result, suggesting perhaps that they were able to recognise and predict defensive plays better than offensive ones. This could perhaps be because the athletes relied on basic defensive strategies, such as stopping the ball or interfering with the ball handler, but the basic offensive strategies, such as passing to a teammate, were more complexly worded in the answer choices, and referred to multiple variations of passing to a teammate (*i.e.,* “Player X passes to Player Y on the inside of Player Z”), which may have been more confusing than simply, “Player X hooks Player Y”. Future studies should examine the complexity of the answer choices to ensure both offensive and defensive choices are worded similarly. Another potential explanation for the Study 2.2 athletes only performing better that controls in the defensive condition may lie in the cohort’s demographics. Of the literature examining cognitive skills transfer between sports, the athletes demonstrating transfer effects have been experienced/elite/near-elite performers (Abernethy et al.., 2005; Berry et al., 2008; Smeeton et al., 2004), whilst the athletes sampled in the current studies have been relatively inexperienced, amateur-level athletes. Therefore, it is possible that the athletes in the current studies may not have developed as detailed a mental model as the athletes in the literature, thus, they were not as proficient at employing their mental models to aid in anticipating outcomes of novel situations. Future research should endeavour to sample varying levels of experience within athlete cohorts to investigate the role of experience on sports cognitive skills transfer.

Lastly, whilst not an explicit aim of the two studies, the development and creation of a sports WHN task was given extensive consideration, particularly with identifying the precursors and freeze-frame points for each clip. As discussed by Ventsislavova et al. (2018) and Kroll et al. (2020), the selection of clips, hazards (offensive or defensive events in the studies presented in the thesis), and occlusion/freeze-frame points are imperative for the success of the task. Additionally, creating MCQ distractors that are plausible but do not have the necessary precursors to indicate they would happen. The two studies in this thesis took a professionally filmed, televised high-goal (22-goal) game and separated the footage into shorter clips, each clip showcasing a naturally occurring and common polo play, with half the clips showing an offensive play (*i.e.,* passing to a teammate, running with the ball, shooting towards the goal) or defensive play (*i.e.,* intercepting the ball, hooking an opponent's mallet, bumping an opponent off the ball). The freeze-frame point for each polo clip was determined by firstly identifying the event, and secondly by setting the freeze-frame point prior to the event, when enough visual information was available to indicate what would happen next. Experienced polo and sports researchers analysed the precursors available at the cut-off points to ensure the visual cues would properly allude to the event. Importantly, the events selected were fully developed, meaning the event (such as passing to a teammate or intercepting the ball) was actually completed; events that could have happened, but did not, were not chosen for the WHN clips, in accordance with transportation WHN studies (Ventsislavova et al., 2018). Using events that might have happened, but did not, in sports WHN tasks is an area for potential study and is discussed in the section below. The polo clips used in these studies (see Appendices 7.3, 7.4, 7.7, and 7.8) provided the first iteration of a WHN task used in a sport setting. These clips, similar to the transportation WHN and Hazard Perception clips, will undoubtedly undergo further refinement over time, hopefully to provide participants and researchers with diverse play situations to better understand the SA in polo players at all levels.

The studies presented in this thesis developed a polo-specific WHN task to investigate sports experience and its role in SA. From a practical perspective, this test could be used to identify player strengths and weaknesses in anticipatory skills, coach players on reading and understanding different types of play situations, and perhaps improve player performance on the field. Additionally, a WHN task could be used to certify players, coaches, and umpires. Currently, players may be asked to complete a rules test to become an official player or compete in certain tournaments, such as the Intercollegiate/Interscholastic (I/I) program in the United States (USPA, 2024a). Likewise, umpires must take an annual outdoor or arena rules test to achieve and maintain certification (USPA, 2024b), and coaches undergo a training and evaluation process to become a Certified Polo Instructor (CPI) (USPA, 2016) in the United States or an HPA-Accredited Coach in the UK (HPA, 2024). Thus, it is possible that a WHN test could be incorporated into a certification process for polo participants. However, this test at its current stage is strictly theoretical; it should be tested against performance on the polo field to fully assess its usefulness. It is too early to make any claims about this method from a practical sense without rigorously testing it. As it stands, the WHN task in polo simply provides the basis or foundation for further polo SA research.

4.3.1 Limitations.

The studies in this chapter have limitations that should be addressed. Firstly, the low accuracy percentages across all groups indicated that the task may have been too difficult, even for the polo players. It is perhaps reasonable to assume that the clips were paused too soon, and thus, participants were unable to gather enough visual information with which to anticipate the final outcome. A temporal occlusion paradigm (in which a video is occluded at different time frames) is commonly used in sports research to determine the time window in which expert athletes display a clear advantage over novices in anticipation tasks (*e.g.,* predicting the direction of a tennis serve) (Suss & Ward, 2013). While many sports studies, through a progressive temporal occlusion paradigm, have shown expert athletes are better than novices at picking up more information in a shorter amount of time (Farrow et al., 2005), there is an occlusion point where even experts are unable to gather sufficient information. This occlusion point also can differ between sports, with different sports or situations (tennis serve compared to penalty kick) having different optimum windows of occlusion (Baker et al., 2009; Rowe et al., 2009).

For instance, Rowe et al. (2009) investigated expert and novice tennis players' anticipation accuracy when predicting shot direction. The video footage of a tennis player volleying the ball was occluded at 120ms, 80ms, 40ms before the racquet-ball contact, at the contact, and 40ms after the contact. The results showed a ceiling effect for the occlusion point 40ms after the contact and was thus disregarded. Experts performed above chance at all occlusion points and showed a significant increase in accuracy between -80 and -40ms, while novices only showed a significant improvement after the -40ms occlusion point (Rowe et al., 2009). Another study by Baker et al. (2009) examined the anticipation accuracy in expert and novice field hockey goalkeepers when defending a shot. The video of a field hockey shooter was occluded at 360ms before ball release, 240ms before release, 120ms before release, at the point of release, and 120ms after release. The results showed that expert goalkeepers significantly improved in accuracy at 120ms before release (continuing on through the later occlusion points). The experts were relatively late in their information pick-up, suggesting that the occlusion points prior to 120ms before release did not offer enough relevant information to form a prediction (Baker et al., 2009). Even in driving WHN studies assessing Hazard Prediction in drivers, the point of occlusion was determined to be an important factor in accuracy. Crundall (2016) showed that earlier occlusion points (1250ms before the onset of a hazard) were detrimental to the accuracies in both novice and experienced drivers. It was suggested, therefore, that information immediately available prior to a hazard is crucial for prediction.

These studies did not have specific occlusion time points prior to or after ball contact, as has been seen in the sports literature. In the sports literature which utilises a progressive temporal occlusion paradigm, the 'event' being examined is most frequently a specific manoeuvre, such as a basketball free throw (Aglioti et al., 2008), a tennis serve (Rowe et al., 2008), or a soccer penalty kick (Causer et al., 2017). The current WHN studies, however, looked at general play situations rather than isolating a specific, isolated event, for example, a penalty shot. Instead, the current studies occluded the video prior to an offensive or defensive event occurring, regardless of the time of ball contact. Therefore, the occlusion point was set for each individual clip just prior to the offensive or defensive event, which resulted in the varying lengths in clips. However, these variances in clip lengths and accuracies were accounted for using the binary logistic mixed effects modelling. Importantly, this variation did lead to some clips being 'easier' than others, as determined by accuracy percentages. Additionally, there were also some clips that were 'harder' than others, potentially as a result of the variance in length. This difficulty may have been due to an inadequate enough time to scan the environment in some of the shorter clips, and thus, future studies may opt for slightly longer clips to give participants time to immerse themselves in the scene. Ultimately, it was decided that the clip lengths overall gave a good representation of polo plays and the speeds at which they happen, and the variances were accounted for statistically.

An important point to concede, though, is, as noted by Baker et al. (2009), occlusion points are determined *a priori* during the creation of the stimuli, and thus may fall prey to experimenter bias in which the experimenter(s) may occlude the video at less-than-optimal points based on having seen the clips so many times and knowing how it 'ends'. It is rather difficult to determine how much visual information is needed for a successful anticipation when the experimenter has seen the clip dozens of times and already knows the outcomes—thus they may occlude too soon and not leave enough information available to the participants. For future works, occluding the video clips even a few milliseconds later may prove to be beneficial to participants. Additionally, research has shown that piloting the WHN clips and occlusion points is an important aspect for methodological validity and rigour (Ventsislavova et al., 2022). While these clips were piloted informally, future research in this area should invest the time and resources towards piloting the WHN probes, including occlusion points and distractor answers.

A second limitation to this study is that the WHN methodology examines SA by asking, "What happens next?" which is valuable in areas such as driving (Jackson et al., 2009), because it is linked to avoiding hazards and safer driving (Horswill & McKenna, 2004). However, in sports, the performance measure is often not about avoiding hazards, but scoring goals and setting up and executing successful plays and strategies. Polo players, and other athletes, may identify plays with a higher probability of success (Williams et al., 2011), but obviously, those plays are not always successful for a number of reasons (*e.g.,* defence interference, poor execution of a hit, *etc.*) Therefore, successful players may not ask themselves, "What happens next?" but instead, "What *should* happen next?" when creating plays. It is possible that the overall lower scores associated with the two studies' cohorts may have indicated that participants were answering the WHN probes with what they though should happen next, regardless of the visual cues present. Currently, there is no direct causal link between what actually happened in the clips compared to what maybe *should* have happened. Asking, "What should happen next?" to sports practitioners may indeed give further insight into the processing mechanisms at play with anticipation and decision-making, and thus is an area for further research. Interestingly, Kroll et al. (2020) conducted a similar mechanism whereby they asked drivers to choose a course of action they would take to avoid a driving hazard; these answer choices were categorised as risk-averse and risky, and a driving instructor chose the correct choice. Experienced emergency response drivers were found to outperform their control counterparts in hazard prediction and observation. This suggests that such hypothetical probes (what *should* have happened/what *would* you do next?) may offer an interesting insight into decision-making and planning.

As an example of athletes predicting possible outcomes based on what they believe should happen, the Take-The-First heuristic (TTF) (Johnson & Raab, 2003) has been used to investigate how athletes generate options for a course of action under time pressure. The TTF heuristic is comparable to the Recognition Primed Decision (RDF) model (Hutton & Klein, 1999) that suggests experts make fewer, albeit better, decisions than novices. Johnson & Raab (2003) suggest that athletes develop responses to play situations based on their memory and patterns from prior experience. Critically, with each option generated, they are of increasingly lower quality—suggesting that the first option is generally the best option (Johnson & Raab, 2003). In one study, expert, near-expert, and non-expert handball players were presented with handball situations that were frozen at a crucial point where the participants had to decide what do next. The expert players chose higher quality options compared to the near-experts and non-experts (Raab & Johnson, 2007). Similarly, Belling et al. (2015) examined the anticipation and decision-making abilities in D1 NCAA (expert) soccer players and recreational (novice) soccer players. The expert players were more accurate in their anticipation skills and generated more task-relevant options compared to novices, suggesting that option generation is an important distinguishing factor between expertise groups. Therefore, future studies could amend the WHN task to include "What should happen next?" questions to target SA through option generation and decision-making. There is also the possibility that collective team thinking and SA might even be more important than asking, "what happens next?" or "what should happen next?" in the context of anticipation and decision-making in team sports. This area of further research is discussed in-depth in Chapter 6, Section 6.2.4 There's no 'I' in 'Team'—The suggestion for investigating Team Situation Awareness in sports with a novel SyncSA approach.

A third limitation is that it is possible that the time allocated for the participants to choose an answer may have been too long, and participants—in particular, polo players—could have fallen victim to second-guessing their initial answer choice and changed their answer incorrectly. This is also supported by the TTF heuristic which suggests that, with experts or more experienced athletes, the first decision-making option is generally the best, and as time goes on and experts develop more and more choices, the quality of those choices degrades (Johnson & Raab, 2003). Ideally, participants should already know the answer before the answer choices appear on the screen. Therefore, once the answer choices are presented, participants should just have to search for the answer choice which matched their initial prediction. These studies allocated twenty seconds (Study 2.1) and ten seconds (Study 2.2) for participants to read the answer choices and make their predictions. However, it is possible that participants were spending that time 'working backwards' and using the answer choices provided to make their prediction instead of using the information presented in the video to predict what happens next. Future studies should therefore limit the amount of time given to participants to choose their answer.

Lastly, the verbiage used in the MCQs answer choices and distractors may have been confusing to participants who were not overly familiar with polo terms. Answer choices were developed to contain as neutral language as possible, foregoing using specific shot types and instead implementing non-specific descriptions. For instance, whilst a clip may have shown a player taking a nearside backshot pass to a teammate, the answer choice would have simply stated that the player passes to a teammate (with the jersey colour and number to indicate which player). However, some polo terminology was incorporated when there was no general term to describe a manoeuvre. This was most commonly seen in the defensive clips, where answer choices included terms such as 'bump' or 'hook'. It can be argued that knowledge of these terms may have provided an advantage, however, both studies demonstrated that the control groups (control participants in Study 2.1 and athletes in Study 2.2) were just as or more proficient in the defensive condition, suggesting that the polo-specific terms were not a hindrance. Informal piloting with non-polo players was conducted during the creation of the WHN task, however, in the future it would be beneficial for more extensive piloting and beta testing to ensure parity across the terms used in the task.

4.4 Conclusion

The literature of sports SA is scarce for direct, objective methods for assessing SA in athletes, with no definitive links between SA and experience. This chapter therefore introduced the What Happens Next? (WHN) method to assess the role of sports experience on SA. Participants were scored based on their accuracy in predicting what would happen next following the occlusion of a polo play using both offensive and defensive situations. Overall, the results demonstrate a weak experience effect; polo players were only more accurate than control participants when provided additional situational context. However, it does show that the WHN probes were sensitive enough to target anticipation skills which are important for SA performance, thus validating the use of WHN methods for inferring SA in sporting environments. This is an important finding, as the WHN methods have been employed and validated in mainly transportation domains to measure Hazard Perception and Hazard Prediction abilities in drivers (Jackson et al., 2009; Kroll et al., 2020; Ventsislavova et al., 2019), while the SAGAT method (of which the WHN task was derived) has only been used once in a sporting context (Ng et al., 2013) to no effect. Additionally, the results showed that how stimuli are presented is important for overcoming any expectation biases as it allows participants (particularly those with prior expertise) to better match the current situation with previously created mental models from past experience. Lastly, the results showed some evidence of a transfer effect if athletes have engaged in similarly structured different sports. SA is an important component to sports (di Tore, 2015), however, there are relatively few studies which investigate the framework of SA within a sports context (Ng et al., 2013). The use of WHN methods can perhaps spearhead the movement towards objectively assessing SA in sports with the aim of improving performances in polo and sports in general. The following chapter (Chapter 5) will therefore investigate different types of SA training using the WHN paradigm.

Chapter 5 Phase III: The effectiveness of different visual search training interventions on 'What Happens Next?' (WHN) prediction accuracy and eye movement behaviours in a polo Situation Awareness task

This final experimental chapter aims to develop polo Situation Awareness training programmes using visual cueing and expert commentary training methods based on the Attention Guiding Principle. A second aim was to investigate the effect of training on eye movement behaviours, such as number of gaze fixations, fixation durations, and fixation dispersions, with the goal of training absolute beginners to search like an expert. The results show no evidence that the training programmes promoted higher-order cognitive skills improvement, nor did they promote extensive scene searching off the ball. This study demonstrates that more nuanced, prolonged, or scaffolded approaches to SA training may be required for complex tasks such as equestrian polo or sports in general.

5.1 Introduction.

The previous chapter introduced the What Happens Next? (WHN) paradigm as an objective inference measure of Situation Awareness (SA) in sports, at least within equestrian polo. The results of the experimental studies presented in the previous chapter showed that the WHN paradigm discriminated polo experience, with polo players outperforming control participants when supplemented with situational context, thus suggesting that the tool was sensitive enough to target higher-order sports cognitive skills, such as anticipation. Experience in polo likely allowed participants to better predict the outcome of polo plays, indicating that they had better SA in a holistic setting. Additionally, the studies presented in Chapter 3 showed that the Spot the Ball (STB) tool was also effective in discriminating experience—it showed that experience allowed polo players to better locate a missing ball, particularly in 'off-ball' situations where the photographed player's gaze was not directed at the ball but instead downfield. This ultimately suggests that sports SA may be developed across the entire playing field, with experience allowing for better SA in such situations.

While the previous studies of the thesis have demonstrated experience effects using methods such as the STB and WHN tools, an important question still remains: How can we improve, or train, SA in polo? Polo is, as has been discussed in Chapter 1, a highly dangerous sport, particularly for novice (or completely new) players. The combination of inherent equestrian risks, such as falling, with the high speed and physicality of the game (Best & Standing, 2019a; 2019d) and the complex rules dictating the flow of the game (Dale, 2015; Watson, 1989) makes polo a difficult sport to learn safely. As has been shown with new drivers who struggle to effectively search their surroundings because their attention is directed towards vehicle control (Mackenzie & Harris, 2017), there is a high cognitive load for new polo players who must—all at once—pilot a horse (a complex skill in and of itself), hit a moving target (the ball) whilst also moving, track up to seven other players, and remember the line-of-the-ball (LOB) and the right-of-way (ROW). With new players, particularly those brave enough to learn how to ride a horse *and* play polo concurrently, it is common to see an attentional narrowing where the player simply focuses on staying on the horse; all other aspects of the game are neglected, which is dangerous not only for the individual player but also the other players and ponies. Perhaps if a new player could learn the ins and outs of the game off the horse and develop SA in a safe environment, there may be a benefit towards training individuals with no prior experience. Studies have shown that prior experience in a domain benefits training effects, where those with more experience demonstrate a higher level of learning compared to those with little to no experience (Castro et al., 2016), but there is also a need to train absolute beginners. Everyone, no matter the discipline, starts with no experience, thus, there is a need to develop training programmes for those individuals, regardless of the research showing that training is more effective with prior experience. Abernethy et al. (1999) demonstrated that even participants with no prior experience in racquet sports could improve their anticipation of squash stroke direction and depth with specific perceptual training. The authors concluded that sport specific perceptual training may allow absolute beginners (no prior experience) to improve their anticipatory skills. So, whilst it would be perhaps more beneficial to develop a training programme aimed at novice polo players (with at least some prior experience), visuo-cognitive training targeting absolute beginners has shown some promise.

Historically, there have been studies investigating SA training methods in dynamic environments, such as aviation, maritime control, and transportation. There have also been studies that investigate different methods of training visual search and decision-making abilities, two skills associated with SA (Hadlow et al., 2018). Importantly, however, there are no studies pertaining to direct SA training in sports, possibly due to the paucity of general, empirical SA studies in sports. Thus, the overarching aim of this chapter is to explore the different methods of SA training in a population with no previous polo experience to investigate if, and how, polo SA can be trained in a novice population. Additionally, this chapter aims to investigate the role of training methods on different eye movement behaviours, such as number of fixations, fixation durations, and fixation dispersions, which can be used to infer specific attentional processing. Lastly, this chapter will attempt to collate the learnings of previous chapters by employing the WHN paradigm as a measurement of SA and by using the visual cues explored in the STB studies as SA training material.

5.1.1 Eye movements and their applications in sports.

Eye movements are important for collecting information about the environment, thus contributing to an individual's perception (Level I SA) (Barbieri & Rodrigues, 2020). Visual behaviours and eye movements have long been studied within a sports setting (Harris et al., 2022), as researchers and practitioners are often interested in how athletes—particularly elite athletes—use these behaviours to influence their performance under immense time constraints (McGuckian et al., 2018). In other words, researchers are interested in where elite athletes look during gameplay and specific situations, such as shot/penalty blocking, that allow them to perform at such a high level. Recently, however, sports researchers have also demonstrated an interest into why these behaviours are performed in the first place (Barbieri & Rodrigues, 2020). There is a chicken-and-egg situation with athletes' visual behaviours and performance: is the performance effective because of visual searches, or are visual searches guided largely from effective performances? This is the main crux of the eye movements research in sports, and therefore, the following sections will briefly describe different eye movement behaviours, such as gaze fixations and durations, that are important in sports and the current study. Importantly, the eye movements discussed within this chapter and thesis do not include ‘focussing’ visual behaviours such as Quiet Eye (QE), which are used by athletes to internally quiet their mind and focus on a target during a shot (Digmann et al., 2018; Gonzalez et al., 2017; Harris et al., 2017; Vickers, 2009; Vickers et al., 2017, 2019; Vine et al., 2011; Walters-Symons et al., 2018; Walters-Symons et al., 2017; Wood & Wilson, 2012). The eye movements examined in this chapter are the ‘searching’ behaviours such as gaze fixations and durations, plus the dispersions of fixations in the scene, which may offer insight into an individual’s perceptual skills and locus of attention (Grant & Spivey, 2003).

Eye movements, such as gaze fixations and durations, have been studied in a multitude of sports such as tennis (Murray & Hunfalvay, 2017), golf (Binsch et al., 2009), baseball (Kato & Fukuda, 2002), soccer (McGuckian et al., 2018, 2020; Savelsbergh et al., 2005), ice hockey (Hancock & Ste-Marie, 2013), basketball (van Maarseveen, Savelsbergh, et al., 2018), volleyball (Afonso et al., 2012; Jafarzadehpur et al., 2007), and even equestrian show jumping (Hall et al., 2014). Typically, these eye movement studies examine the differences in visual search behaviours between elite and novice athletes (Klostermann & Moeinirad, 2020), usually with the aim to show that elite athletes utilise a more efficient visual search through their individual eye movements, or that they focus on more relevant areas to derive as much visual information about a situation as possible. Elite or higher-skilled athletes are thought to optimise their visual behaviours to process information in a rapid manner to fit in the extreme time constraints of sports actions (Klostermann & Moeinirad, 2020). It has been found that elite athletes are more efficient with their search patterns (Savelsbergh et al., 2005; Williams & Ericsson, 2005) and use fewer fixations with longer durations (Murray & Hunfalvay, 2017) and exhibit more fixations on task-relevant locations (Klostermann & Moeinirad, 2020), suggested to reduce the processing time with fewer errors, thereby improving response accuracy (Mann et al., 2007). For instance, elite tennis players have been shown to employ visual searches with longer fixation durations on areas such as the shoulders and arms, whereas novices fixated more on the racquet and ball (Murray & Hunfalvay, 2017). In soccer, expert goalkeepers exhibited more efficient search strategies with fewer fixations and longer durations on relevant locations like the legs and ball, whereas novices had more fixations on irrelevant locations such as the hips, trunk, and upper body (Savelsbergh et al., 2002).

An important theme of this thesis has been the suggestion that experience in a sport also allows athletes to gain visual information from sources other than the ball; in other words, experienced athletes can take their eyes off the ball to search their surroundings, thus taking in more visual cues, such as player posturing (Navia et al., 2013; Smeeton & Huys, 2011), positioning (Goodspeed, 2006; Gredin et al., 2018; Levi & Jackson, 2018) and kinematics (Alder et al., 2014; McEllin et al., 2018; Müller et al., 2014), which allows them to anticipate future outcomes more accurately. It has been demonstrated that experienced athletes often do not rely on information stemming directly from the ball, yet they are still able to successfully hit or intercept the ball, suggesting that they gather visual information from sources off of the ball. Similarly, experienced athletes often do not track the ball for the entirety of the ball's flight, but instead incorporate saccades to locate and fixate on spots where the ball is about to land or bounce. For instance, Land & McLeod (2000) measured the eye movements of three cricketers with differing abilities (professional, Minor Counties amateur, and low-level club player). The cricketers' eye movements were recorded during sequences of bowls at various speeds (fast, medium, and slow) from an automatic bowling machine. The results showed that during fast-paced bowls, the cricketers did not track the ball throughout the entirety of the bowl; instead, they fixated on the ball at delivery for 100 – 150ms, then shifted their fixation to the spot where they anticipated the ball to land, then followed the ball off the bounce for another 200ms. Interestingly, the success rate of hitting the bowls was 100% for the professional player and Minor Counties amateur, suggesting that it is not necessary to fixate on the ball for the entirety of its flight to make a successfully hit (Land & McLeod, 2000). Expert baseball batters displayed longer fixations durations on the pitching arm compared to novices, and experts were better at utilising their periphery to track the ball (Kato & Fukuda, 2002), suggesting that the experienced batters could maintain covert attention on the ball. Even in non-sports tasks, such as a lab-based Multiple Object Tracking (MOT) or Multiple Object Avoidance (MOA) task, athletes were shown to exhibit better covert attention on the targets (Mackenzie et al., 2022), lending support to the suggestion that athletes can attend to objects without actually having to directly fixate on them.

Importantly, much of the eye tracking literature examines sports and situations where a ball is intercepted (*e.g.,* tennis serve, baseball pitch, cricket bowl, soccer penalty shot), and not necessarily situations where team plays must be created on an open field, such as in basketball, hockey, or soccer (non-penalty shots). Ryu et al. (2013) noted that the visual search behaviours of experienced and novice team-ball athletes during offensive and defensive plays are not as clear as those behaviours exhibited by different levels of athletes in intercepting tasks. Therefore, the authors developed an experiment which investigated the role of central and peripheral vision on basketball decision-making. Skilled and novice players watched a series of basketball plays which were either unrestricted (full-image, no occlusion), a moving window (central vision), or a moving mask (peripheral vision) and were asked to decide on whether the ball-handler should drive to the basket or pass the ball to a teammate. The skilled players were significantly more accurate in their decision-making in all three conditions, and during the full-image, they spent less time viewing the ball-handler than their novice counterparts (Ryu et al., 2013). Ultimately, this suggests that experienced athletes pick up visual information from sources off of the ball, whereas novices may rely more heavily on the ball/ball-handler for their information. This off-ball searching, as has been demonstrated by the experienced athletes in this thesis (polo players and soccer players), may be an important factor in gathering SA in strategic sports as it allows the athletes to gain a more holistic understanding of the playing field (more in-depth Level I SA).

Efficient and effective visual search behaviour has been argued to be important in sports, irrespective of the type of sport played. However, what is unclear is how athletes learn these behaviours, and if so, can they be trained in novices? Recently, there has been interest in developing training programmes targeted towards improving athletes' visual behaviours with the goal of improving sports performance (Khanal, 2015). There have been mixed results with sports visual training, with Clark et al. (2012) showing improvement in baseball batting averages through a series of training, but Abernethy & Wood (2001) suggesting that visual training does not promote improvement in racquet sports. Importantly, such discrepancy may be the result of the athletes' experience; the cohort sampled by Clark et al. (2012) consisted of experienced collegiate baseball players whilst the Abernethy & Wood (2001) cohort was comprised of individuals with no such prior experience in any racquet sport. This suggests that visual training in sports may be influenced by the athletes' experience level, with experienced athletes benefitting more from training. Additionally, there may also be a difference in training effectiveness from different types of training methods. Wimshurst et al. (2018) investigated the effectiveness of practical drills, online training, and Nintendo Wii training on the improvement of visual skills in cricket. The practical drills consisted of training to improve eye focus, speed, and eye-body coordination using a reaction ball, juggling, 'pencil push-ups' (moving a pencil closer and closer to the face until the vision goes double), focussing exercises (keeping a series of letters in focus), juggling whilst kicking a ball, numbers/letter tracing, Brock string (keeping the eyes focused on a ball at the end of a moving string), peripheral ball catching, punching small holes in several letter "O's", and a balancing catch. The online training consisted of tasks targeted towards eye movement speed, peripheral awareness, changing focus from near to far, moving object tracking, jumping fixations from point to point, and identifying hidden words in a stereogram. The Nintendo Wii training used games such as ‘Shooting Range’ ‘Archery’, ‘Skeet Shooting’ (shooting targets), ‘Find Mii’ (visual search based on characteristics), ‘Table Tennis’, ‘Pose Mii’ (moving avatar into floating bubbles), ‘Trampolining’ (make avatar jump up and down on a trampoline), ‘Rowing’ (rowing a boat using the controller), ‘Football Heading’ whilst on a balance board, ‘Table Tilt’ (moving balls into holes by tilting the controller), ‘Ski Slalom’ (shifting weight on a slalom course), and ‘Bubble Balance’ (shifting weight and controller to move down a river). The control group performed basic fielding drills which did not specifically target visual skills. The participants, after having completed the training exercises, were tested using visual skills tests and cricket-specific tests. The authors found that the experimental groups performed better at the visual skills and cricket skills tasks following the training protocols, whereas the control group did not perform any differently after training. Interestingly, there were no differences in performance between the training groups, despite a trend where the practical drills showed a greater improvement. Ultimately, the authors suggested that visual skills training may produce an improvement in sports skills due to a carryover of the visual skills in a sports setting (Wimshurst et al., 2018). Therefore, it could be reasonable to suggest that visual search behaviour training may be effective in improving sports SA.

5.1.2 Situation Awareness training in dynamic environments.

As shown above, visual search behaviours, which can be linked to Level I SA (perception) (McGuckian et al., 2020), are important for athletes’ performance, and there is evidence that training these behaviours may influence sports cognitive skills. Arguably then, training SA in athletes may also produce an improvement in such skills due to the connection between perception and overall SA (Endsley, 1995b). However, potentially due to an already scarce literature selection regarding SA in sports, there has been no empirical study investigating training SA in a sports setting. Therefore, the following section will briefly describe and discuss the current SA training literature and methodology from various domains with the aim of showcasing the efficacy of different SA training programmes.

The aviation sector is generally acknowledged as the birthplace of SA as we know it today (Endsley, 1995b), so it would also be reasonable that this domain would first investigate training SA. Endsley & Garland (2000) were perhaps the one of the first to describe the rationale and potential tenets for training SA in general aviation pilots (pilots not contracted with major airlines or the military). The authors noted that better, more experienced, pilots spent more time preparing before the flight and focused more on the comprehension and projection of situations. They argued that to train—or improve—SA in pilots, the industry must teach task management, basic operating procedures, vigilance, awareness, effects of weather, dealing with malfunctions, building accurate mental models, and critical thinking skills. While Endsley & Garland (2000) mapped out potential areas to improve the SA in pilots, it is important to note that they did not actually test their guidelines, and thus there was no empirical data to examine. Endsley & Robertson (2000) expanded on the guidelines of SA by theorising how both individuals and teams should be trained to improve their SA. To train team SA in the aviation maintenance sector (*e.g.,* aircraft maintenance technicians, line mechanics, leads, supervisors), a SA training course was administered by a major airline that covered maintenance resource management, perception and understanding of situations, verbalising information that goes into decision-making, feedback from the system, teamwork to establish shared goals and understanding, reducing distractions, and working through extraneous variables such as noise, lighting, and memory issues. The participants in the SA training course completed a questionnaire that measured the differences in attitudes following the course. Overall, participants rated each area of training as ‘very useful’ or ‘extremely useful’. It was also determined that in a follow-up questionnaire administered one month after the course, participants self-reported that they were making changes suggested in the training course. The authors concluded that SA training is important in improving decision-making and performances, which could reduce aviation accidents (Endsley & Robertson, 2000). However, this study relied solely on self-reports, and no actual performance data was collected, thus making it difficult to suggest that SA objectively improved or was successfully trained during the course. Similarly, Muehlethaler & Knecht (2016) developed a SA training design for general aviation pilots which combined theoretical information—SA theory, scanning behaviours, perception processes, and mental models—and practical exercises in a flight simulator. Eye trackers would be worn during simulation training to allow the researchers and flight instructor with real-time information about the pilots' scan paths and potential SA. However, this training protocol was also purely theoretical, with no empirical data provided.

Surprisingly, for many years, SA training was more conceptual, rather than practical, despite evidence of the importance of SA for safety and performance in dangerous, dynamic environments (Endsley, 1995b). It was also noted that there were few empirical studies investigating the effects of SA training (Burkolter et al., 2010). Thus, Burkolter et al. (2010) conducted a comparative study of three different methods of improving process control performances: 1. Emphasis Shift Training (EST), 2. EST plus SA training (EST/SA), and 3. Drill and Practice (D&P). EST focussed on training participants in attention management through multiple changes in the priority of task components, thus teaching performance strategies, schemas, and attention control. EST/SA training described the three levels of SA (perception, comprehension, projection) in conjunction with EST. The EST/SA training used a freeze-probe technique similar to Endsley's (1995a) Situation Awareness Global Assessment Technique (SAGAT) which showed a simulation that was frozen, and participants answered questions about the different levels of SA. D&P training involved participants practicing instruction manual drills which focussed on the system control and finding faults. Participants were trained in a five-hour long module then tested three times (immediately after training, two weeks after training, and six weeks after training). The participants in the EST/SA group were shown to be better at diagnosing novel system faults, while the D&P group was better at diagnosis on familiar system faults. However, the authors concluded that the EST and EST/SA training were not as effective as they predicted (Burkolter et al., 2010). The authors suggested that the SA approach (*i.e.,* using the SAGAT-like method) may have interfered with the EST, particularly in novices who struggled with a higher cognitive load when shifting from rule-based tasks to anticipating future outcomes. Additionally, the authors argued that the novices may not have yet developed the expertise necessary to successfully answer the SA questions. They therefore proposed that novices master the D&P to establish a familiarity of procedures and skills before then progressing to more advanced SA training (Burkolter et al., 2010). Notably, this study demonstrates the importance of experience in SA training, ultimately suggesting that some level of prior knowledge may be necessary to benefit from higher-order cognitive training.

An interesting method for training SA came about in the form of gamification, or making a game out of learning a new skill. Chauvin et al. (2009) used decision-making games to improve the SA of trainee ship-handling watch officers. The participants were given a description and simulation of an ambiguous situation and were required to come up with a decision about how to react to the situation. At the end of the decision-making exercise, there was a general discussion to help participants learn what was/was not done well, what could be done differently, and any important lessons. The authors noted that when listing potential decisions, trainees used a 'scrambled' mode of decision-making, while experts used a tactical mode in which they applied rules and an association of event features to create a suitable action. The participants then completed a multiple-choice test which examined the three levels of SA, the participant's rules interpretation, and the ultimate decision made. Overall, the decision-making game improved the trainees' analysis of complex situations. The authors suggested that decision-making games may facilitate schemata-building, but more than one session of the games were needed to fully train SA (Chauvin et al., 2009). Also employing a gamification-style training method, Lehtonen et al. (2017) used a computer game to examine the effectiveness of training children bicyclists' SA. A video was shown of a scene shot from the point of view (POV) of a child cyclist. The participants' task was to identify the hazards in the scene which earned them points. If a hazard was missed or identified too late, the game was paused, and feedback was given. After the completion of the game, participants completed a SA test which showed similar videos as the training game. During the test, the video was paused, occluded, and rectangles appeared on the screen. Participants were required to choose the rectangle which contained (or masked) a hazard. The results showed that the game reduced response times, but not the sensitivity to hazards. Therefore, the authors argued that because it did not improve sensitivity to hazards, it was not an effective method for training SA, particularly in children (Lehtonen et al., 2017). An important aspect to note about the Lehtonen et al. (2017) study is that the authors used the same task (choosing the correct rectangle that covered a hazard) in their training and assessments. Arguably, the assessment methods should be different than the training methods to avoid the unintentional training of the assessment method (*i.e.,* clicking on rectangles) and not the actual content (*i.e.,* SA).

Zeuwts et al. (2017) similarly investigated SA training for child bicyclists, but instead opted for classroom training over gamification. Participants attended two group classroom sessions where they were taught about Hazard Perception (HP)—SA on the road (Horswill & McKenna, 2004). During the training sessions, participants watched short video clips of a cyclist's POV and raised their hand when they saw a potential hazard. Feedback was given on the spot followed by a short discussion about what may happen, where the hazard occurred, and how the hazard was predicted. Following the training sessions, the participants completed a HP test where they watched similar cycling clips and pressed a button when they spotted a hazard. The participants were also outfitted with eye trackers to examine the gaze behaviours. The study showed that those in the training group detected more hazards and were faster than the control group. The training group, however, showed no improvement in visual search behaviours. The authors suggested that the classroom training interventions improved the cognitive processing and prediction abilities of children cyclists (Zeuwts et al., 2017), unlike the computer game training of Lehtonen et al. (2017).

As evidenced from above, the effectiveness of direct SA training in many environments is inconclusive, and the methodology is not exact. However, it is perhaps beneficial to not teach overall SA, but instead teach the individual levels of SA (perception, comprehension, projection). Starting with Level I (Perception), which forms the base of a person's overall SA (Endsley, 1995b), it may be possible to teach novices visual-perception skills, such as where to look, what to look at, and when to look (Amadieu et al., 2011; Schnotz & Lowe, 2008; Young et al., 2017). Similarly, it may even potentially be possible to guide eye movements to relevant areas of the environment using visual-perception training, and thus improve cognitive processing through perceptual guidance (de Koning et al., 2010). As was discussed previously, there have been successes with training visual skills in sports (Wimshurst et al., 2018), therefore, it is perhaps relevant to train sports visual skills to improve overall SA. Two different types of visual-perception training using dynamic stimuli have been identified from the literature: 1) visual cueing training, and 2) commentary training. These methods, which will form the rationale for the current study, will be described in further detail below.

5.1.3 Visual cueing training.

Visual cueing training, or training interventions that provide non-content information (*e.g.,* arrows, circles, lines) to an image or video (de Koning et al., 2009), are used to direct attention to relevant areas or elements to train individuals where to look, what to look at, and in dynamic scenes, when to look (Amadieu et al., 2011; Schnotz & Lowe, 2008). This is based on the Attention-Guiding Principle (AGP), which theorises that directing a learner's attention to important parts of the material may improve overall learning (Betrancourt, 2005), as well as the Cognitive Load Theory (CLT), which states that during learning, there are limited attentional resources in the mind (Sweller et al., 1998). Therefore, visual cueing appropriately directs a learner's attention to important areas in the environment to reduce the cognitive load of searching out relevant information (de Koning & Jarodzka, 2017). It is believed that learners in a dynamic environment must create a mental model of an environment, and to do so, they must extract relevant information from visualisations of that environment (Richard Lowe & Boucheix, 2008). That information must then be attended to and processed in the working memory where it will then be subsequently stored in the long-term memory and combined with existing knowledge (Jarodzka et al., 2013), thus supporting learning.

Teaching novices to appropriately search their environment is key for building their mental model and SA (Kovácsová et al., 2020), as many novices' visual search behaviours are underdeveloped (Cantwell et al., 2013). When viewing an environment, many novices employ a bottom-up processing technique that relies on salient information (Kriz & Hegarty, 2007)—even if it is not relevant (Lowe, 2003)—simply because they do not have the experience which would allow for a more top-down, goal-orientated processing (Balslev et al., 2012). They must also sift through numerous sources of environmental information which compete for their limited attentional resources (Schnotz & Lowe, 2008). Therefore, to direct novices' attention to relevant areas of the environment, salient non-content information should be applied to visualisations of the environment; this is believed to reduce attentional requirements by highlighting relevant information which a learner can attend to while ignoring irrelevant information (Amadieu et al., 2011). It is argued that relevant information should be processed in a timely manner, particularly in dynamic situations, because that information may be missed and could lead to a detriment in performance (Jarodzka et al., 2013). Attention-guiding may be done with verbal cueing (Mautone & Mayer, 2001) or with graphic cueing (Kriz & Hegarty, 2007), such as using arrows (Boucheix & Lowe, 2010), coloured circles (Jarodzka et al., 2013), coloured lines (Boucheix & Lowe, 2010), or even anti-cueing in which a 'spotlight' is placed on the relevant information while the irrelevant information is blurred (Lowe & Boucheix, 2011). In static images, bright colours can be used which point to important information and thus guide a learner's attention to those areas (Jamet, 2014). Similarly, in dynamic environments, such as a videos or animations, coloured cues can be used, but they can be designed so they change colours as the video progresses to indicate a progression of unfolding events (Boucheix & Lowe, 2010). Such cueing, based on the AGP, is suggested to aid in organising and integrating relevant information, thus promoting learning (de Koning et al., 2009).

Boucheix & Lowe (2010) examined the effectiveness of point (static, arrow) and continuous (dynamic, spreading-colour) cueing training on learners' comprehension of a piano mechanism. The arrows added to the animation of a piano mechanism were only one colour and pointed only to the local movement of the parts. The spreading-colour arrows were ribbons of colour overlapped on the most relevant areas of the animation which moved with the animation. Participants were sorted into three learning groups: 1) Arrow, 2) Continuous Spreading-Colour, and 3) No-Cueing. The study reported that the participants in the Continuous Spreading-Colour group outperformed the participants in the Arrow and No-

Cueing group in a comprehension test following the learning. In a follow-up experiment, it was demonstrated that synchronising the cueing with the user-control of the animation improved comprehension. The authors suggest that continuous spreading-colour cueing synchronised with the animation is more effective at fostering learning and understanding better than simple arrow cues or no cueing at all because it encouraged better target detection (Boucheix & Lowe, 2010). In a follow-up study, Boucheix et al. (2013) investigated the effectiveness of two different forms of cueing which targeted the relationships between the components. The Progressive Path cues were created as moving colour bands that cover the entire causal chain, while Local Coordinated cues only had colour at specific, important locations. Participants were shown the same piano mechanism diagram as used in Boucheix & Lowe (2010), only now the cues were more targeted. The study showed that the learners in the two experimental groups (Progressive Path and Local Coordinated) were more attentive to the cues and demonstrated a better understanding of the mechanism during a comprehension test. The authors suggest that these visual cues can be used for improving the instructions in educational animated material for their ability to foster a greater attention level to more relevant features important for creating higher-order comprehension (Boucheix et al., 2013).

Whilst there is evidence that visual cues may promote effective visual and attentional allocation to relevant areas in an environment, there is a question that arises asking where the relevant areas are? How are they identified in the first place so that they may be cued? One such answer may be employing experts and identifying where they look when viewing an environment or diagram. To investigate if experts' eye movements could promote learning, Jarodzka et al. (2013) conducted an experiment which tested the efficacy of eye movement modelling examples (EMME) visualised with a coloured 'dot' or 'spotlight' on teaching participants about fish locomotion. A marine zoologist expert provided the eye movements (which were converted to dots or spotlights) and a commentary explaining the relevant information on how the fish moved. The dot was a solid-coloured yellow dot which moved along the eye movements of the model. The spotlight highlighted the eye movements by blurring the surrounding, irrelevant areas. Participants were separated into three training groups: 1) Dot Display, 2) Spotlight Display, and 3) Control with no visual guidance. Participants were trained with a video featuring a fish swimming; the different training groups were shown visual cues which highlighted the important patterns in the fish's locomotion. The results showed that the training groups (Dot Display and Spotlight Display) more effectively guided the learners' attention to relevant areas, as captured by eye tracking. The spotlight group attended to relevant areas more quickly, however the dot group showed better performance in the multiple-choice tests about the locomotion. The authors suggested that visual cues formed from an expert's eye movements may successfully guide learners' attention to relevant areas, thus improving visual selection of information and organisation and integration of that information (Jarodzka et al., 2013).

Perhaps in a more practical application, Litchfield et al. (2010) investigated the efficacy of eye movements modelling on accuracy when looking for pulmonary nodules on radiographs. The authors posited that novices may develop appropriate scanning behaviours, detection skills, and decision-making abilities from watching the eye movements of more experienced individuals, therefore improving their overall practical skills. The first experiment investigated if viewing another person's search behaviour would improve the visual search and decision-making skills of an observer when reading radiographs to detect pulmonary nodules. Novice and experienced radiographers took part, but it is important to note that the novices had previous clinical and radiograph experience. The model scan paths were created from both an experienced and a novice radiographer. Participants were separated into one of three groups: 1) Free Search (observers could make an immediate decision on identifying nodules), 2) Image Preview (observers had to wait for 20s before making a decision), and 3) Eye Movement

Preview (observers were shown either an expert or novice's eye movements for 20s before making a decision). The results showed that all participants—experienced radiographers included—benefitted from watching another's eye movements, with participants making more accurate decisions. The authors suggested that the novices adopted the scan paths of the experienced eye movement modellers but struggled to explain the experienced radiographers' increased accuracy. Interestingly, there were no performance differences in watching experienced or novice eye movements, leading to the authors to conclude that task specificity of the eye movements was more important than the experience of the modeller (Litchfield et al., 2010).

To gain insights in the findings of the first study, the authors conducted a follow-up experiment to investigate if the increased accuracy was due to the task specific eye movements or simply an effect of viewing dynamic stimuli leading to heightened attention (Litchfield et al., 2010). This experiment used three conditions: 1) Image Preview (no eye movements), 2) Expert Search (experienced eye modellers), and 3) Unrelated (eye movements taken from an unrelated task). The procedure followed the same as the first study but included more trials. The results showed that novice radiographers benefitted from the Expert Search, but the experienced radiographers did not. Interestingly, novice and experienced radiographers performed similarly within the Expert Search condition, suggesting that the novices were able to learn from the modeller and perform just as well as an experienced individual. The authors also suggested that the expert eye modeller provided some level of task-relevant information that the novices were able to use when reading the radiographs, however, it was unclear what that information was.

Finally, Litchfield et al. (2010) conducted a third study to investigate further the role of task specificity and expert eye movement modelling in interpreting radiographs. Four conditions were used: 1) Naïve-No-Task (eye movements of an individual with no previous radiography experience during a free search), 2) Naïve-Search (eye movements of a non-radiographer asked to identify nodules), 3) Expert Search (the same as the second experiment), and 4) Incongruent Search (eye movements of an expert superimposed onto a different radiograph—the eye movements were task specific, but not image-specific). The procedure was similar to the second experiment but used only novice radiographers. The results showed that performances were more accurate in the Naïve-Search compared to Naïve-No-Task and Incongruent Search, but interestingly, the Naïve-Search and Expert Search showed no performance differences. The authors concluded that the modeller experience is not a contributing factor to performance benefits from novices—especially during early stages of learning—therefore, learning effects from eye movement modelling may be derived from the task specificity and not the experience of the modeller. Additionally, the authors argued that such benefits from eye movement modelling may be short-lived and only suitable for learners who are just starting out; for more experienced individuals, a different method of learning would be necessary (Litchfield et al., 2010). Ultimately, the Litchfield et al. (2010) studies showed that novices may indeed learn and base their decisions off of the specific visual search behaviours of an eye movement modeller, regardless of the modeller's experience.

While some studies have demonstrated the effectiveness of visual cueing, there is little evidence that these benefits extend long-term. For instance, de Koning et al. (2009) suggested that visual cueing was effective at guiding a learner's attention to relevant areas, however, it did not improve the cognitive processing of the environment. Similarly, de Koning et al. (2010) showed that visual cueing failed to improve the learner's understanding of the environment, and any learning that did take place was not transferred to performance. Boucheix et al. (2013) also demonstrated that any learning effects may deteriorate after a short amount of time. De Koning & van der Schoot (2013) also suggested that static visual cues may not necessarily improve cognitive processes. A criticism of visual cueing is the idea that cueing, particularly in static environments, do not address when to look, which is arguably just as important as identifying where to look (Schnotz & Lowe, 2008). Additionally, it is possible that visual cues do not provide continuous information about sequences of events in dynamic environments (Boucheix & Lowe, 2010), and some visual cues may not be noticeable enough in dynamic environments to fully guide a learner's attention away from salient—but irrelevant—information (Schnotz & Lowe, 2008). Simply cueing relevant areas may guide an individual's attention to those areas (*i.e.,* Level I SA perception), but it does not provide contextual information on why those areas are important (*i.e.,* Level II SA comprehension). Comprehension, or understanding the meanings and significance of the environmental elements perceived is an important step in creating a mental model of the task and obtaining and maintaining good SA (Endsley, 1995b), therefore, visual cueing may not be entirely adequate for training SA in novices.

5.1.4 Expert commentary training.

Verbal cueing, or narration which is dubbed over an animation or dynamic scene (Mautone & Mayer, 2001), is yet another way to guide a learner's attention to relevant areas with the aim to promote learning. One method of verbal cueing is known as commentary training, or training interventions in which either a subject matter expert (SME) or the individual trainee produce an on-going dialogue about the situation. Commentary training is commonly used in teaching novice drivers to develop their Hazard Perception (HP) abilities (Zhang et al., 2022). Simply put, commentary training in HP teaches drivers to verbally anticipate hazards on the road (Young et al., 2017). Researchers suggest that commentary training may improve the visual scanning behaviours in novice drivers—who generally lack the skills to search the whole visual space (Cantwell et al., 2013)—and such improvement may lead to an enhanced understanding and awareness of the whole driving scene (Young et al., 2017). These visual search skills are imperative to building and maintaining an individual's overall SA—or more specifically HP—but are particularly important for Level I (perception) SA (Endsley, 1995b), which forms the base for the higher levels of SA. In HP commentary training, novice drivers are shown videos of a roadway situation, and are either asked to provide their own running commentary about what they see in the environment, what they are doing, what may happen, and any potential actions for avoiding hazards (Crundall et al., 2010; Young et al., 2017), or are asked to listen to an SME, usually an experienced driving instructor, give commentary over the video (Wetton et al., 2013). Transportation researchers have found that commentary training generally produces a positive effect on novices' learning and HP abilities by decreasing HP response times (Crundall et al., 2010), thus suggesting that it is an effective method for training novice drivers to anticipate potential hazards on the road.

One such commentary training method, known as self-generated commentary training, calls for participants to produce a running commentary aloud about the driving scene they are viewing. This is believed to encourage the trainees to search farther down the road and verbally predict hazards that may occur (Young et al., 2017). Research has shown that self-generated commentary may improve novice drivers' HP responses. For instance, Isler et al. (2009) found that novice drivers trained in generating HP commentary performed just as well as experienced drivers in a HP test; the trained novices also performed significantly better than control novices with no training. Crundall et al. (2010) similarly showed that novice drivers who were trained to produce a verbal commentary had fewer crashes and braked sooner in a driving simulator than those who were untrained, thus suggesting that their HP abilities improved from the training. Cantwell et al. (2013) conducted an experiment which examined the effects of self-generated commentary on visual search behaviours and HP in learner drivers. The authors found that those who generated driving commentaries identified more hazards and demonstrated more fixation clusters on a greater number of areas in the driving scene which were spread more horizontally across the scene, similar to the scan-paths of experienced drivers (Underwood et al., 2003). Notably, there were no differences between the commentary drivers and non-commentary drivers in the number of fixations on the wing mirrors. However, the authors suggested that self-generated commentary training may improve novices' SA and HP by changing the visual search behaviours and how drivers process information from the scene (Cantwell et al., 2013).

While there have been positive outcomes from self-generated commentary training, not all studies have demonstrated a learning effect through self-generated commentary training. For example, Young et al. (2014) showed that HP responses slowed when trainee participants produced their own commentary. Young et al. (2017) replicated those results and showed that producing a self-generated commentary, even after practice, has detrimental effects on HP responses. The authors also demonstrated that exposure to an expert commentary improved HP responses initially but had no effect in later tests (Young et al., 2017). It is possible that self-generated commentaries produced detrimental effects on HP response times due to the increased workload of verbalising thoughts (McCarley et al., 2004), particularly in novice drivers who are already under a high mental workload demand from their lack of driving experience (Gregersen & Berg, 1994; Isler et al., 2009). These studies do, however, highlight the importance of considering mental workload and attention allocation when training individuals in a domain which requires both motor control (*i.e.,* steering and vehicle control) and cognitive skills (*i.e.,* SA and HP).

Unlike self-generated commentary, expert commentary does not require the trainee to produce any verbalisations during the training intervention. Instead, an SME, such as a driving instructor, produces a commentary which is played over a video of a driving scene. This commentary focusses on potential hazards in the scene, how to spot them, and avoidance actions that can be taken (Zhang et al., 2022). Researchers have found that expert commentary has improved HP responses in novice drivers. For instance, Poulsen et al. (2010) investigated the effectiveness of commentary training on improving HP abilities in drivers with attention deficit hyperactivity disorder (ADHD). Participants in the training group were shown a continuous video shot from a driver's point of view, and they were asked to produce a running commentary about what they were paying attention to on the road. The clip was replayed with a pre-recorded expert commentary over the top which described areas to be aware of on the road and the potential hazards in the video. WHN exercises were added in which participants listed all the things that could potentially occur. The participants who received the training significantly improved their HP response times in comparison to those who did not receive any training. Similarly, Horswill et al. (2013) also used both self-generated and expert commentary to improve experienced drivers' HP. During the training intervention, participants viewed several driving clips which showed potential hazards. The first time viewing the clips, participants created their own running commentary, and the second time, participants listened to an expert commentary voice-over. Following the training, participants completed a HP test. The results showed the training group identified hazards more quickly than the control group. The training group maintained that advantage in a one-week follow-up HP test. The authors argued that HP—and thus SA—can be improved with a short training intervention, even in experienced individuals (Horswill et al., 2013). One thing to note, however, is that these studies (Horswill et al., 2013; Poulsen et al., 2010) used both self-generated and expert commentary training, and thus it is difficult to say which method—or if both methods combined—had a greater effect on the HP response times.

Another method for improving SA skills was created using the 'What Happens Next' (WHN) paradigm in combination with the expert commentary training. The WHN paradigm, as discussed in previous chapters of this thesis (Chapter 4), was designed to specifically target an individual's anticipation (or projection—Level III SA) abilities (Jackson et al., 2009), and has been used to assess the Hazard Prediction—SA on the road (Horswill & McKenna, 2004)—abilities (Ventsislavova et al., 2019). Typically, clips of a roadway situation are shown from a driver's POV. The clips occlude suddenly prior to a hazard occurring, and participants must answer questions about what may occur next (Jackson et al., 2009). There is evidence that experienced drivers generally perform better on WHN tasks (Crundall, 2016), and the results from the Chapter 4 studies showed that the WHN paradigm discriminated experience in polo, suggesting that the tool was sensitive enough to target higher-order cognitive skills associated with SA. Therefore, it is reasonable to investigate the effectiveness of the WHN paradigm as a training method for this chapter's experimental study.

In driving, the WHN paradigm has historically been used a measure of HP abilities, and in some studies, the effect of a training intervention, with the hopes that training would improve WHN scores. For instance, Wetton et al. (2013) combined self-generated commentary, expert commentary, and WHN training interventions to investigate which method had the greatest effect in improving HP skills in novice drivers. Drivers were split into five training groups: 1) WHN Training, 2) Expert Commentary Training, 3) Hybrid (Expert Commentary plus Self-Generated Commentary), 4) Full (WHN Training plus Expert and Self-Generated Commentary), and 5) Control. They completed three WHN HP tests: 1) Prior to training, 2) Immediately after training, and 3) One week after training. All training groups recorded significantly lower HP response times in the WHN test immediately following the training interventions. The Full training intervention showed the largest reduction in HP response time, and it even held its effect in the WHN test a week later. This study suggests that a combination of training methods, including expert commentary and WHN exercises, can hold its training effect after some time and may be beneficial to improving HP in novice drivers (Wetton et al., 2013). Similarly, Castro et al. (2016) compared the effects of an expert commentary on HP in drivers of different experience levels (learner, novice, and experienced). During a pre-training test, participants in this study viewed several video clips shot from the driver's point of view; each video clip was occluded prior to a hazard, and participants were required to answer: 'What is the hazard?', 'Where is the danger?', and 'What happens next?' The Proactive Listening to a Training Commentary group then viewed the pre-training test videos accompanied by a voiceover which described the traffic scene and the important visual cues to help in hazard detection. The participants then completed a post-training test with the same procedure as the pre-training test. The study showed that the Proactive Listening to a Training Commentary training intervention can improve HP abilities in all driving groups (learner, novice, and experienced) because the training commentary helps to improve knowledge and increase sensitivity to hazards (Castro et al., 2016). Interestingly, it was the experienced group which received the most benefit from the training intervention, suggesting that there may be an advantage to prior experience because those who have not been exposed to a variety of roadway hazards and situations (*i.e.,* learners and novices) generally process the situations slower and may become overwhelmed by complicated scenarios, something that may be mitigated with experience (Castro et al., 2016).

Recently, Kovácsová et al. (2020) designed a computer game for training SA in adult electric bicyclists using the WHN paradigm as well. The training intervention was separated into two modules—instruction and practice—with participants receiving expert commentary and feedback during the instruction module. During each module, participants viewed WHN clips shot from a cyclists' point of view. The videos were occluded prior to a hazard occurring. Following the occlusion point in each clip, participants answered two questions: 1) What is the location of the hazard, and 2) What happens next? by clicking icons on the screen. Expert commentary and feedback were provided for each clip. Following the training interventions, participants completed a WHN test and questionnaires about perceived risk and stress levels.

The results showed that the training group were significantly faster than the control groups, but there were no differences between number of hazards detected. Additionally, there were no differences in perceived risk or stress. The authors argued that the training intervention improved the visual search behaviours of the training group participants without creating overconfidence (Kovácsová et al., 2020).

Thus, there is evidence that viewing videos with an expert commentary may improve HP, and thus, SA in drivers. Therefore, it is plausible that employing the WHN and expert commentary paradigm to sports—in this case, polo—may provide positive training effects even in individuals with no polo experience. Importantly, expert commentary may direct visual attention to relevant areas in the environment (Level I SA perception) but also provide explanations of why those areas are important (Level II SA comprehension). This, as explained earlier, is necessary for building mental models of a task and maintaining SA (Endsley, 1995b). Possibly, to foster learning and SA training, learners should understand why their attention is being directed to certain locations and environmental cues so that they may incorporate that knowledge into similar tasks at a later point in time. The main goal of the above-mentioned training paradigms is to direct the learners' attention to relevant areas of the environmental scene, thus providing them with knowledge and experience necessary to conducting successful searches in similar tasks.

The introductory sections talked briefly about different visual searches and eye movement behaviours in sports and attention-guiding training paradigms. As mentioned previously, the training paradigms' aim is to guide a learner's attention to relevant areas of the display using either visual cueing or verbal expert commentary. The eye movements behaviours of the learners may then give insight into their attention—what they are attending to and when they shift their attention to something new. These behaviours may then also be used to infer the effectiveness of visual cueing and commentary training on shifting attention. The current study will use the WHN paradigm from Chapter 4: Study 2.1 and 2.2 along with the off-ball visual cues from the STB studies (Chapter 3: 1.2) with the aim to train the SA and anticipation abilities of non-polo playing participants in a polo video task. Despite the WHN task's somewhat weaker-than-expected ability to discriminate sport experience (as evidenced by the two previous studies), it still showed an experience effect of polo players performing better than control participants. That, and given a wide body of literature showing the WHN paradigm taps into higher order skills (Mackenzie et al., 2023), it was chosen as an inference measure of SA for the current study.

5.1.5 The current study, aims & objectives, and hypotheses.

From the literature above, the study has two aims: 1) to investigate the efficacy of different cueing-based training interventions on WHN performances in novices, 2) to examine the visual search behaviours and eye movements, such as gaze fixations, durations, and dispersions, in a WHN task before and after training to investigate if training SA produces a shift in attention—as measured by eye movements—towards relevant areas of the environment (indicating a shift from bottom-up to top-down processing). The study will investigate the effectiveness of different SA training interventions in individuals with no specific polo experience. The participants for this study will be randomly separated into three training groups: 1) visual cueing (CUE), 2) expert commentary (COM), and 3) control (CONT). Importantly, as will be discussed more in-depth in later sections, a hybrid training group consisting of both visual cueing and expert commentary training was not pursued in this study due to logistical limitations of participant recruitment, payment, and time constrictions. Statistically, including a fourth level would require many more participants than were possible to recruit given the above-mentioned limitations; this is ultimately a limitation to this study.

For this study, participants will complete two polo WHN tests to determine their SA and accuracy, one before training and one after training. The WHN accuracy results will be used to infer the effectiveness of each training intervention. Additionally, the participants' eye movements will be recorded during the pre-training WHN test and the post-training WHN test to investigate the abilities of each training intervention to shift visual attention to relevant areas of the scene.

The first hypothesis of the study is that participants in the training intervention groups, both visual cueing and expert commentary, will show an improvement in WHN accuracy scores in the post-training WHN test compared to the participants in the control group. The second hypothesis is that within the training interventions, the participants in the expert commentary (COM) group will have better WHN accuracy scores in the post-training WHN test compared to the participants in the visual cueing (CUE) group. The third hypothesis is that there will be an interaction between training group and WHN test, with the training groups showing better accuracy scores in the post-training WHN test. The fourth hypothesis can be separated into individual predictions for each eye movement. First, that there will be more fixations on locations off the ball during the post-training WHN test compared to the pre-training WHN test. Second, that the fixation durations off the ball will be longer during the post-training WHN test compared to the pre-training WHN test. Third, there will be a wider dispersion of gaze fixations along the x and y axis during the post-training WHN test compared to the pre-training WHN test, indicative of a wider search.

5.2 Methods

5.2.1 Design.

Three experimental designs were used for this study based on the specific aim being investigated. These designs are discussed separately below and in more detail in Section 5.2.6.

Design 1: To investigate the effect of the training packages on WHN accuracy, a 3 x 2 mixed-factors experimental design of training group by WHN test was used. The training group (visual cueing (CUE), expert commentary (COM), and control (CONT)) was analysed as the between-subjects predictor variable, and the WHN test period (pre-training, post-training) was analysed as the within-subjects predictor variables. The accuracy in the WHN tasks were analysed as the outcome variable.

Design 2: To investigate the Area of Interest (AOI) measures (number of fixations and fixation durations) as a measure of processing, a 2 x 2 x 3 mixed-factors experimental design of Area of Interest (AOI) by WHN test by training group was used. The training group (CUE, COM, CONT) was analysed as the between-subjects predictor variable, and the AOI (ball proxim (on or near the ball), off-ball), and the WHN test (pre-training, post-training) were analysed as within-subjects predictor variables. The number of fixations, the average length of fixation durations (ms), and the fixation durations as a percentage of time were analysed separately as the outcome variables.

Design 3: To investigate the fixation dispersions as a measure of visual search behaviour, a 2 x 3 mixed-factors experimental design of training group by WHN test by training group was used. The training group (CUE, COM, CONT) was analysed as the between-subjects predictor variable, and the WHN test (pre-training, post-training) was analysed as within-subjects predictor variables. The average dispersion area (pixels) was analysed as the outcome variable.

5.2.2 Participants.

Participants were recruited through the NTU SONA website and word-of-mouth advertisement. An *a priori* sample size calculation was performed using R (R Core Team, 2020) with the package '*pwr*' (Champley et al., 2017). The effect size (*r)* = 0.44 was based on data from the previous study (Chapter 4: Study 2.2). A conservative estimate of power at 0.95 and an alpha error probability of 0.05 was used to give an overall sample size of 92 participants (31 in each group). Participants were excluded if they had taken part in any previous WHN polo tests (Study 2.1 and Study 2.2), did not complete the study, answered the WHN questions in a systematic way (*i.e.*, answering all a, or a, b, c, d repetitively), or were under the age of 18. However, due to difficulties in participant recruitment and limited funding to pay participants, this study did not achieve the necessary sample size and is thus underpowered relative to the predicted effect size. No participants were excluded from this study.

In total, 38 participants (28 female) ranging in age 18 – 35 years (*M* = 23.08, *SD* = 4.07) completed the study. Fourteen participants (9 female), ranging in age 18 – 31 (*M* = 22.40, *SD* = 4.22) were sorted into the visual cueing (CUE) training group. Twelve participants (10 female), ranging in age 19 – 32 (*M* = 23.20, *SD* = 3.60) were sorted into the expert commentary (COM) training group. Twelve participants (9 female), ranging in age 20 – 35 (*M* = 23.67, *SD* = 4.56) were sorted into the control (CONT) training group. No participant had any previous polo experience. See Table 5.1 for the participant demographics.

Table 5.1 *Participant demographics.*

	Training Group		
	Visual Cueing (CUE)	Expert Commentary (COM)	Control (CONT)
N	14	12	12
Gender			
Male (%)	5 (35.71)	2 (16.67)	3 (25.00)
Female (%)	9 (64.29)	10 (83.33)	9 (75.00)
Age (*M*, *SD*)	18—31 (23.08, 4.07)	19—32 (23.20, 3.60)	20—35 (23.67, 4.56)

Note. N = 38.

5.2.2.1 Ethical approval.

This study was approved by the Nottingham Trent University Business Law and Social Sciences Schools Research Ethics Committee (BLSS SREC). Participants gave informed consent prior to taking part in the study. Non-NTU student participants who completed the entire experiment received compensation with a £10 Amazon voucher. NTU Psychology students received 6 SONA credits. Participants were required to be at least 18 years of age.

5.2.3 Materials.

5.2.3.1 Pre-training WHN test stimuli.

Participants viewed 18 polo video clips ranging in length from 2.24—22.04 (*M* = 10.64s, *SD* = 6.49s). Nine clips showed offensive plays (Range = 2.24—22.04s, *M* = 8.26s, *SD* = 7.45s) and nine showed defensive plays (Range = 6.05—20.18s, *M* = 13.01s, *SD* = 4.61s). The video stimuli were created using footage from the 2021 C.V. Whitney Cup Final polo match between Scone Polo (red jerseys) and Park Place (blue jerseys), which was played at the International Polo Club in Palm Beach, Florida on 7 March 2021. Both teams had cumulative

22-goal handicaps. Video footage was provided with permission from Global Polo TV®. The video stimuli were created following the same format as Chapter 4: Study 2.1. See Appendix 7.5 for descriptions of the pre-training WHN stimuli and Appendix 7.9 for the corresponding YouTube links. Table 5.2 shows the precursors available immediately prior to the freeze-frame and WHN probe.

Table 5.2 *List of precursors available immediately prior to the freeze-frame and WHN probe.*

Clip No.	Clip Type	Precursors Available	Play Outcome
1	Offensive	Blue 2 angles his horse to come behind Blue 3. Blue 3 does not position his mallet for a swing.	Blue 3 leaves the ball for Blue 2
2	Offensive	Red 2 looks over right shoulder at Red 4. Red 4 prepares for a swing towards Red 2.	Red 4 passes the ball to Red 2
3	Offensive	Red 4 angles his horse behind Red 2. Red 2 does not position his mallet for a swing.	Red 2 leaves the ball for Red 4
4	Offensive	Blue 2 blocks the path to the centre. Red 4 angles his horse and mallet to the right.	Red 4 takes the ball to the right
5	Offensive	Blue 2 runs his horse to the right. Red 3 blocks the path to the centre. Blue 3 angles his horse and mallet to the right.	Blue 3 passes to Blue 2 on the outside of Red 3
6	Offensive	Blue 3 angles his horse behind Blue 4. Blue 4 looks to the left to go to Red 3. Blue 4 does not prepare for a swing.	Blue 4 leaves the ball for Blue 3
7	Offensive	Red 4 is open behind Red 2. Red 2 looks over his left should shoulder at Red 4.	Red 2 backs the ball to Red 4
8	Offensive	Red 2 runs his horse to the left to get open. Red 4 angles his mallet to pass to the left.	Red 4 passes to Red 2
9	Offensive	Red 3 runs his horse to the right to get open. Red 4 angles his mallet to pass to the right.	Red 4 passes to Red 3
10	Defensive	Red 2 is in possession of the ball on his right. Blue 3 reaches his mallet over the left side of his horse's neck.	Blue 3 hits a backshot
11	Defensive	The ball is in front of Red 2 and Blue 2. Red 2 moves his horse to meet up with Blue 2. Red 2 has his mallet prepared for a swing.	Red 2 bumps Blue 2 and steals the ball
12	Defensive	Red 3 angles his horse towards the loose ball. He brings his mallet up for a backshot.	Red 3 hits a backshot
13	Defensive	Red 3 hits the ball up towards Blue 2. Blue 4 moves his horse to the right to get open behind Blue 2.	Blue 2 passes to Blue 4 on the outside of Red 4
14	Defensive	Red 3 has the ball on his right side. Blue 4 angles his mallet	Blue 4 hooks Red 3

		above his horse's left shoulder, parallel to Red 3.	
15	Defensive	Blue 2 hits the ball up to Red 2. Red 2 looks over his right shoulder at the ball.	Red 2 intercepts the ball
16	Defensive	Red 2 has the ball on his right side. Blue 2 turns his horse sharply to the left. Blue 2 raises his mallet for a forehand shot on his right side.	Blue 2 intercepts the ball and takes it forward
17	Defensive	Red 4 hits the ball at an angle to the left. Blue 4 turns his head to look at the ball and runs his horse to the ball's line.	Blue 4 hits a backshot
18	Defensive	Red 2 has the ball on his right. Blue 4 raises his mallet above his horse's left shoulder, parallel to Red 2.	Blue 4 hooks Red 2

5.2.3.2 Visual cueing training stimuli.

The stimuli video clips for the visual cueing (CUE) training intervention came from the 2021 C.V. Whitney Cup Final polo match. There were three offensive plays and three defensive plays, ranging in length from 150.08—173.25s (*M* = 159.40s, *SD* = 9.50s). Three clips showed offensive plays (Range = 150.08—169.16s, *M* = 157.65s, *SD* = 10.13s) and three showed defensive plays (Range = 153.14—173.25s, *M* = 161.15, *SD* = 10.66s). Please refer to Appendix 7.6 for descriptions of the training stimuli and Appendix 7.10 for the YouTube links to the training materials. There was no sound included in these video clips. The cueing stimuli consisted of multi-coloured circles and arrows overlaid on the video which appeared and moved to follow the pertinent information to direct visual attention to the important visual cues which would aid in predicting what happens next. The visual cues were created by a polo SME with over 15 years of playing experience and a sport psychologist researcher with extensive experience in SA and WHN methodologies. The cues followed a traffic light system—similar to Boucheix & Lowe's (2010) spreading-colour cues—of green, yellow, and red. Participants were given a handout sheet which remained with them throughout the training duration that explained each cue; they were subsequently asked if they had any questions about the cues or the language used. Any questions were answered by the experimenter.

In offensive videos: green-coloured cues meant there was no/low defensive pressure on the ball-handler. The player/arrow highlighted in green indicated an appropriate area to pass/shoot towards. Yellow-coloured cues meant there was medium defensive pressure on the ball-handler. The player/arrow highlighted in amber indicated a likely appropriate area to shoot/pass towards, but it was not confirmed yet. Red-coloured cues meant there was a high defensive pressure on the ball-handler. The player/arrow highlighted in red indicated an unsafe area to pass/shoot towards.

In defensive videos: green-coloured cues meant there was a good opportunity to make a defensive play. The player/arrow highlighted in green indicated an appropriate area to make a play. Yellow-coloured cues meant there was an opportunity to make a defensive play. The player/arrow highlighted in amber indicated it was likely to be an appropriate area to make a play, but it was not confirmed yet. Red-coloured cues meant that there was no opportunity to make a defensive play. The player/arrow highlighted in red indicated an inappropriate area to make a play. Lastly, the ball-handler was highlighted with a white circle.

Other visual cues included circles and arrows, which were coloured green, yellow, or red. These circles and arrows followed the same traffic light scheme as above, depending on whether they were shown in offensive or defensive clips. Circles around a player were meant to highlight that player. Solid arrows in any direction were meant to highlight the direction the ball-handler could run towards. Dotted arrows in any direction were meant to highlight the direction the ball-handler could pass/shoot towards.

For example, a green circle around the ball-handler's teammate indicated that the teammate was open for a pass, and that the ball-handler should pass to him. A yellow circle around an empty space on the field indicate that the ball-handler could potentially pass the ball to that area, but he should wait until a teammate became open or until an opposing player moved out of that area. Conversely, a red arrow indicated that the direction in which the arrow pointed towards was blocked by an opposing team member, and that the ball-handler should not move the ball in that direction. Figure 5.1 shows a progression of the cues used in an offensive play situation, and Figure 5.2 shows a progression of the cues used in a defensive play situation.

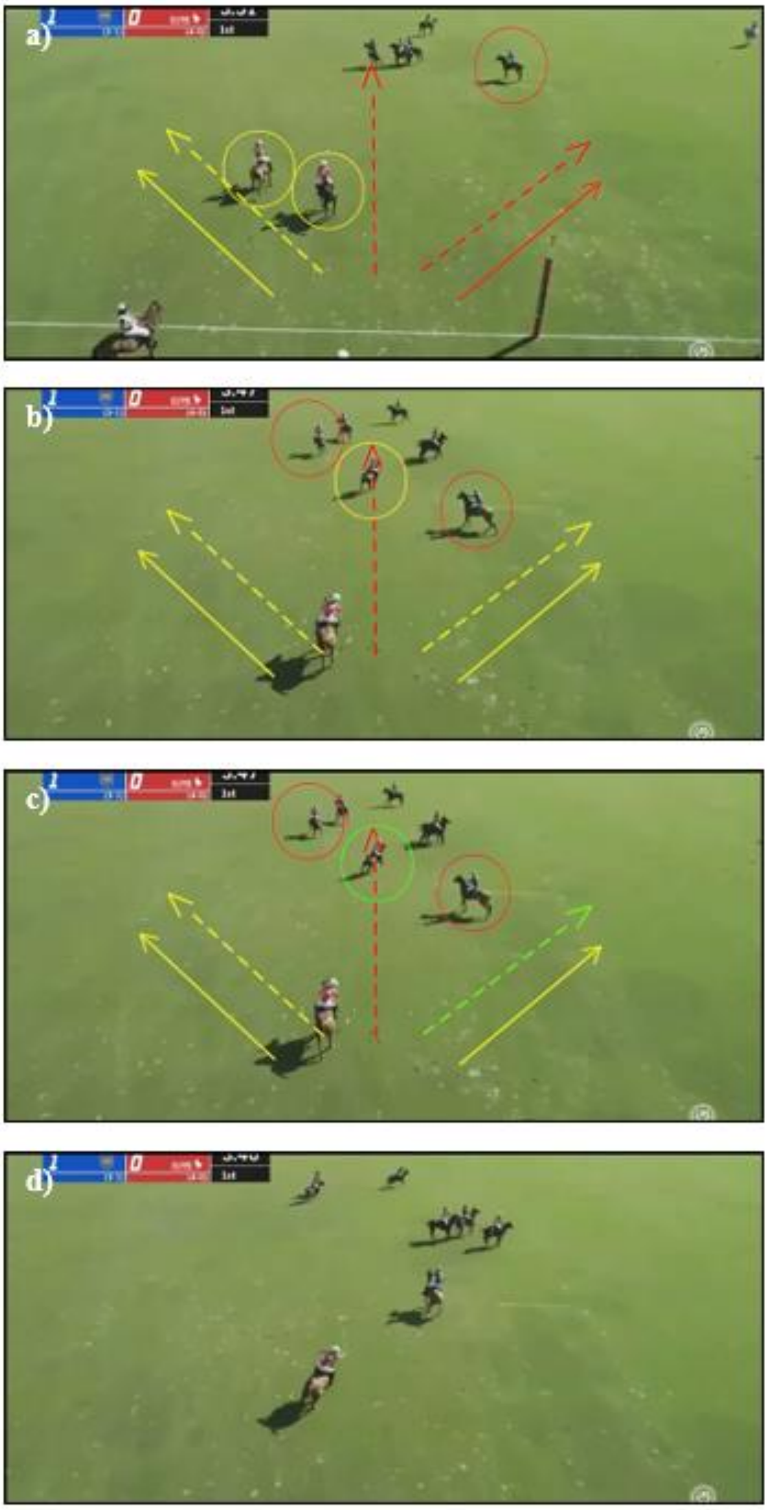

Figure 5.1 *Example of the progression of visual cueing used in an offensive-play video clip. Figs. 5.1a and 5.1b—The yellow circles and lines indicate a possible path to run or pass to, whilst the red circles and lines indicate a poor path to run or pass to. Fig. 5.1c—The green circle and green dotted arrow indicated an appropriate player to pass the ball to. The yellow arrows indicated a possible path to run or shoot the ball towards. The red circles and red dotted arrows indicated a poor possible path to run or shoot the ball towards. Fig. 5.1d—The final completion of the pass.*

Figure 5.2 *Example of the progression of visual cueing used in a defensive-play video clip. Figs. 5.2a and 5.2b—The white circle highlights the ball-handler, and the yellow arrows indicate a possible direction to block or intercept a pass. Figs. 5.2c and 5.2d—The white circle highlights the ball-handler. The green arrow shows an appropriate direction to make a defensive play. The red arrow shows an inappropriate direction to make a defensive play. Fig. 5.2e—The final completion of a defensive ride-off ("bump") with a neckshot from the red player.*

5.2.3.3 Expert commentary training stimuli.

The stimuli video clips for the expert commentary (COM) training intervention were the exact same clips used in the CUE intervention. Please refer to Appendix 7.6 for descriptions of the training stimuli and Appendix 7.10 for the YouTube links to the training materials. There were three offensive plays and three defensive plays. The commentary was added over each pause in the videos. There were no additional cues added to the videos, and outside of the commentary, the videos had no sound. The audio commentary was written and recorded by a subject matter expert (SME) in polo. The purpose of the commentary was to draw the participants' attention towards the important visual cues which would aid in predicting what happens next. The commentary focussed on off-ball information, general strategies for the offensive and defensive players, and the three levels of SA (perception, comprehension, projection). Importantly, the commentary was not a play-by-play description of what was happening on the field (as one would hear over a professional game with announcers), but instead identified general strategies the participants could use to help them make sense of the plays shown in the videos. The first bit of commentary introduced each clip by describing the situation (knock-in, throw-in, midfield pass) and who was currently in possession of the ball.

An example excerpt of the commentary for an offensive video is shown below:

> (1st Frame Hold) Red 4 is hitting the ball in from the end line (knock-in). His main goal is to move the ball downfield towards his goal. He can do this by running with the ball himself or passing to a teammate. Oftentimes, the easiest, most effective strategy is to pass to an open teammate, but not

always. The defence—the blue player's main goal is to gain possession of the ball. They can do this by intercepting a pass, hooking the ball-handler with their mallet, or bumping the ball-handler off the ball.

As the clip progresses, try and find other red players whom Red 4 can pass to. Additionally, find blue players who are likely to make a defensive move on him. Lastly, think about the open spaces on the field where he can potentially pass towards or run the ball.

(2nd Frame Hold) Which teammates are open? Which teammates are marked by an opposing player? Are there any sides of the field that are controlled by the red players, which may be a good location to pass to? Are there any sides of the field that are controlled by the blue players, which would be a poor location to pass to? Are there any sides of the field that are not actively controlled by the defence, but could easily become controlled by them?

(3rd Frame Hold) Has a red teammate made a move to get open for a pass, or are they marked by opponents? Look at the proximity of the blue player to Red 4 (the ball-handler). Is he close by, or far away? What direction is the blue player's horse traveling, which would indicate the area of field he can now control. Could Red 4 make a pass to a teammate, or would it be better for him to run the ball down the field himself?

(4th Frame Hold): Think about the things to perceive: the positioning of the players on the field as well as the empty spaces on the field.

Think about why these things are important to the ball-handler: Are the players red teammates or blue opponents? Which teammates are open?

Which teammates are marked by an opponent? Which side of the field is open and free from defenders? Which side of the field is controlled by the defence? What direction are the teammates' and opponents' horses moving in? Are they in the same or different direction?

Use this information to predict what happens next.

An example of excerpt of the commentary for a defensive video is shown below:

(1st Frame Hold): Blue 2 (green helmet) is hitting the ball downfield, a little short of the midfield mark. His main goal is to move the ball downfield towards his goal. He can do this by running with the ball himself or passing to a teammate. Oftentimes, the easiest, most effective strategy is to pass to an open teammate, but not always. The defence—the red player's main goal is to gain possession of the ball. They can do this by intercepting a pass, hooking the ball-handler with their mallet, or bumping the ball-handler off the ball.

As the clip progresses, think about how Blue 2 will move the ball downfield, then try and find red players who are likely to make a defensive move on Blue 3 as he moves the ball downfield. Think of the direction the defence must carry the ball once they gain possession. Lastly, think about the open spaces on the field which are controlled by the defence. Are the red players in these positions potentially able to make a defensive play?

(2nd Frame Hold): Red 3 has now gained possession of the ball. His goal is still to move the ball downfield towards his goal. He can do this by running with the ball himself or passing to a teammate. Oftentimes, the easiest, most effective strategy is to pass to an open teammate, but not always.

As the clip progresses, think about how Red 3 will move the ball downfield, then try and find blue players who are likely to make a defensive move on Red 3 as he moves the ball downfield. Think of the direction the defence must carry the ball once they gain possession. Lastly, think about the open spaces on the field which are controlled by the defence. Are the blue players in these positions potentially able to make a defensive play?

(3rd Frame Hold): Red 3 has passed the ball downfield. Are there blue players who are poised to make a defensive play on the ball? What direction are the defensive players running in? Is the empty space controlled by the red players (offense) or the blue players (defence)?

(4th Frame Hold): Think about the things to perceive: the positioning of the players on the field as well as the empty spaces on the field. Think about the things to comprehend:

Think about why these things are important to the defence: Can the blue defensive players easily get to the ball? Are the blue defensive players marked by a red offensive player, or are they by themselves? Is there an empty area on the field to take the ball once the defence gains possession?

Use this information to predict what happens next.

5.2.3.4 Control training stimuli.

The stimuli video for the control (CONT) training, titled, "Steve Thompson Polo—Top 10 Polo Tips" was obtained from Steve Thompson Polo, with open access availability on YouTube (https://www.youtube.com/watch?v=SzrzB44fxM0). The video covered topics relevant to playing polo, but it described no anticipation strategies as in the CUE and COM interventions. The topics covered included: hitting the ball correctly, swing techniques and mallet grips, riding and leg positions, training exercises to correct bad hitting habits, and saddle and equipment fitting. This video lasted 920 seconds (15 minutes, 20 seconds).

5.2.3.5 Post-training WHN test stimuli.

The stimuli video clips used for the post-training WHN test were the same used in the previous studies (Chapter 4: Study 2.1 and Study 2.2) but were different than the video clips used in the pre-training WHN test. The test consisted of 18 polo video clips ranging in length from 3.06 – 29.07 seconds (M = 12.36s, SD = 6.90), with nine clips showing offensive plays (Range = 6.08—21.11s, M = 10.57s, SD = 4.73) and nine showing defensive plays (Range = 3.06—29.07s, M = 14.16s, SD = 8.45). Please refer to Appendix 7.4 for descriptions of the post-training WHN stimuli and Appendix 7.8 for the corresponding YouTube links. The video stimuli were created using footage from the 2021 USPA Gold Cup Final polo match between Scone Polo (red jerseys) and Tonkawa (green jerseys), which was played at the International Polo Club in Palm Beach, Florida on 28 March 2021. Both teams had cumulative 22-goal handicaps. Video footage was provided with permission from Global Polo TV®.

5.2.4 Apparatus.

5.2.4.1 Adobe® Premiere Pro®.

The video stimuli were edited using Adobe® Premiere Pro® software (Version 13.1.5) on a Lenovo ThinkCentre computer. The clip edits followed the same methods as discussed in Chapter 4: Study 2.1.

5.2.4.2 Audacity® recording and editing software.

The audio for the expert commentary was recorded using Audacity® recording and editing software (Version 3.1.1) on a Lenovo ThinkCentre computer with a Rode NT1-A microphone (S/N0871635). The audio files were exported as .mp3 files and added to the training videos using Adobe® Premiere Pro® software (Version 13.1.5).

5.2.4.3 SensoMotor Instruments® iViewX RED500 eye tracker and BeGaze analysis software.

The study was designed using the SensoMotor Instruments® Experiment Centre (Version 3.6.53). The eye movements and visual search behaviours were recorded using a screen-based SensoMotor Instruments® iView X RED500 (Version 2.8) eye tracker integrated with a 22in monitor, sampled at 500 Hz, and BeGaze (Version 3.6.52) analysis software on a Lenovo laptop and screen. Eye movements were calibrated using a 9-point calibration system plus a subsequent validation. This model of eye tracker was suitable for those with normal or corrected-to-normal vision.

5.2.4.4 Qualtrics.

The participant demographic questionnaire was created and hosted using Qualtrics software, Version 11.2020 (Qualtrics, Provo, UT). Additionally, the stimuli for each training package were played using Qualtrics. The Qualtrics questionnaire and training stimuli were presented using a Lenovo laptop with a 15.3in screen. The data was collected between 6 September 2022 – 11 November 2022.

5.2.5 Eye movement measures.

5.2.5.1 Number of gaze fixations, average length of fixation durations (ms), fixation durations as a percentage of time, and average area of gaze dispersions.

The number of fixations, average length of fixation durations (ms), fixation durations as a percentage of time, and average area of fixation dispersions were used as inference measures of participants' attentional allocation. The participants' eye movements were recorded and analysed using the SensoMotoric Instruments® iView X RED500 eye tracker. The position of gaze (POG) was determined by the corneal reflection of near-infrared light with an accuracy of +/- 0.3 degrees. The BeGaze analysis software was used to analyse the POG and fixation durations and dispersions for each participant and stimuli video.

5.2.5.2 Areas of Interest (AOIs).

There were two areas of interest (AOI) that were measured in this study. There are several different methods of constructing AOIs, with numerous procedures outlining what an AOI should and should not include (Hessels et al., 2016). For this study, man-made (rather than machine-made) AOIs were constructed. AOI 1 was described as the "ball proxim" and included the ball and the ball-handler, if applicable. The "ball proxim" AOI size was determined by a Subject Matter Expert (SME) so that it contained *both* the ball and ball-handler when the ball-handler carried the ball close to him (within reach of his mallet), or *only* the ball when the ball-handler did not have the ball close to him (*e.g.,* a long shot or pass). Importantly, the "ball proxim" AOI contained the relevant objects with 'padding' (extra space around the objects) so that the AOI tracking software (BeGaze) would count each fixation given its precision of +/- 0.3 degrees (Goldberg & Helfman, 2010). The padding around the ball and ball-handler was drawn with a precision of +/- 1 degree. AOI 2 was described as "off-ball" and included the entirety of the field, excluding the ball proxim AOI. Importantly, the "ball proxim" AOI was created to move around the screen and expand/contract in size following the relevant visual information. The AOI's were created using the BeGaze analysis software in the AOI Editor by drawing a rectangle that covered each AOI location(s) for each stimuli video in the pre-training and post-training WHN tests. A rectangular shape, rather than a circle, was used as it was able to encompass the rider/horse dyad closely; a circle could also have been used but provided the areas of the shapes equalled roughly the same, there would be negligible differences between shapes. Figure 5.3 shows examples of the AOIs in the AOI Editor.

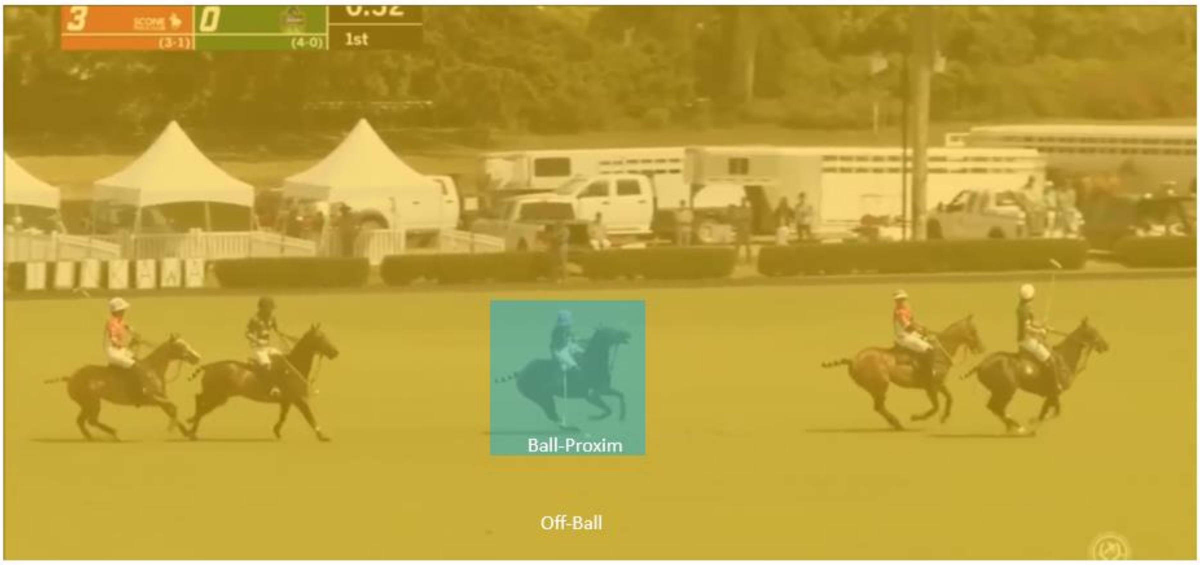

Figure 5.3 *Area of Interests (AOI) in the BeGaze AOI Editor. AOIs were defined as 'ball proxim' or 'off-ball'.*

5.2.6 Procedure.

Participants completed the experiment in a laboratory setting at Nottingham Trent University on a desktop computer equipped with a keyboard and mouse, seated approximately 60cm away from the screen. The experiment was completed using SensoMotoric Instruments® Eye Movement recording software which was pre-loaded on the desktop computer. After giving informed consent, participants completed a brief demographics questionnaire and were then randomly placed into one of the three training intervention groups (visual cueing, expert commentary, or control). Participants' eye movements were tracked and recorded using a 9-point manual calibration system with a subsequent validation. Participants' eye movements were calibrated and validated at the beginning of each block (offensive and defensive) during each WHN test (pre-training WHN test and post-training WHN test) to protect against drift.

5.2.6.1 Pre-training WHN test.

Once in their training intervention groups, participants completed the Pre-training WHN test. Participants were instructed to view each video clip and answer the question of, "What happens next?" by clicking a button on the screen which corresponded to the letter choice (a, b, c, d). Participants were given a maximum of 10 seconds to choose their answer before the task would auto-progress to the next video. Participants viewed two practice polo clips (one offensive and one defensive) to familiarise themselves with the procedure that did not count towards their overall WHN accuracy. Upon completion of the practice clips, participants then viewed 2 separate blocks of 18 polo clips (Block A consisted of nine offensive clips, and Block B consisted of nine defensive clips) that counted towards their WHN accuracy score. Participants were informed of the type of clips they would be seeing prior to viewing each block. The videos within each block were randomised, and the blocks themselves were randomised for each participant so that no participant viewed the same order of clips. Each question was scored discretely with 1 = correct and 0 = incorrect. Participants were not allowed to leave a question blank. Following the completion of the task, each participant was awarded with an accuracy percentage, or the number of questions they got correct out of 18. This task took approximately 10 – 15 minutes to complete. Participants' eye movements were calibrated and validated before each block of clips.

5.2.6.2 Training interventions.

5.2.6.2.1 Visual cueing training.

Participants in the CUE intervention were shown two blocks of three videos each (six videos total). Block A showed three clips of offensive plays, and Block B showed three clips of defensive plays. The blocks were randomised for each participant, and the videos within each block were randomised so that no participant saw the same order of videos. The participants saw each video clip three separate times. The first time showed the clip in full, with no pauses or cueing added to the first viewing. The second time showed the clip in full, with pauses and multi-coloured cues added. Multi-coloured (green, yellow, red) cues (circles and arrows) directed participants' attention to important visual cues on the screen. The third time showed the clip in full, with no pauses or cues. Once participants completed all ten video clips, they progressed to the post-training WHN test.

5.2.6.2.2 Expert commentary training.

Participants in the COM intervention were shown two blocks of three videos each (six videos total), which were the same videos shown to the CUE intervention group. Block A showed three clips of offensive plays, and Block B showed three clips of defensive plays. The blocks were randomised for each participant, and the videos within each block were randomised so that no participant saw the same order of videos. The participants saw each video clip three separate times. The first time showed the clip in full, with no pauses or cueing added to the first viewing. The second time showed the clip in full, with pauses and commentary added. Pauses at important moments in the play were held for the duration of the commentary segment before progressing through the clip. Audio commentary played during the pauses directed participants' attention to important visual cues on the screen. The third time showed the clip in full, with no pauses or commentary. Once participants completed all ten video clips, they progressed to the post-training WHN test.

5.2.6.2.3 Control training.

Participants in the CONT intervention were shown a video which explained relevant polo instructions, but not anything regarding anticipation strategies. This video was shown once. After the completion of the video, participants progressed to the post-training WHN test.

5.2.6.3 Post-training WHN test.

Once participants completed their training interventions, they were given a brief rest if needed. Upon resuming the experiment, participants completed the post-training WHN test. This test followed the exact same format as the pre-training WHN test; however, different video stimuli were used. This task took approximately 10 – 15 minutes to complete. Participants' eye movements were calibrated before the practice clips and twice during each block (at the beginning and halfway through the block) for a total of five times. Participants were then thanked, debriefed, and emailed a link to claim their £10 Amazon voucher. Nottingham Trent University Psychology students were awarded 6 SONA credits. Overall, the experiment took no more than one hour, including breaks.

5.2.7 Data analysis.

5.2.7.1 WHN test accuracy scores.

The outcome variable was the WHN accuracy score. Each individual trial was scored discretely, with 1 = correct and 0 = incorrect. Each participant was then awarded an overall accuracy percentage for the task based on the ratio of correct trials out of 18 (*e.g.,* 9 correct out of 18 would earn an accuracy percent of 50%). The higher the accuracy percentage, the better the participant's SA. The first main effects predictor variable was the training intervention, separated into three training groups: CUE, COM, CONT. The second main effects predictor variable was the WHN test, separated into two tests: pre-training and post-training. The random effects variables were the participant ID and clip number (trial) and were analysed with a fixed slope. The participant ID was analysed as a nested random effect, and the clip number was analysed as a crossed random effect.

Binary logistic mixed effects modelling was used to determine the relationship between WHN accuracy and the predictor variables. The data analysis was performed using R (Version 3.6.3) (R Core Team, 2020) with the *lme4* package (Bates et al., 2020). Model comparisons were used to determine the overall best 'fit' of the data. Each model was run sequentially in order of increasing complexity, beginning with a null model (a model with constants instead of fixed effects). Each main (fixed) effect was added to the model and compared with the previous model. For the main effects models, all fixed effects were included for each model comparison. Interaction effects were also examined. Reduced-maximum likelihood ratios (REML) were used to compare the current model with the previous one to generate *p*-values (Luke, 2017), and any interaction was broken down using post-hoc Tukey tests. For the interaction effects, the fixed effects were modelled as a two-way interaction of training group x WHN test.

5.2.7.2 Number of gaze fixations and fixation durations.

The first eye movement behaviours outcome variable was the number of fixations on each Area of Interest (AOI), defined as the 'ball proxim' and 'off-ball'. Each fixation, which lasted greater than or equal to 150ms (Vansteenkiste et al., 2015) and remained in a small, localised area (Blignaut, 2009), was counted for each AOI in each trial in the pre- and post-training WHN tests. The second eye movement behaviours outcome variable was the average length of fixation durations on each AOI for each trial in the pre- and post-training WHN tests as, and fixation durations as a function of percentage of time. The first main effects predictor variable for the eye movement behaviours were the Areas of Interest (AOI), which were defined as the 'ball proxim' and 'off-ball'. 'Ball proxim' referred to the actual ball in addition to the ball-handler (if applicable). 'Off-ball' referred to the rest of the scene excluding the ball and ball-handler. The second main effects predictor variable was the WHN test, followed by the third main effects predictor variable, the training groups. The random effects variables were the participant ID and clip number (trial) and were analysed with a fixed slope. The participant ID was analysed as a nested random effect, and the clip number was analysed as a crossed random effect.

Linear mixed effects modelling was used to determine the relationships between the eye movement behaviours (number of fixations and fixation durations) and several predictor variables. The data analysis was performed using R (Version 3.6.3) (R Core Team, 2020) with the *lme4* package (Bates et al., 2020). Model comparisons were used to determine the overall best 'fit' of the data. Each model was run sequentially in order of increasing complexity, beginning with a null model. Each main (fixed) effect was added to the model and compared with the previous model. For the main effects models, all fixed effects were included for each model comparison. Interaction effects were also examined. Reduced-maximum likelihood ratios (REML) were used to compare the current model with the previous one to generate *p*-values (Luke, 2017), and any interaction was broken down using post-hoc Tukey tests. For the interaction effects, the fixed effects were modelled as a three-way interaction of AOI x WHN test x training group.

5.2.7.3 Average fixation dispersions.

The last eye movement behaviours outcome variable was the average fixation dispersions, or how broadly the participants searched the scene on the x and y axis, measured in pixels. The first main effects predictor variable was the WHN test (pre-training and post-training), followed by the training groups (CUE, COM, CONT). The random effects variables were the participant ID and clip number (trial) and were analysed with a fixed slope. The participant ID was analysed as a nested random effect, and the clip number was analysed as a crossed random effect. As with the analyses for the number of fixations and fixation durations, the data for the average fixation dispersions was analysed using linear mixed effects modelling, where the best 'fit' of the data is determined using model comparisons. Each main effect was added to the model and compared with the previous model. For the interaction effects, the fixed effects were modelled as a two-way interaction of WHN test x training group.

5.3 Results

5.3.1 WHN test accuracy.

The data was analysed as a 3 x 2 binary logistic mixed effects model with the training group (visual cueing (CUE), expert commentary (COM), and control (CONT)) and the WHN test (pre-training and post-training) measured as the predictor variables. For the outcome variable, performance was measured as accuracy in the WHN task. Participant ID and clip number were analysed as random effects. The accuracy percentages were collected over 36 video clips (18 offensive, 18 defensive) over two tests. The mean (and standard deviation) accuracy scores for each training group (CUE, COM, CONT) by each test (pre-training, post-training) are shown in Table 5.3.

Table 5.3 *Mean WHN accuracy scores (out of 100), and standard deviations for the pre-training WHN test and post-training WHN test by training group (CUE, COM, CONT).*

	Pre-Training WHN Test	Post-Training WHN Test
CUE	26.79 (44.38)	34.64 (47.67)
COM	27.60 (44.82)	30.00 (45.92)
CONT	27.60 (44.82)	31.25 (46.44)

Note. N = 38.

5.3.1.1 Main effects.

A binary logistic mixed effects model analysis was used to examine the effects of the predictor variables, training group (CUE, COM, CONT) and WHN test period (pre-training and post-training), on the outcome variable, or WHN accuracy. Fixed effects were added, one at a time, to models of increasing complexity and were compared using likelihood ratio tests to the model prior. See Table 5.4 for a list of the main effects model comparisons. Results showed that there were no main effects of training group (χ^2 (2) =0.40, p = 0.82) or WHN test (χ^2 (1) = 0.51, p = 0.48). Figure 5.4 shows the predicted (95%) confidence intervals for the overall WHN accuracy by training group, Figure 5.5 shows the predicted (95%) confidence intervals for the WHN accuracy by WHN test.

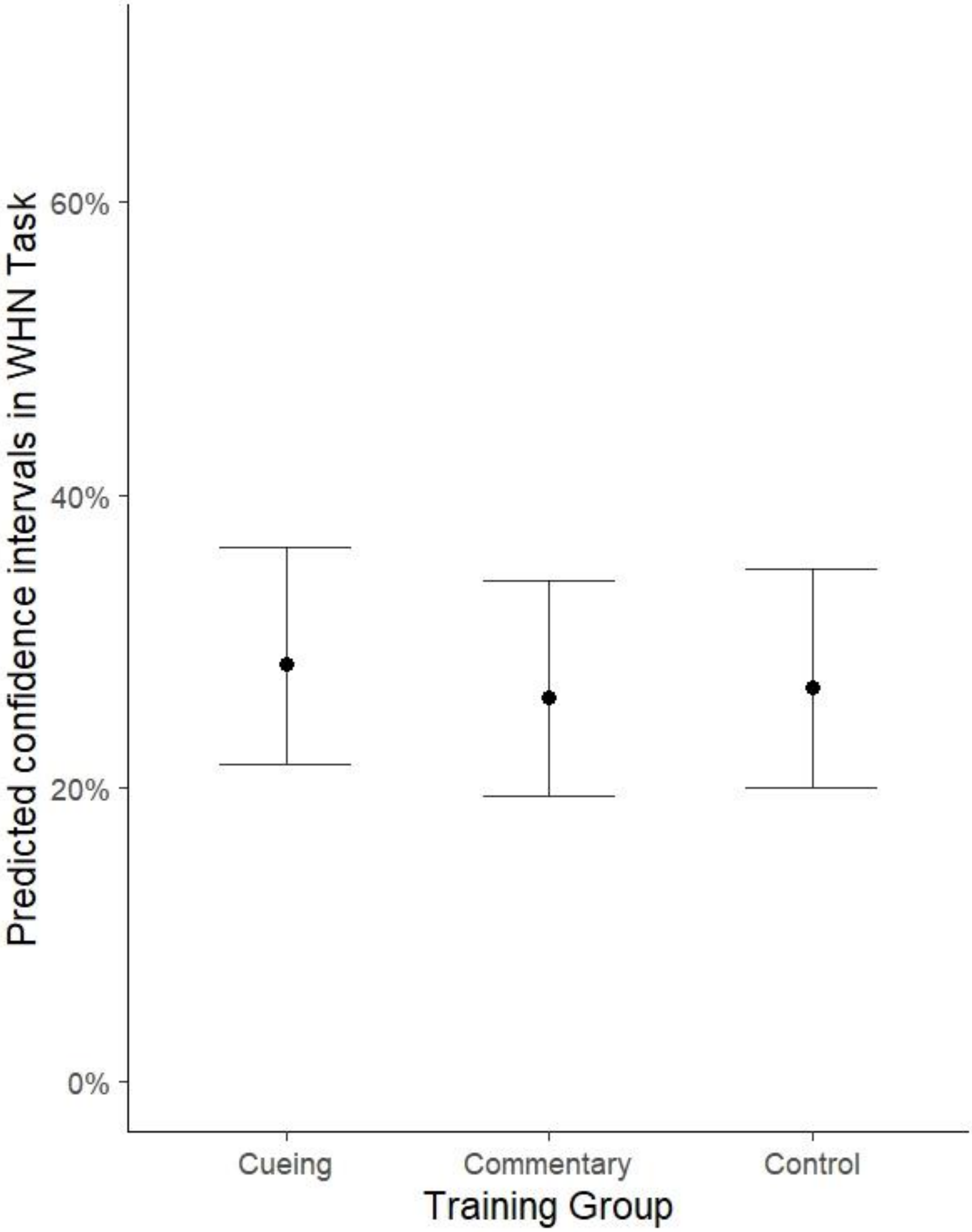

Figure 5.4 *Predicted (95%) confidence intervals of WHN accuracy by training group.*

Note. N = 38.

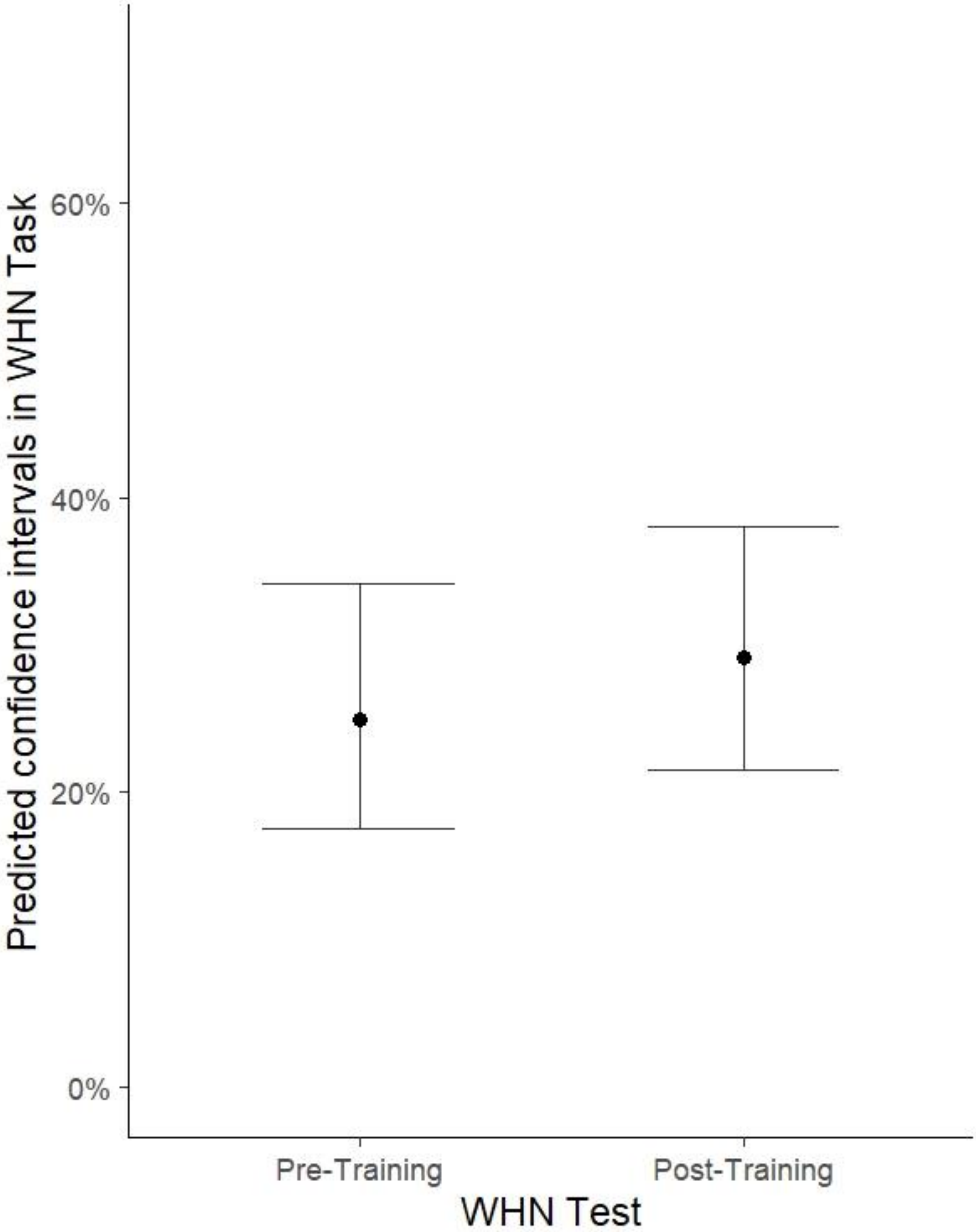

Figure 5.5 *Predicted (95%) confidence intervals of WHN accuracy by WHN test.*

Note. N = 38.

Table 5.4 *List of main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	1580.9	-	-	-
ME1	Training Group	ME1 / Null	1584.5	0.40	2	0.82
ME2	Training Group + WHN Test	ME2 / ME1	1586.0	0.51	1	0.48

Note. N = 38.

5.3.1.2 Interaction effects.

Table 5.5 presents the list of interaction effects models. Results showed there were no two-way interaction effects of training group by WHN test (χ^2 (2) = 1.01, p = 0.60). Figure 5.6 shows the predicted (95%) confidence intervals of the training groups (CUE, COM, CONT) by the WHN tests (pre-training and post-training).

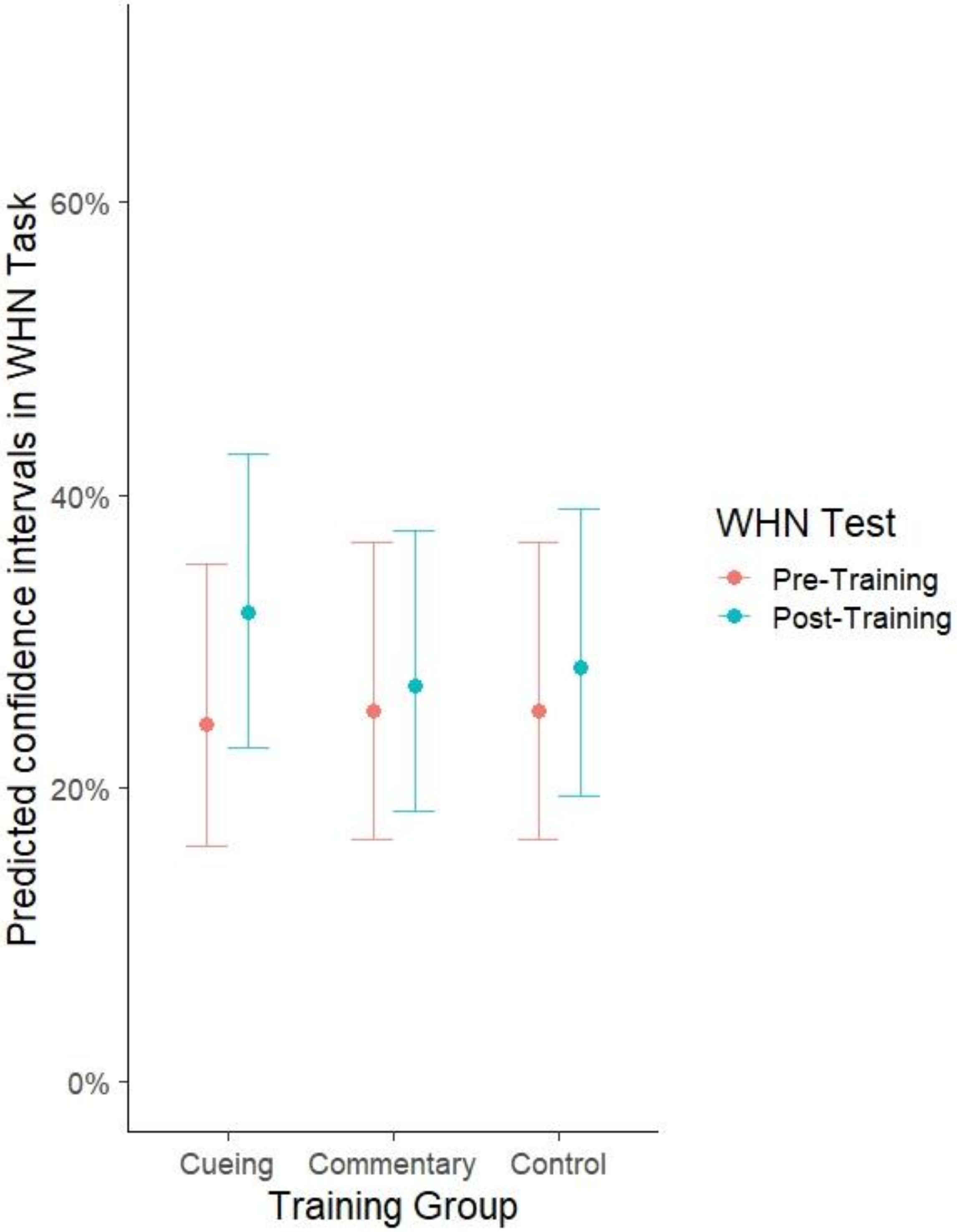

Figure 5.6 *Predicted (95%) confidence intervals for each training group by WHN test.*

Table 5.5 *List of interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	1580.9	-	-	-
ME1	Training Group	ME1 / Null	1584.5	0.40	2	0.82
ME2	Training Group + WHN Test	ME2 / ME1	1586.0	0.51	1	0.48
INT1	Training Group x WHN Test	INT1 / ME2	1589.0	1.01	2	0.60

Note. N = 38.

5.3.2 Number of gaze fixations.

The data was analysed as a 2 x 3 x 2 linear mixed effects model with the area of interest (AOI; ball proxim, off-ball), the WHN test (pre-training, post-training), and training group (CUE, COM, CONT), measured as the predictor variables. For the outcome variable, performance was measured as the number of fixations. Participant ID and clip number were analysed as random effects. The fixation counts were collected over 36 video clips (18 offensive, 18 defensive) over two tests. The mean (and standard deviation) number of fixations for each test (pre-training, post-training) and AOI (ball proxim, off-ball) by training group (CUE, COM, CONT) are shown in Table 5.6.

Table 5.6 *Means and standard deviations of the number of fixations for each WHN test (pre-training, post-training) and Area of Interest (ball proxim, off-ball) by the training group (CUE, COM, CONT).*

	Pre-Training WHN Test		Post-Training WHN Test	
	Ball Proxim	Off-Ball	Ball Proxim	Off-Ball
CUE	22.37 (16.01)	30.03 (19.71)	23.67 (18.29)	32.73 (22.78)
COM	23.45 (16.82)	32.86 (20.60)	23.49 (17.75)	33.02 (22.00)
CONT	21.76 (17.86)	28.71 (21.80)	22.96 (18.54)	31.04 (22.57)

Note. N = 38.

5.3.2.1 Main effects.

A linear mixed effects model analysis was used to examine the effects of the predictor variables, AOI, WHN test, and training group, on the outcome variable, or number of fixations. Fixed effects were added, one at a time, to models of increasing complexity and were compared using likelihood ratio tests to the model prior. See Table 5.7 for a list of the main effects model comparisons. Results showed that the main effect of model of AOI best fit the data (χ^2 (1) = 140.09, $p < 0.001$). Pairwise comparisons with Tukey corrections revealed that there were more fixations off the ball (M = 31.45, SD = 21.66) than on the ball proxim (M = 22.98, SD = 31.45; $p < 0.001$). Figure 5.7 shows the ranges, interquartile ranges, and medians of the number of fixations for each Area of Interest (AOI).

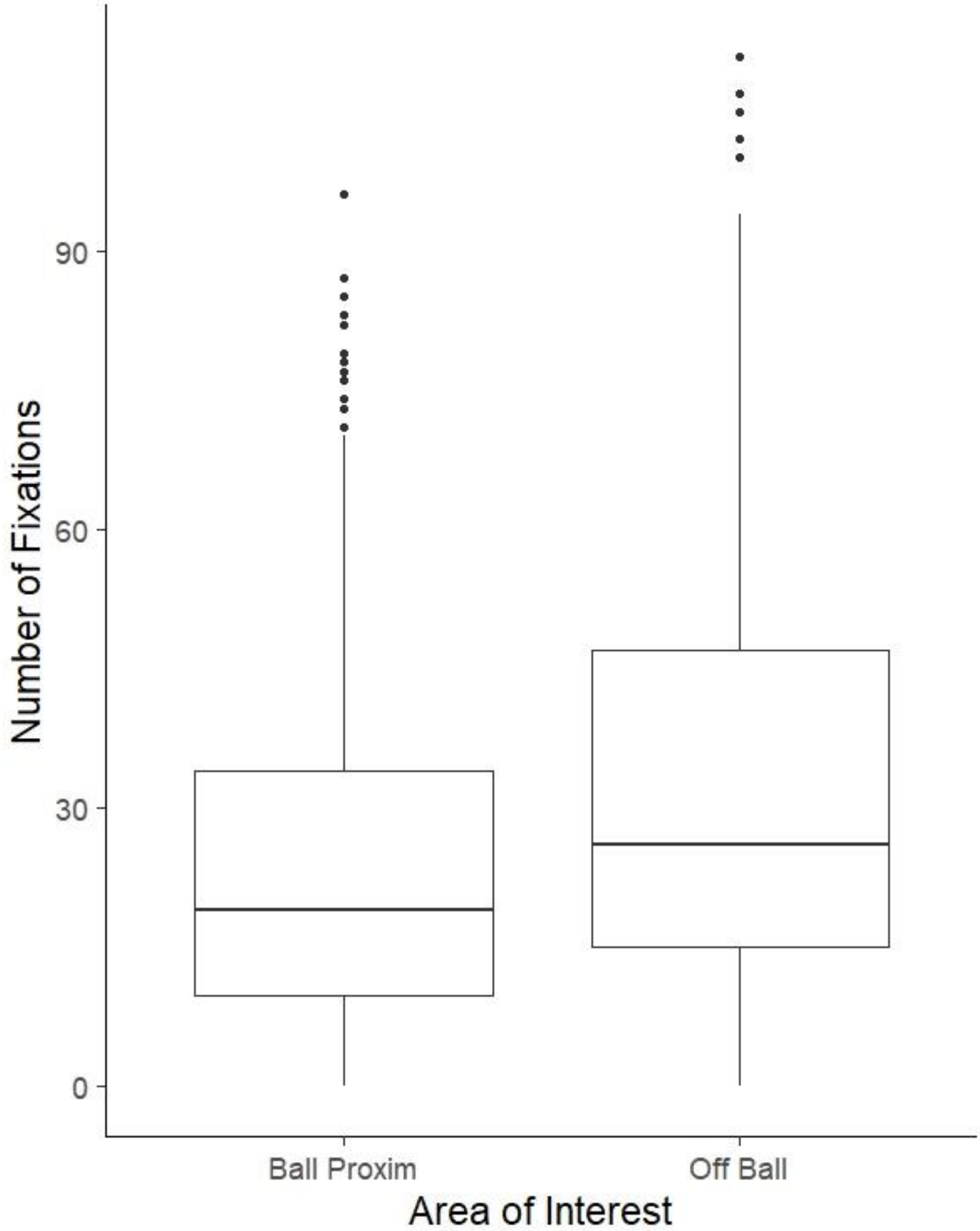

Figure 5.7 *The ranges, interquartile ranges, and medians of the number of fixations for each Area of Interest (AOI).*

Note. N = 38.

Table 5.7 *List of main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	22568	-	-	-
ME1	AOI	ME1 / Null	22429	140.09	1	< 0.001
ME2	AOI + WHN Test	ME2 / ME1	22428	3.16	1	0.07
ME3	AOI + WHN Test + Training Group	ME3 / ME2	22432	0.36	2	0.83

Note. N = 38.

5.3.2.2 Interaction effects.

Table 5.8 presents the list of interaction effects models. Results showed there were no two-way interaction effects of AOI by WHN test (χ^2 (1) = 0.41, p = 0.52) or three-way interaction effects of AOI by WHN test by training group (χ^2 (8) = 1.99, p = 0.93).

Table 5.8 *List of interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	22568	-	-	-
ME1	AOI	ME1 / Null	22429	140.09	1	< 0.001
ME2	AOI + WHN Test	ME2 / ME1	22428	3.16	1	0.07
ME3	AOI + WHN Test + Training Group	ME3 / ME2	22432	0.36	2	0.83
INT1	AOI x WHN Test	INT1/ME2	22430	0.41	1	0.52
INT2	AOI x WHN Test x Training Group	INT2/INT1	22444	1.99	8	0.93

Note. N = 38.

5.3.3 Fixation durations.

5.3.3.1 Average fixation durations (ms).

The data was analysed as a 2 x 3 x 2 linear mixed effects model with the area of interest (AOI; ball proxima, off-ball), training group (CUE, COM, CONT), and the WHN test (pre-training, post-training) measured as the predictor variables. For the outcome variable, performance was measured as the average fixation duration (ms). Participant ID and clip number were analysed as random effects. The average fixation durations (ms) were collected over 36 video clips (18 offensive, 18 defensive) over two tests. The mean (and standard deviation) fixation duration (ms) for each test (pre-training, post-training) and AOI (ball proxim, off-ball) by training group (CUE, COM, CONT) are shown in Table 5.9.

Table 5.9 *Means and standard deviations of the fixation durations (ms) for each WHN test (pre-training, post-training) and Area of Interest (ball proxim, off-ball) by the training group (CUE, COM, CONT).*

	Pre-Training WHN Test		Post-Training WHN Test	
	Ball Proxim	Off-Ball	Ball Proxim	Off-Ball
CUE	221.00 (132.06)	209.06 (110.80)	228.57 (122.93)	216.66 (100.74)
COM	209.80 (126.00)	202.63 (99.66)	220.46 (117.26)	206.82 (89.99)
CONT	190.06 (134.68)	185.78 (115.17)	198.30 (112.36)	185.77 (91.68)

Note. N = 38.

5.3.3.1.1 Average fixation durations (ms) main effects.

A linear mixed effects model analysis was used to examine the effects of the predictor variables, training group, WHN test, and clip type, on the outcome variable, or average fixation durations (ms). Fixed effects were added, one at a time, to models of increasing complexity and were compared using likelihood ratio tests to the model prior. See Table 5.10 for a list of the main effects model comparisons. Results showed that there was a main effect of AOI (χ^2 (1) = 10.75, p = 0.001). Pairwise comparisons with Tukey corrections revealed that there were longer average fixation durations (ms) on the ball proxim (*M* = 212.33, *SD* = 124.73) than off the ball (*M* = 201.86, *SD* = 102.04; p = 0.001). Figure 5.8 shows the ranges, interquartile ranges, and medians of the fixation duration (ms) for each Area of Interest (AOI).

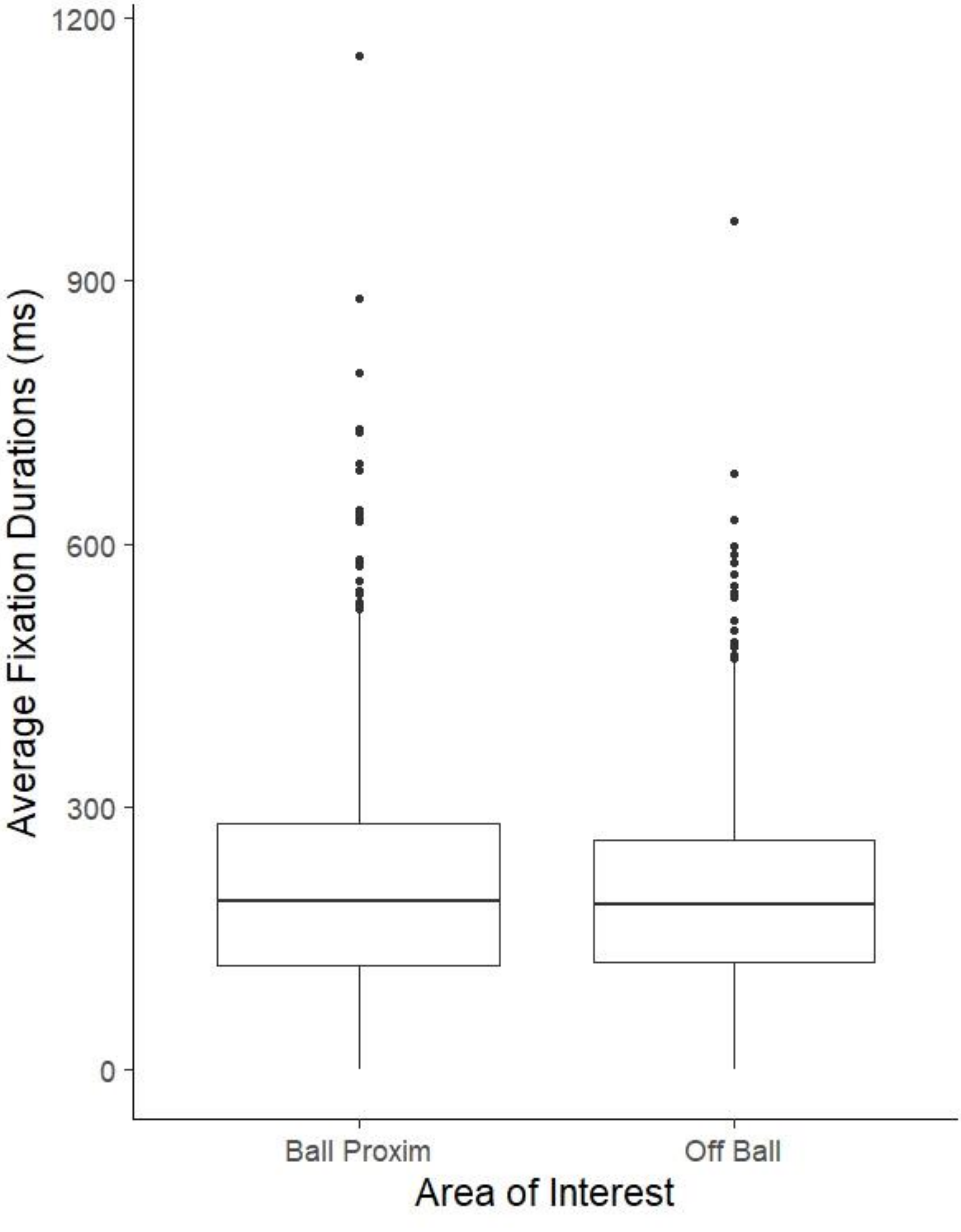

Figure 5.8 *The ranges, interquartile ranges, and medians of the average fixation durations (ms) for each Area of Interest.*

Table 5.10 *List of fixation durations (ms) main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	30272	-	-	-
ME1	AOI	ME1 / Null	30281	10.75	1	0.001
ME2	AOI + WHN Test	ME2 / ME1	30270	3.66	1	0.06
ME3	AOI + WHN Test + Training Group	ME3 / ME2	30273	1.46	2	0.48

Note. N = 38.

5.3.3.1.2 Fixation durations (ms) interaction effects.

Table 5.11 presents the list of interaction effects models. Results showed there was no two-way interaction effects of AOI x WHN Test (χ^2 (1) = 0.53, p = 0.47) and no three-way interaction effects of AOI x WHN Test x Training Group (χ^2 (8) = 2.95, p = 0.94).

Table 5.11 *List of fixation duration (ms) interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	30272	-	-	-
ME1	AOI	ME1 / Null	30281	10.75	1	0.001
ME2	AOI + WHN Test	ME2 / ME1	30270	3.66	1	0.06
ME3	AOI + WHN Test + Training Group	ME3 / ME2	30273	1.46	2	0.48
INT1	AOI x WHN Test	INT1/ME2	30272	0.53	1	0.47
INT2	AOI x WHN Test x Training Group	INT2/INT1	30285	2.95	8	0.94

Note. N = 38.

5.3.3.2 Fixation durations as a percentage of time.

The data was analysed as a 2 x 3 x 2 linear mixed effects model with the area of interest (AOI; ball proxima, off-ball), training group (CUE, COM, CONT), and the WHN test (pre-training, post-training) measured as the predictor variables. For the outcome variable, performance was measured as the fixation duration as a function of percentage of time. Participant ID and clip number were analysed as random effects. The fixation durations (ms) were collected over 36 video clips (18 offensive, 18 defensive) over two tests. The mean (and standard deviation) fixation duration (ms) for each test (pre-training, post-training) and AOI (ball proxim, off-ball) by training group (CUE, COM, CONT) are shown in Table 5.12.

Table 5.12 *Means and standard deviations of the fixation durations (%) for each WHN test (pre-training, post-training) and Area of Interest (ball proxim, off-ball) by the training group (CUE, COM, CONT).*

	Pre-Training WHN Test		Post-Training WHN Test	
	Ball Proxim	Off-Ball	Ball Proxim	Off-Ball
CUE	21.60 (15.76)	27.32 (17.65)	21.44 (14.06)	28.16 (16.14)
COM	21.07 (14.80)	28.16 (16.16)	21.13 (13.45)	28.33 (15.66)
CONT	19.45 (15.48)	24.54 (18.01)	20.02 (14.80)	26.00 (17.37)

Note. N = 38.

5.3.3.2.1 Fixation durations (%) main effects.

A linear mixed effects model analysis was used to examine the effects of the predictor variables, training group, WHN test, and clip type, on the outcome variable, or fixation durations as a function of percentage of time. Fixed effects were added, one at a time, to models of increasing complexity and were compared using likelihood ratio tests to the model prior.

See Table 5.13 for a list of the main effects model comparisons. Results showed that there was a main effect of AOI (χ^2 (1) = 179.22, $p < 0.001$). Pairwise comparisons with Tukey corrections revealed that there was a larger percentage of time spent fixating on areas off the ball (*M* = 31.45, *SD* = 21.66) than on the ball proxim (*M* = 22.98, *SD* = 17.56; *p* = 0.001). Figure 5.9 shows the ranges, interquartile ranges, and medians of the fixation duration (%) for each Area of Interest (AOI).

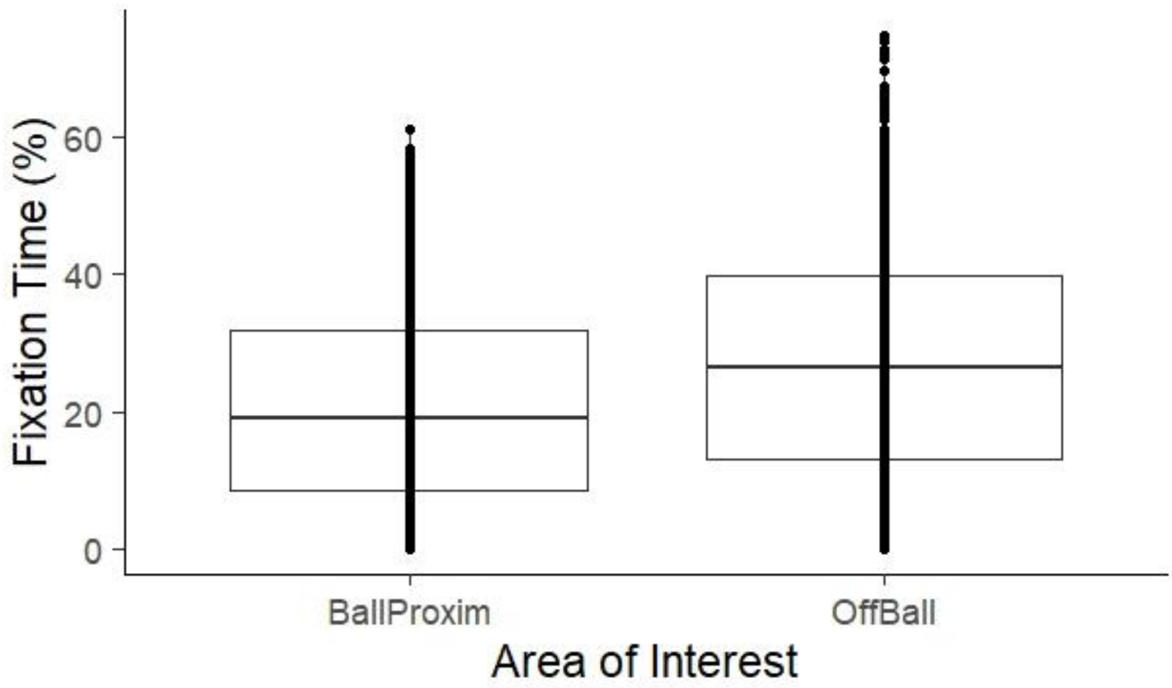

Figure 5.9 *The ranges, interquartile ranges, and medians of the average fixation durations (%) for each Area of Interest.*

Table 5.13 *List of fixation durations (%) main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	20535	-	-	-
ME1	AOI	ME1 / Null	20358	179.22	1	< 0.001
ME2	AOI + WHN Test	ME2 / ME1	20359	1.21	1	0.27
ME3	AOI + WHN Test + Training Group	ME3 / ME2	20362	0.62	2	0.73

Note. N = 38.

5.3.3.2.2 Fixation durations (%) interaction effects.

Table 5.14 presents the list of interaction effects models. Results showed there was no two-way interaction effects of AOI x WHN Test (χ^2 (1) = 0.65, p = 0.43) and no three-way interaction effects of AOI x WHN Test x Training Group (χ^2 (8) = 2.85, p = 0.94).

Table 5.14 *List of fixation duration (%) interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	20535	-	-	-
ME1	AOI	ME1 / Null	20358	179.22	1	< 0.001
ME2	AOI + WHN Test	ME2 / ME1	20359	1.21	1	0.27
ME3	AOI + WHN Test + Training Group	ME3 / ME2	20362	0.62	2	0.73
INT1	AOI x WHN Test	INT1/ME2	20360	0.65	1	0.43
INT2	AOI x WHN Test x Training Group	INT2/INT1	20373	2.85	8	0.94

Note. N = 38.

5.3.4 Average area of fixation dispersions.

The data was analysed as a 3 x 2 linear mixed effects model with the WHN test (pre-training, post-training) and training group (CUE, COM, CONT) measured as the predictor variables. For the outcome variable, performance was measured as the average area of fixation dispersions (pixels). Participant ID and clip number were analysed as random effects. The average fixation dispersion areas (pixels) were collected over 36 video clips (18 offensive, 18 defensive) over two tests. The mean (and standard deviation) fixation dispersions (pixels) for each WHN test (pre-training, post-training) by training group (CUE, COM, CONT) are shown in Table 5.15.

Table 5.15 *Means and standard deviations of the average area of fixation dispersions (pixels) for each WHN test (pre-training, post-training) by each training group (CUE, COM, CONT).*

	Pre-Training WHN Test	Post-Training WHN Test
CUE	108.84 (189.19)	65.82 (57.19)
COM	105.53 (147.56)	59.66 (21.54)
CONT	146.73 (286.23)	73.95 (86.90)

Note. N = 38.

5.3.4.1 Main effects.

A linear mixed effects model analysis was used to examine the effects of the predictor variables, training group, WHN test, on the outcome variable, or average fixation dispersions (pixels). Fixed effects were added, one at a time, to models of increasing complexity and were compared using likelihood ratio tests to the model prior. See Table 5.16 for a list of the main effects model comparisons. Results showed that there was a main effect of WHN test (χ^2 (1) =

43.92, $p < 0.001$). Pairwise comparisons with Tukey corrections revealed that there was a significant reduction in the dispersion of fixations between the pre-training WHN test (M = 118.26, SD = 210.20) and the post-training WHN test (M = 66.44, SD = 61.30; $p < 0.001$), so that the post-training WHN test had a smaller average fixation dispersion area than the pre-training WHN test. Figure 5.10 shows the ranges, interquartile ranges, and medians of the average fixation dispersions (pixels) for each WHN test.

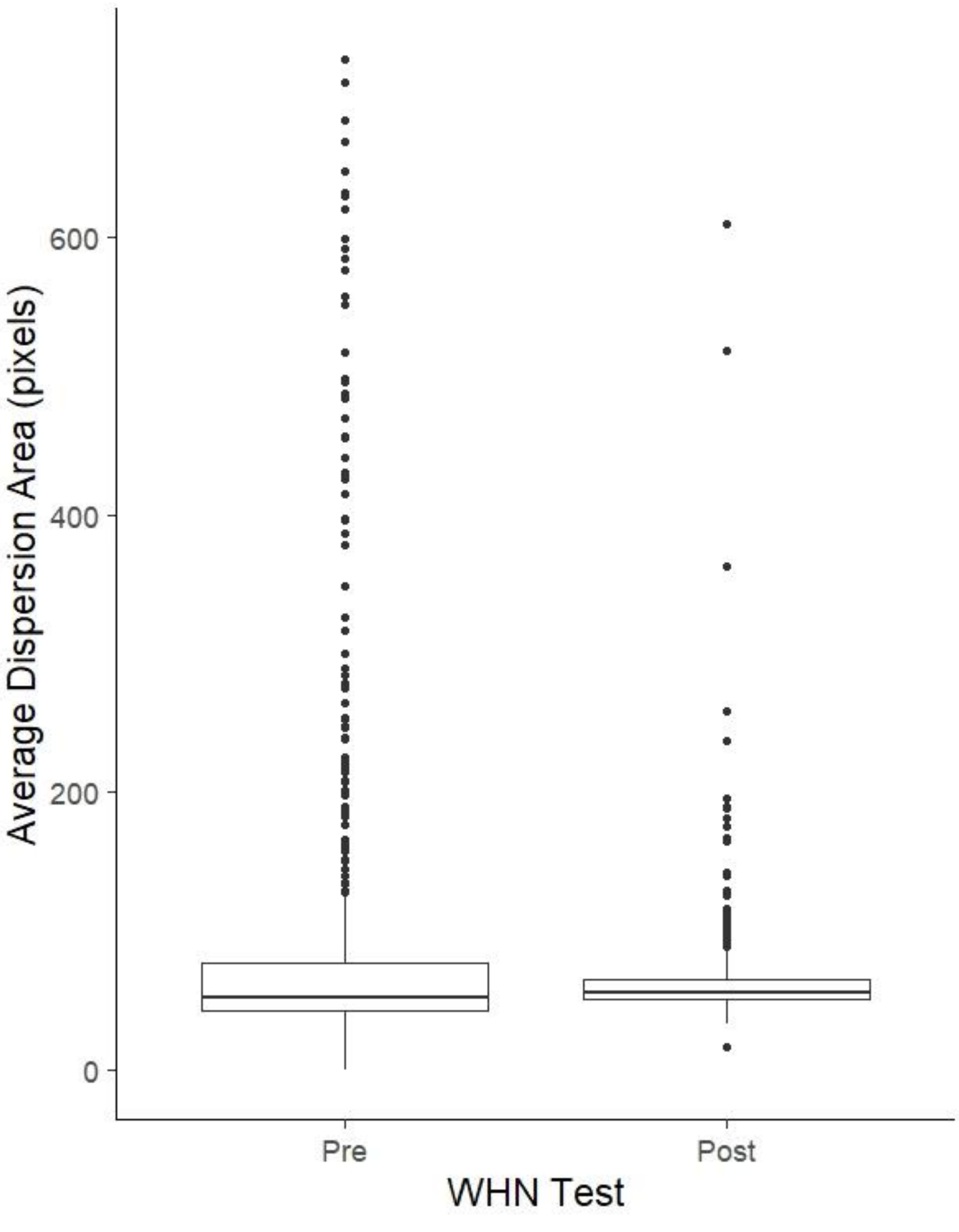

Figure 5.10 *The ranges, interquartile ranges, and medians of the average fixation dispersion area by the WHN test.*

Table 5.16 *List of main effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	16378	-	-	-
ME1	WHN Test	ME1 / Null	16337	43.92	1	< 0.001
ME2	WHN Test + Training Group	ME2 / ME1	16338	2.80	2	0.25

Note. N = 38.

5.3.4.2 Interaction effects.

Table 5.17 presents the list of interaction effects models. Results showed there was no two-way interaction effects of WHN test by training group (χ^2 (2) = 2.98, p = 0.23).

Table 5.17 *List of interaction effects model comparisons.*

Model No.	Fixed Effects	Model Comparison	AIC	χ^2	*df*	*p*
Null	Null	-	16378	-	-	-
ME1	WHN Test	ME1 / Null	16337	43.92	1	< 0.001
ME2	WHN Test + Training Group	ME2 / ME1	16338	2.80	2	0.25
INT1	WHN Test x Training Group	INT1/ME2	16339	2.98	2	0.23

Note. N = 38.

5.4 Discussion

The first aim of the study was to investigate the efficacy of different cueing-based training interventions on WHN performances in complete beginners. It was hypothesised that participants in the training intervention groups, both visual cueing and expert commentary, would show an improvement in WHN accuracy scores in the post-training WHN test compared to the participants in the control group, and that of the training groups, the participants in the expert commentary (COM) group would have better WHN accuracy scores in the post-training WHN test compared to the participants in the visual cueing (CUE) group. It was also hypothesised that there would be an interaction between training group and WHN test, with the training groups showing better accuracy scores in the post-training WHN test. There was no evidence to support these hypotheses, with all training groups performing similarly to each other in both the pre-training and post-training WHN tests. A second aim of the study was to examine the visual search behaviours and eye movements, such as gaze fixations, durations, and dispersions, in a WHN task before and after training to investigate if training SA produces a shift in attention—as measured by eye movements—towards relevant areas of the environment (indicating a shift from bottom-up to top-down processing). It was hypothesised that there would be more fixations on locations off the ball during the post-training WHN test compared to the pre-training WHN test, and that the fixation durations off the ball would be longer during the post-training WHN test compared to the pre-training WHN test. Lastly, it was believed that there would be a wider dispersion of gaze fixations along the *x* and *y* axis during the post-training WHN test compared to the pre-training WHN test, indicative of a wider search. There was also no evidence to support these hypotheses. Participants, regardless of training group, demonstrated fewer fixations of longer durations on the ball (ball proxim AOI). Additionally, following training, participants actually reported smaller average fixation dispersions in the post-training WHN test. The following sections will discuss the results, the theoretical rationale with support from the literature, and the implications of the study.

5.4.1 Situation Awareness training did not lead to an improvement in WHN performance.

This study devised an experiment to investigate the effectiveness of different training methods in improving SA in a polo WHN task in participants with no prior polo experience. It was hypothesised that the expert commentary training would provide the largest improvement in WHN accuracy scores, followed by the visual cueing training. The expert commentary training theoretically would have provided the participants with information to shift attention to relevant areas of the environment whilst also providing information on the significance of those locations. In other words, the commentary would have provided the when, where, and why of the visual search, which should have allowed participants to achieve Level I SA (perception) and Level II SA (comprehension), and thus have a better strategy for predicting what would happen next (Level III SA, projection). Conversely, the visual cueing training would have only provided the when and where (Level I SA), as there was no context provided on why participants should look at a certain location. The results showed that SA training interventions did not lead to an improvement in in WHN performance, as was initially hypothesised. Instead, participants, regardless of training intervention, performed similarly to each other in the WHN tests. Therefore, it appears that the SA training was ineffective for this study.

One such reason for the lack of improvement in WHN performance may be that the training interventions, both expert commentary and visual cueing, did not provide enough information to adequately build SA in a polo WHN task. It is possible that, because the participants had no prior knowledge of polo, the information that was provided in the training interventions was too complex, or participants were unable to grasp the fundamentals of the training; there was no mental model to work from, and therefore the information was mostly meaningless. There is, additionally, the possibility that the training interventions themselves created a high cognitive load which ultimately hindered any learning effects. The visual cueing training, consisting of moving coloured arrows and circles, may have been difficult to follow or understand. Thus, in future endeavours, examining and reducing the complexity of the training stimuli should be considered.

Importantly, of the SA training studies presented earlier, none of the studies sampled true beginners (no prior experience). The participants all had some level of experience for the training to build upon, unlike this study which sampled participants with no prior polo experience. Interestingly, it was even shown that SA training actually benefitted those with more experience in a domain than those with less experience, suggesting that experience makes learning easier in complex situations (Castro et al., 2016). In sports visual training studies, participants with no prior experience did not benefit from training interventions (Abernethy & Wood, 2001). In a driving HP training study, the experienced drivers showed the most improvement following an expert commentary training intervention; the authors believed that experience is important for learning because individuals with more experience have been exposed to more situations, and therefore, have a better foundation and understanding of the domain in general (Castro et al., 2016). Similarly, Litchfield et al. (2010) showed that novices with at least some level of experience benefitted the most from training programmes. Thus, sports SA training may only be useful to learners who have a basic knowledge or understanding of the sport; attempting to train SA in a complicated sport like polo to individuals with no such prior experience may have been akin to teaching calculus to children who are just learning how to add and subtract.

The results of the current study suggest that developing a SA training programme for true novices is a complex task, and as it stands, the visual cueing and commentary training might not provide enough information to be useful for beginners. Without any prior knowledge, experience, or familiarity with the sport, training beginners where to focus their attention to 'see like an expert' may have been overzealous. A more effective training study could instead first take polo players of differing experience levels and identify their visual behaviours and information processing mechanisms. Do more experienced players exhibit different loci of attention and scan paths? What do experienced players consider to be important visual cues in a polo scene? Do those visual cues differ by experience level? Does this correspond with WHN accuracy scores? This would better demonstrate experience differences, and those results could then be used to perhaps more effectively train beginners. As discussed in the beginning of this chapter, there is a need to train the game flow and strategy in beginner polo players without endangering themselves and the horses; in other words, an off-field training programme to introduce new players to the sport and develop SA before they even pick up a mallet. The current study's results simply represent a need to delve further into experience differences in SA and visual behaviours to truly develop a training programme.

Another explanation for a lack of training effect may have stemmed from the length of the training itself. The training sessions in the current study were also only about fifteen minutes in length, and participants were only trained once before they were tested. This may have also been detrimental to the success of the training interventions. Complex, higher-order cognitive skills, such as SA, are not thought to be learned in a short setting, particularly in a completely novice population. This is most notably evident in learning how to drive: new drivers are not fully licensed after one afternoon of training, but instead (depending on the country) after several hours of classroom instruction and practical driving experience (Peck, 2011; Watson-Brown et al., 2020); even then, newly drivers are still classified as 'probational' with restrictions on their licenses (Curry et al., 2013). In sports, it is argued that to become an 'expert' takes years of training (Ericsson, 2008; Williams & Ericsson, 2005), not one practice session. Notably, when training SA specifically, it has been suggested that more than one training session is needed to fully train SA (Chauvin et al., 2009). Therefore, it possible that for the polo SA training to be effective, there should be several sessions spread out over a period of time. This would, potentially, allow novices to gain more background knowledge and experience in the sport, an import aspect in learning complex cognitive skills (Castro et al., 2016; Litchfield et al., 2010).

Of note, it may be argued that the training programme tested in this study may not have actually targeted SA in the first place. This might explain the lack of a training effect, however, there are a few rebuttals against this supposition. The training programme, consisting of both visual cueing and expert commentary stimuli, were modelled after the training studies presented in the literature review; these reviewed studies showed promise in their ability to target and train SA and its underlying components (perception, comprehension). Thus, the current study's training programme took a grounded theoretical approach for its development. Additionally, as with SA research as a whole, different methodologies and assessment approaches are developed with the assumption that they are tapping into SA abilities; the training studies that were reviewed and the training programme that was developed also make that assumption based on the behavioural performance of participants. Based on how participants perform in the task, which was created to specifically target specific skills, inferences may be made about their cognitive and SA abilities. Therefore, while this study was theoretical, it still has its merits for furthering the field of sports SA.

5.4.2 Eye movement behaviours demonstrated attentional allocation towards the ball.

The number of fixations, average length of fixation durations (ms), fixation durations as a percentage of time, and average area of fixation dispersions were used as inference measures of participants' attentional allocation, with the location of those fixations indicative of the locus of attention (Frischen et al., 2007; Styles, 2006), the durations indicative of processing time (Falkmer et al., 2008), and the dispersions indicative of how wide of a search was conducted (Blignaut, 2009). The participants, regardless of training condition, displayed fewer fixations of longer durations on the ball proxim AOI, suggesting that their attention was directed at the ball/ball-handler. It was originally hypothesised that, following training, participants in the training groups would display more fixations off the ball in the post-training WHN test, which would suggest that the training promoted off the ball visual searching, as was demonstrated in Chapter 3 with the STB studies where experienced athletes were better than controls in image conditions where the athlete's gaze was off the ball. Off-the-ball searching has been linked to experience in a sport, with experienced athletes demonstrating that they do not need to fixate on the ball (*i.e.,* track the ball) during its entire flight to successfully hit it (Land & McLeod, 2000), and that they spend less time fixating on the ball-handler (Ryu et al., 2013); this ultimately suggests that experience in a sport allows an athlete to, essentially, take their eyes off the ball while gathering additional information. This study showed that the participants, despite undergoing training, mainly gathered information stemming from the ball/ball-handler. This potentially highlights the higher processing demands in beginners; the beginners, instead of searching the entire playing field as an experienced player would, 'zeroed-in' on the ball/ball-handler and largely ignored the rest of the players. Thus, as was shown with the WHN accuracy scores, participants were poor in their prediction abilities, potentially because they gathered their information from a singular source. In sports, it has been demonstrated previously that novice basketball players spent more time fixating on the ball-handler and made less accurate decisions than experienced players, suggesting that visual information should come from locations off of the ball, as well as from the ball/ball-handler (Ryu et al., 2013).

Additionally, because longer fixation durations can indicate a longer cognitive processing time (Falkmer et al., 2008), it is possible that the participants were simply processing the information from the ball/ball-handler longer than, say, an expert would. However, with that slower information processing, the participants likely did not have enough time to conduct additional searches of the surrounding areas (off the ball) before the WHN clip ended. When conducting visual searches in sports, expert athletes typically optimise their visual search strategies to adapt to the time constraints of sports actions (Klostermann & Moeinirad, 2020); they, like the participants in this study, generally have fewer fixations of longer durations (Murray & Hunfalvay, 2017), but importantly, fixate more on relevant areas (Klostermann & Moeinirad, 2020) which reduces overall processing time (Mann et al., 2007). It is possible that the participants in the study were fixating on less relevant areas and therefore, did not pick up the right information with which to make accurate predictions about what would happen next. Additionally, it is possible that the novices failed to extrapolate the same information as an experienced athlete would when looking at the same location. Hancock & Ste-Marie (2013) showed that novice and experienced referees conducted similar searches in ice hockey, but the experienced referees made more accurate decisions, suggesting that they gathered and processed more information than novices. Therefore, it is possible that the participants simply failed to process the information available.

The fixation dispersions were used as an indicator of how widely the participants searched along the *x* and *y* axis, with a larger dispersion area indicative of a wider search (Blignaut, 2009), and is often displayed with experienced individuals, such as when experienced drivers conduct a wider horizontal scan of the roadway (Underwood et al., 2003). It was believed that the SA training would promote further searching of the environment by providing either visual or verbal cues that would direct attention to relevant areas, thus promoting learning and the creation of a mental model to be used for future similar situations (*i.e.,* the post-training WHN test). However, the participants actually searched the environment less, which was opposite of what the training interventions had intended. Thus, the current study's results suggest that the novice participants, having had zero exposure to polo previously, likely allocated their attention to finding and tracking the ball rather than searching the field for potential plays. Because their fixation dispersion actually narrowed following training, suggests that the training, whilst designed to promote off-ball searching, actually made it easier for the novices to find and track the ball/ball-handler. It is possible that the cueing, both visual and commentary, successfully made the ball/ball-handler more salient amongst the cluster of play activity. Additionally, it is also possible that the repeat viewing of the polo video clips improved the participants' ability to find and follow the ball. This is generally referred to as a 'mere-exposure effect', where simply repeat viewings of similar stimuli results in positive responses, or learning (Hicks & King, 2011).

Ultimately, visual search—related to Level I SA (Perception) (Barbieri & Rodrigues, 2020) is influenced by information and instructions or goals; this information may be salient which promotes a bottom-up processing, or it can be guided by previously constructed mental models which promote a top-down processing (Land, 2009; Wolfe & Horowitz, 2017). This experiment aimed to provide training to novices with the hopes of potentially fostering the creation of mental models with which they could then use to search the polo environment more extensively (Collins & Gentner, 1987). However, it appears that the training, rather than promoting a wide visual search, actually provided information useful for detecting and following the ball. Such attentional allocation towards the ball/ball-handler may be indicative of a higher cognitive load (Mackenzie et al., 2022) and slower processing speeds (Falkmer et al., 2008), which is status quo for novices, particularly exhibited in novice drivers (Underwood et al., 2003). Interestingly, the results of the study appear to circle back to the original experimental studies of this thesis: the STB studies, in which participants were asked to spot the location of a missing ball in polo (or soccer) images. The training provided in this study may have allowed novice participants to become better at 'spotting' the ball. Thus, one could suggest that the training may have been the first step towards building a polo mental model. Sure, it may be a rudimentary model at best, but it possibly improved participants' perception skills, which is, as has been discussed previously, an important first step in building SA (Endsley, 1995b).

5.4.3 Would training effects transfer to on-field performance?

An important point to consider is whether any effects seen in a SA training programme would transfer to on-field performance. As discussed in Chapter 1, there is limited research investigating the relationship between SA and sport performance, and of the explicit SA training research examined in this chapter, 'in-situ' performance was not measured. Thus, it is difficult to make predictions about the transfer of SA training to actual sport performance based on the literature. For this reason, research into how SA abilities affect actual sport performance should be explored more thoroughly. In the specific example of the current study, if the training programme had produced an effect in absolute beginners, it is difficult to say whether that training effect would carry onto the field right away. By nature, polo is incredibly complex, with highly specialised physical skills required to be successful. More than likely, if the cohort from this study were put on horses and asked to play, any SA training would be neglected as the new players would divert their cognitive resources towards riding the horse, hitting the ball, and simply surviving. This situation would be akin to new drivers who allocate their resources towards vehicular control (steering, lane positioning, speed, clutch, *etc.*) and thus do not extensively search their surroundings (Mackenzie & Harris, 2017). However, this does not mean that any SA training is for nought. As the player progresses through their physical abilities, the SA training will perhaps become more and more relevant and important. As such, it may be advisable for researchers and industry professionals to conduct SA training alongside physical skills training. Of course, this is an area for further research.

5.4.4 Limitations.

This study has some limitations that should be addressed. Firstly, as has been discussed in the literature, there is often combinations of training interventions in which a ‘full’ training intervention is created that collates the separate interventions into one. For instance, Wetton et al. (2013) used Hazard Perception training packages that included WHN exercises, expert commentary, expert plus self-generated commentary (hybrid), and a full training package consisting of the WHN exercises plus the hybrid package. The authors reported that the full training package led to the largest improvement in HP scores whilst the WHN exercises produced the smallest improvement, indicating that the full package may be better than the sum of its parts. Therefore, it is possible that combining the visual cueing with the expert commentary training may have produced a training effect in the current study. This is a large limitation of the study, however, due to difficulties in participant recruitment and limited funding for participant payment, it was logistically not feasible to investigate a combination training package. Future studies should investigate the training effect in such a package that combines visual cueing and expert commentary.

A second limitation is that the training interventions were a one-off, hour-long session with a limited number of training stimuli. This was done to mainly reduced participant fatigue during the training session and prevent participants from dropping out during the study. A perhaps more effective training strategy may be to have multiple training sessions conducted over a period of time. When training SA specifically novice ship-handling watch officers, Chauvin et al. (2009) devised a SA training program which used games as an exercise to improve decision-making abilities. While the experimenters noted that the decision-making exercises may have promoted schemata-building in the novice officers, the officers were still largely unable to predict or choose a safe decision for the situations. It was therefore argued that a single session is inadequate for learning complex decision-making, and it was recommended that repetition of these types of exercises be employed when training novice naval officers (Chauvin et al., 2009). It is difficult to promote the learning of a completely new subject in such a short amount of time, which was demonstrated in the study as the training packages produced no such training effect. However, as was discussed previously, there was limited time and funding resources to conduct such a study with multiple training sessions. In the future, a longitudinal study that employs training participants over a longer period of time may perhaps be beneficial to training novel sports anticipation and SA.

Lastly, while this study aimed to develop a SA training programme directed specifically at absolute beginners (participants with no prior polo experience), the programme was not piloted in any way due to limited resources with recruitment and funding. Therefore, the lack of effectiveness of the training was not identified prior to actual testing. Should the training programme be experimentally tested again, a pilot test using participants with polo experience may yield more insights into the effectiveness of the methodology. It is possible that a more experienced cohort would have benefitted from the training; in theory, with the prior knowledge provided by domain experience, polo players might be able to capitalise on the information provided within the training programme leading to a larger training effect. Such experience, as has been discussed throughout the thesis, provides mental models used for acquiring and maintaining SA (Endsley, 1995b). Similarly, the domain-specific memory developed through experience in the sport could potentially allow experienced players to better contextualise the training information and apply that information towards anticipating the outcome of an event (Castro et al., 2016; Eccles, 2020; Kalén et al., 2021). Should the training programme show effects with an experienced cohort, it may be considered as an appropriate tool for training SA. Conversely, if the programme shows no training effects even within an experienced cohort, the methodologies would need to be revised. Ultimately, for a polo SA training programme to be successful, more time and resources than what was given in this thesis should be devoted.

5.4.5 Future directions.

Situation Awareness training is a complicated subject, with limited empirical studies, numerous methodologies, and contradicting evidence for its support. Similarly, there is conflicting results on the effectiveness of different types of visuo-perception training using visual cues or expert commentaries. Therefore, future research could be conducted to further investigate how to train SA in dynamic environments, such as with sports. Multi-session or longitudinal training interventions should be considered for such research given the evidence that a short, one-off training session is inadequate to promote the learning of complex cognitive skills. Additionally, combining training interventions, for instance, a visual cueing + expert commentary intervention, may be another direction to take in the future. There is a possibility that combining different training interventions into one package may promote a greater learning effect as the whole may be greater than the sum of its parts, as was shown by Wetton et al. (2013). Lastly, eye tracking WHN training studies could be conducted with experienced polo players in addition to novices to investigate the visual search behaviours of both experienced and inexperienced participants to gain a better understanding of the relevant areas to search for during a polo game. It is possible that by investigating the eye movement behaviours of experienced polo players, a training intervention may be developed which utilises the experienced players' eye movements as training stimuli, such as the work by Jarodzka et al. (2013) who investigated teaching through eye movement modelling examples (EMME). Overall, future research conducted with the intent of training SA in sports has many possibilities.

5.5 Conclusion

The aims of the study were to 1) to investigate the efficacy of different cueing-based training interventions on WHN performances in participants with no prior polo experience, and to 2) examine the visual search behaviours and eye movements, such as gaze fixations, durations, and dispersions, in a WHN task before and after training to investigate if training SA produces a shift in attention—as measured by eye movements—towards relevant areas of the environment. The results showed that the SA training interventions did not provide enough information to improve SA in a polo WHN task, as was evidenced by the lack of change in WHN accuracy scores. The eye movement behaviours, showing fewer fixations of longer durations on the ball highlight the higher processing demands in novices. Their attention towards the ball/ball-handler suggests that novices largely look for information stemming from those locations and not across the entire field. Lastly, the results showed that training produced a shrinking effect in the average dispersion area. This suggests that the training may have inadvertently brought attention to the ball/ball-handler but did not promote the off-ball searching as was intended. Overall, there is a need for a more prolonged, scaffolded approach which considers expertise level and player experience when training SA in complex tasks, such as sports.

Chapter 6 General Discussion

This final chapter in the thesis will further discuss the results of the experimental studies, explain the implications of the results, explore some of the theoretical limitations of the studies, and offer future practical applications for the line of research. Lastly, this chapter will provide a summary of the conclusions drawn from the thesis.

6.1 Introduction

Polo is an equestrian sport characterised by fast speeds, physical contact, and complex playing strategies, thus making it a highly dynamic and dangerous environment for both experienced and inexperienced players. In an effort to keep players and ponies safe during play and to promote a high level of performance, a framework known as 'Field Awareness' (FA) was developed. In polo, FA is largely understood as knowing the positioning of the players and umpires, the past, present, and future line-of-the-ball, and the right-of-way to the ball (Goodspeed, 2005), and it can be related to the broader term of Situation Awareness. Situation Awareness (SA), or the perception of elements in an environment, the comprehension of their meaning, and the projection of the future state of the environment, has long been thought of as an important indicator in domain safety and performance (Endsley, 1995b) yet is largely unexplored in sports settings (Ng et al., 2013).

There have been numerous frameworks and methodologies associated with SA, particularly within the aviation and transportation domains (Durso et al., 1999; Endsley, 1995a, 1995b; Taylor, 1990), however, the frameworks and methods described in the sports SA literature are generally underdeveloped, descriptive, retroactive, and do not account for experience when assessing SA performance. Cognitive skills, such as visual search behaviours, attention, memory, anticipation, and decision-making, have been associated with SA (Endsley, 1995b; Hadlow et al., 2018), yet the sporting literature generally analyses these skills independently, as evidenced by studies conducted solely on visual search behaviours (Abernethy, 1990; Savelsbergh et al., 2002, 2005; Singer et al., 1996; Ward et al., 2002; Williams et al., 2004), anticipation (Cañal-Bruland et al., 2011; Causer & Williams, 2015; Huys et al., 2009; Loffing & Cañal-Bruland, 2017; Mori & Shimada, 2013; Murphy et al., 2019; Runswick et al., 2018; Williams et al., 2009; Wright et al., 2011), and decision-making (Afonso et al., 2012; Burnett et al., 2017; Cañal-Bruland, 2009; Causer & Ford, 2014; del Campo et al., 2011; Levi & Jackson, 2018; Macquet & Fleurance, 2007; Murray et al., 2018; Silva et al., 2020) in individual and team sports. Incidentally, while these cognitive skills can be linked to SA, such a link is rarely explicitly made, making the sports SA literature sparse and unclear at times. There is scope within the sports field to investigate these cognitive skills together to explore how they interact and influence each other. One such way to go about this could be to study SA as an entity in various sports. Given the shortfalls of the sports SA literature and the general lack of studies investigating any cognitive skills in equestrian polo, this thesis set out to investigate SA in polo. Overall, this thesis had several questions that were considered in each experimental chapter, but the main questions explored were: What are objective methods that may be used for inferring SA in sports, what is the role of sports experience on SA performance, and can SA be trained in a sporting context?

First, Phase I (Chapter 3) developed a pre-requisite tool for assessing Level I SA (perception) using a static-image, 'Spot the Ball' (STB) task. Participants were asked to locate a missing ball on several images of polo (and soccer, Study 1.1). This task targeted participants' abilities to look at the right place without necessarily reacting to a stimulus; it simply tapped into the prior knowledge of the participants. The STB studies examined the role of sport experience and visual cues on perception skills, and they assessed whether perception skills could be transferred to novel sports. The results demonstrated the task's ability to target perception skills in polo, with sport experience and gaze cueing as the main drivers of such skills.

Second, Phase II (Chapter 4) developed a 'What Happens Next?' (WHN) task for inferring polo SA and anticipation skills. Participants were asked to predict what would happen next in a series of polo plays. The study also investigated the role of sport experience and situational context in anticipation abilities, as well as if those abilities could be transferred between sports. The results showed that the WHN paradigm could weakly discriminate polo players from controls if contextual information about the clips were provided, but ultimately, more research is needed in this area to further refine the methodology.

Lastly, Phase III (Chapter 5) explored if polo SA can be trained in a completely beginner cohort, and if SA training promotes a shift in attention to relevant areas as inferred by eye movement behaviours. Participants were given training interventions consisting of WHN videos with either dynamic visual cueing or expert commentary to accompany the videos. The number of gaze fixations, fixation durations, and fixation dispersions were measured during WHN tasks prior to the training and immediately afterwards; WHN performance accuracy was also measured. The results showed no training effects, suggesting that the SA training likely did not supply enough information to teach prediction abilities and that training led to a decreased visual search which was directed towards the ball and not on surrounding areas. Ultimately, Chapter 5 demonstrated that SA training may require a more prolonged, scaffolded approach that considers experience level of the participants. These experimental findings are further discussed below, along with the theoretical limitations and suggestions for future research of SA in polo, and sports in general.

6.2 Inference measures of Situation Awareness

The first aim of the thesis was to investigate different inference measures of SA which provided objective, empirical data. Ideally, SA assessment tools would discriminate sports experience, thus suggesting that they were sensitive enough to target higher-order cognitive skills, such as prediction or anticipation. Should experienced athletes perform better than controls, it would suggest the tool to be effective in inferring SA in a sports setting.

First, Phase I (Chapter 3) explored the 'Spot the Ball' (STB) method as a pre-requisite for assessing full SA in sports by isolating Level I SA (perception) abilities in a static-image task. In these studies, participants were tasked with locating a digitally removed ball in static images of polo (and soccer, in Study 1.1); the images themselves contained various visual cues thought to aid in perception abilities. The STB tool was developed to target participants' abilities to look at the right thing even when it was not there; ultimately, it was designed to target participants' knowledge of where to look without having to measure reactivity to a stimulus. Additionally, the STB task aimed to examine how sport-specific experience could drive perception skills, whether those skills could be transferred to a novel sport, and which visual cues were important in sports perception. The results showed that sport-specific experience allowed participants to more accurately locate the missing ball, however, that accuracy did not translate to a novel sport. It was also found that gaze cueing was an effective visual cue, as it allowed control participants to perform just as well as those with sport-specific experience when the photographed athletes' gazes were directed at the ball (in the images). However, when the gaze was directed away from the ball, a sport experience effect was seen where those with sport-specific experience were superior in their ability to locate the ball. This led to the conclusion that experienced athletes' (polo players) perception, and thus potentially SA as a whole, could be developed in off-ball situations. The studies developed an objective tool for assessing perception (Level I SA) abilities polo, provided evidence of the relation between polo experience and SA performance, and identified visual cues important for perception in polo.

Second, Phase II (Chapter 4) the 'What Happens Next?' (WHN) paradigm as an inference measure of SA in dynamic, off-ball situations. The WHN task specifically targeted participant's Level III SA (projection) by showing videos of offensive and defensive polo plays and asking participants to predict what would happen next. This paradigm was used to investigate the role of sport-specific experience on anticipation abilities, and whether these abilities would transfer to novel sports. Lastly, the studies explored the role of situational context on anticipation. The studies initially showed no main effects of sport experience on WHN performance, however, when the previously non-hypothesised interaction effects were examined, interesting results were shown. The first WHN study (Study 2.1) showed a large discrepancy between polo players' offensive and defensive scores, with their defensive scores being significantly lower than chance, suggesting an, albeit incorrect, strategy for answering the probes. Post-hoc tests showed that polo players suffered an expectation bias of viewing the clips, whether offensive or defensive, with an offensive frame of reference. This incongruence led to poor accuracy scores in the defensive condition. The second WHN study (Study 2.2) experimentally tested the expectation bias hypothesis by priming participants to the type of play situation they would see before showing the clips. With priming for situational context, there was a main effect seen where polo players were more accurate than the controls; additionally, the large discrepancy in offensive and defensive scores was not seen. Interestingly, when examining if general athletes (Study 2.1) and team, invasion sport athletes (Study 2.2) could transfer their sport experience to a novel sport (polo), mixed results were found. The general athletes failed to show any transfer, and the team, invasion sport athletes showed some evidence of transfer, suggesting anticipation skills may be transferred between different sports if they are of similar play structure. The WHN studies showed the tool could potentially be used for inferring sports SA and anticipation skills, that situational context played a key role in how experienced athletes predict play outcomes, and that prediction abilities could be transferred to novel sports provided the sports were similarly structured.

Ultimately, both the STB and WHN tools provided evidence that they could discriminate sport-specific experience from those with no sport experience. This suggests that the tools could target the skills necessary for the particular task. The STB tool, developed to tap into participants' perception (Level I SA) abilities demonstrated that polo players could more accurately pick the location of a missing ball compared to their control counterparts. Ultimately, these results demonstrate the tool's effectiveness at targeting specific perception skills in polo players. The WHN tool initially showed no discrimination of sport experience, however, when the task was modified to include contextual information that would be known during a real game, there was a discrimination between polo players and controls, where polo players were more accurate in predicting what would happen next. This suggests a level of validity, but it also shows the importance of methodology when developing a task.

The results of the Phase I and Phase II studies follow similar trends seen in SA studies from other domains which use similar methodologies, such as in transportation Hazard Perception WHN tasks (Crundall, 2016; Crundall et al., 2013; Crundall & Kroll, 2018; Jackson et al., 2009; Kroll et al., 2020), aviation SA tasks (Bacon & Strybel, 2013; Bolstad et al., 2010; Durso et al., 1999; Endsley, 2000a, 2021; Endsley & Garland, 2000; Hauland, 2008; Wickens, 2002; Yeo et al., 2017) and medical SA and WHN tasks (Fioratou et al., 2010; Gillespie et al., 2013; Hunter et al., 2020; Mackenzie et al., 2023; Schulz et al., 2013; Wright et al., 2004), which generally show that the SA methods (most commonly WHN and Situation Awareness Global Assessment Techniques, SAGAT) discriminate experience in a domain. It is believed that inference measures such as these target the knowledge necessary to predict the outcome of complex tasks and make correct decisions regarding these tasks; by contrast, if no experience effect is shown, the tools would not be sufficient at targeting such higher-order skills (Mackenzie et al., 2023).

Of course, when stating claims that these tools effectively tap into SA skills, it is important to consider what that actually means. SA, in its broadest sense, is a framework which encompasses numerous cognitive skills, such as perception, comprehension, and projection (which make up its three hierarchal levels), but it also includes attention, memory, prior knowledge, goals, objectives, expectations, automaticity, and experience (to name a few) (Endsley, 1995b). Thus, SA describes how these skills and components work together to allow an individual to make decisions that influence their performance and experience. It is a cycle that, particularly in areas such as sports, is continuously updated with new information. An athlete's mental models, which are key constructs in memory (Barrouillet & Lecas, 1999) and for facilitating behaviours such as visual search (Hout & Goldinger, 2015) and comprehension (Johnson-Laird, 1981), are constantly evolving to match the situation at hand (Collins & Gentner, 1987). When assessing SA as a whole, each component is also being assessed, even if not directly. Thus, because of the interconnectedness of each component, an assumption is made: SA is inferred from its components. So, when researchers use tools (such as STB and WHN) and suggest they are targeting SA, what they really are saying is that they are measuring a quantifiable skill, whether it be perception or anticipation skills, and then inferring SA abilities based on the behavioural data collected. As stated in Chapter 1 and throughout the thesis, this is perhaps one of the more important reasonings behind the call for objective, empirical data when testing SA and its components; with actual behavioural data (not self-reports, qualitative data, or retroactive analyses), there can perhaps be more direct conclusions drawn about the relations between the tested components, the behaviours associated with those components, and SA as a whole.

6.2.1 Experts versus novices within a sport—are the Situation Awareness measures sensitive enough to discriminate athletes of different levels of the same sport?

The SA assessment tasks (STB and WHN tools) used in the thesis showed that, generally, they were sensitive enough to target perception and anticipation skills, meaning that they discriminated sports experience, with athletes who regularly played that sport (*i.e.,* polo) performing better than those who did not play that sport. On a surface level, this largely makes sense; those who have the slightest amount of experience in polo would be expected to outperform anyone, athlete or not, who had no experience with the sport. Importantly, this discrimination may boil down to the polo players having better general knowledge than the control participants and may not necessarily be due to having better SA or cognitive skills like anticipation. Therefore, it can be argued that the STB and WHN methods may only be discriminatory on a surface level. The real test would be whether these methods could discriminate experience *within* a sport—would polo players with more experience be better at these tasks than polo players with less experience? Murray et al. (2018) demonstrated that even within elite athletes, there still may be some differences in SA and decision-making capacities, so it would be reasonable to suggest that there would be differences between novice and elite athletes or experienced and inexperienced athletes.

The literature shows promise that methods such as the WHN tool can discriminate experience within a domain. Mackenzie et al. (2023) showed that in medicine, a WHN tool could discriminate differing levels of trauma experience, with experienced trauma team members making more accurate decisions than those with less trauma experience. Importantly, the authors also found that general knowledge-based questions could not discriminate experience level—both experienced and inexperienced trauma team members performed similarly, suggesting that even inexperienced team members have the basic knowledge that the experienced team members possessed. What actually set the two groups apart was the higher-order SA and decision-making abilities tested for using the WHN tool. Therefore, in future studies, the STB and WHN tools could be used to investigate the SA differences between experience levels of polo players, perhaps even looking at handicap differences. The STB studies in this thesis did not show discrimination between handicap, but that could largely be due to the cohorts containing predominately low-goal players. It is highly probably that the players sampled in the studies possessed relatively similar levels of experience, thus there was no real discrimination between handicaps or experience levels. This has been seen before, with Ng et al. (2013) showing no relation between basketball SA skills and performance, leading to the conclusion that SA was not a predictor of performance. However, just like the polo cohorts in the thesis studies, Ng et al. (2013) only sampled players of similar experience levels; perhaps if an expert-novice (or experience-inexperienced) paradigm was employed, there would be a clearer picture of how experience influences SA and even performance. Therefore, future projects should attempt to sample high-goal players (handicaps above 6-goals) to compare how experience within a sport affects perception abilities. Should these methods discriminate the experience level of players of the same sport, there would be an added layer of validity that these tools do indeed target higher-order cognitive abilities and SA.

6.2.2 'What Happens Next?' (WHN) versus Situation Awareness Global Assessment Tool (SAGAT) methods for assessing Situation Awareness in sports.

The 'What Happens Next?' (WHN) task used in Chapters 4 and 5 was originally derived from the Situation Awareness Global Assessment Technique (SAGAT) described by (Endsley, 1995a; Jackson et al., 2009). Both tasks are very similar: they are offline, freeze-probe tasks which utilise dynamic stimuli or simulations, and they target SA through questions which randomly appear during the task. Both tasks generally discriminate domain experience (Endsley et al., 1998; Endsley, 2021a; Jackson et al., 2009; Kroll et al., 2020; Mackenzie et al., 2023), suggesting that they target higher order cognitive skills necessary to successfully complete complex tasks. However, there are key differences which can affect the information obtained by each method. One such difference is what the task actually targets, or in other words, which level of SA (perception, comprehension, projection) is being tested. The WHN task taps into an individual's anticipation, or projection skills (Level III SA) by asking, "What happens next?" following a freeze in the video or simulation. It is believed that by targeting the highest level in SA, researchers will have a good picture of a participant's overall SA because of the hierarchical nature of the three levels (Endsley, 1995a, 2021a). Theoretically, for a participant to have high Level III SA, they must also have high Level I (perception) and Level II (comprehension) as well. Thus, in the WHN task, there is no probing to investigate the Level I or Level II SA abilities. On the other hand, the SAGAT tasks target all three levels through the different questions asked during the freeze-probe (Endsley, 1995a) and can thus assess a participant's individual SA levels, which the WHN task does not. This may be important when it comes to providing feedback, training, or system design based on the results of a SAGAT task. By targeting each individual level of SA, experimenters can investigate any deficiencies in the levels. For instance, if a participant scores highly on the Level I SA questions, but scores poorly on the Level II and Level III SA questions, the participant likely has a breakdown in SA at the Level II (comprehension) stage, and thus, may benefit from training which targeted comprehension abilities. However, the WHN paradigm was ultimately used as an inference tool for the studies in the thesis based on its ability to discriminate experience in a domain by targeting higher-order anticipation skills whereas knowledge-based tasks, such as those targeting Level I and Level II SA (*i.e.,* SAGAT), have been shown to not be discriminatory within a domain (Mackenzie et al., 2023).

In the future, it is perhaps reasonable to use the SAGAT method to assess SA in polo players—and other athletes—as it gives the researcher insight into the areas where there may be a breakdown in SA. Based on that information, researchers may then create highly tailored SA training approaches that address the 'problem areas' of the athlete. For instance, if the breakdown of SA occurs at the Level I (perception) stage, a training intervention may target visual search skills through attention-guiding principles (such as in Chapter 5). If the breakdown is at the Level II (comprehension) stage, training may address the deficit in game knowledge (*i.e.,* covering the rules of the game). Lastly, if the breakdown is at the Level III (projection) stage, training could focus on anticipation and decision-making skills (*i.e.,* reading advance body cues to anticipate the direction of a shot) (Smeeton & Huys, 2011). So, whilst the WHN task is beneficial to assessing overall SA abilities, as has been demonstrated in the experimental studies of this thesis and in the literature (Jackson et al., 2009; Kroll et al., 2020; Mackenzie et al., 2023), perhaps employing the SAGAT tool in a more diagnostic or training setting would be beneficial to athletes and their coaches.

6.2.3 Situation Awareness task performance and the link to physical sports performance—a case for taking Situation Awareness assessment out of the laboratory.

An important limitation to address concerns the potential, yet vastly unexplored, link between SA and sports performance. SA abilities have been suggested to predict performance, with individuals who display better skills generally performing better than those with lesser skills, which has been shown in studies across different domains, usually in the transportation or aviation sectors (Endsley, 2021a); in a medical setting, better SA abilities were shown to affect trauma response, with experienced team members displaying better SA and decision-making skills (Mackenzie et al., 2023). However, this is not always the case, as there is the possibility that an individual may have perfect SA, but due to conditions outside of their control, the performance may indeed suffer (Endsley, 1995b). In sports, this can be as simple as mis-executing a pass or hit which affects the overall performance. The athlete may have had perfect SA, with an understanding of who to pass to and when, but a 'whiff' on the pass ultimately would lead to poor performance in that play. But should a mis-executed pass brand the player as having poor SA? Conversely, a player may make an excellent pass to a teammate that he didn't know was there; perhaps he just meant to clear the ball out of the defensive zone in a 'hail Mary' type of hit, but as luck would have it, a teammate swooped in and picked up the pass. Does the successful pass mean he had perfect SA? (The teammate picking up the pass, however, had both good SA and good performance). Therefore, it is also important to identify the role SA plays in decision-making and performance: SA is simply one of the many tools that athletes can use in their overall performance, and good SA does not guarantee good overall performance (Endsley, 1995b).

In the literature, the link between SA and sports performance is even muddier, confounded by the lack of empirical studies and rigorous methodology. For instance, Knez & Ham (2006) found that increased physical effort in cycling produced a higher cognitive output when performing a visual search task, suggesting that (somewhat tentatively) better performance was linked to better SA. However, Ng et al. (2013) reported that cognitive skills, and SA in particular, were less predictive of overall basketball performance in teenage players, while physical fitness was a significant predictor, suggesting that performance was not as closely linked to SA as was thought. This is one of limitations of the sports SA literature: there are issues regarding the definition and description of SA frameworks, underdeveloped methods of assessing SA in sports, a lack of comparison between experience levels and SA performance, and conflicting results about the relationship between SA and sports performance. Ultimately, there is work to be done investigating SA in sports. Perhaps with more empirical evidence, a clearer distinction can be made.

Importantly, and a larger limitation of the thesis, the methods used in this thesis do not give any indication of the actual sporting (polo) abilities of the participants. This methodology is merely an indication of the cognitive—particularly SA and anticipation—abilities of the participants. It is hard to assume that polo players who perform well in the STB and WHN tasks are inherently good at playing polo just because they demonstrate a higher level of SA.

Polo is an extremely complex sport, as it requires 1) expert horsemanship and riding abilities, and 2) finely tuned hand-eye coordination when hitting the ball. It is safe to say that both (rather broad) skills require immense allocations of mental resources by themselves, let alone when paired together. However, when seated at a computer, participants (polo players and controls) can fully focus on their SA without having to worry about sitting a jumpy horse or hitting a bouncing ball, thus effectively nullifying any physical advantage polo players have over controls. This is where the relationship of cognitive skills, such as SA, and physical performance becomes unclear. For instance, as shown in Study 2.1, the control participants were overall more accurate than polo players in defensive conditions (though it was hypothesised and later confirmed that an offensive bias contributed to the polo players' poor defensive scores). However, it is likely that if we threw those control participants on a horse and handed them a mallet, their 'better' SA abilities would mean nothing, as they would (most likely) concentrate all their mental (and physical) resources on staying on the horse. Polo players, meanwhile, should have built-up automaticity for riding and hitting the ball, and therefore, could potentially focus more on their SA, thus suggesting that out on the field in real gameplay, polo players would have better SA than controls despite the laboratory results showing the opposite. Therefore, the distinction that good SA does not always equate to good performance should be emphasised in all SA studies, particularly sports SA studies, and future SA and sports studies should investigate more thoroughly the potential link between SA and sports performance. Perhaps future studies could incorporate polo game performance metrics (*e.g.,* goals scored, assists, interceptions, turnovers, throw-ins won, fouls committed, *etc*.) and compare those metrics to SA task performances. Should there be a relation between, say, WHN scores and better game metrics, there may be evidence that there is a link between SA and physical performance.

6.2.4 There's no 'I' in 'Team'—The suggestion for investigating Team Situation Awareness in sports with a novel SyncSA approach.

This section is adapted from a review written by the thesis author entitled 'Situation Awareness in sports: A scoping review' published in Psychology of Sport and Exercise by Huffman et al. (2022). Whilst the SA assessment tools used in this thesis specifically investigated individual SA, it is also important to recognise that many sports, polo included, are team sports, and team members must rely on each other to perform well. Thus, there is a case for investigating Team Situation Awareness (TSA) and how individual team members may contribute to the overall SA of the team. Generally speaking, assessing TSA requires a more complex approach, often incorporating skills such as coordination and information sharing (Endsley, 1995b) that may be difficult to assess. Endsley (2021b) explains that for teams to have good SA, each team member must have the information necessary for their role on a team; it is not enough for one person to have the information and not communicate it to the rest of the members. Additionally, team members should know the status of other team members and their tasks, the effect of their actions on the team, and perhaps most importantly, predictions on the actions of their teammates (Endsley, 2021b). For instance, a polo player playing in the middle (a 'swing' position covering both offensive and defensive plays) would be tasked with predicting what their teammates playing in the back (defensive position) and the front (offensive position) may do with the ball, in addition to their own role of being a mostly tactical leader in creating offensive and defensive plays (Watson, 1989).

TSA has been assessed in a variety of domains, such as medicine (Crozier et al., 2015), air traffic control (Hauland, 2008), and nuclear control (Lee et al., 2016; Yim & Seong, 2016). In sports, as was discussed in Chapter 1, Distributed Situation Awareness (DSA) and Shared Situation Awareness (SSA) have been used to describe the SA across teams (Macquet & Stanton, 2014; Neville et al., 2016; Salmon et al., 2017; Schei & Giske, 2020), but these methods offer no such quantifiable way of measuring SA. However, that does not mean they should be disregarded altogether. One such possibility would be to use the SAGAT or WHN methods of assessment to capture SA at the individual level and compare this across the team. It is possible that the successful teams have increased synchronicity across probe questions. Rather than there being an absolute correct answer for the probe questions, it might be the case that what is important is the synchronicity in the answer across the team where players are interpreting cues in a similar way to arrive at the same answer. And this is despite players having different perspectives and positions. This would allow players on the same team to make decisions regarding the current state of play, safe in the knowledge that their teammates were likely thinking the same thing. This concept is termed 'Synchronised SA' (SyncSA).

This concept of SyncSA would combine the team elements of DSA with the individualized measurement of a SAGAT or WHN probe technique to determine how the overlap of SA in individual team members can influence the effectiveness of a team. Rather than this being a new framework of SA, it takes the principles of the three-level framework, assesses these principles at an individual level using the SAGAT or WHN probe-like method and then compares the synchronicity of answers across the team as a measure of SyncSA. Importantly, it has been suggested that teams may actually share mental models, which aids in the development of TSA and SSA (Endsley, 2021b), thus suggesting some level of synchronicity may be at play in effective teams. The first hypothesis to test would be whether increased levels of SyncSA related to more team wins. The second hypothesis to test would be to investigate the relative importance of SyncSA compared to performance on a more traditional there-is-always-a-correct-answer SAGAT or WHN probe task. As many sports are team-oriented, and one could even argue that coaches may be included in these teams (Macquet & Stanton, 2014), investigating TSA in sports is an important endeavour to undertake in the future. To this end, it may be beneficial to explore the possibilities of a SyncSA model in future research.

6.3 Contributing factors for polo Situation Awareness performance

This thesis aimed to explore any contributing factors for polo (and sports) SA performance, such as experience, visual cues, and situational contexts. One shortfall of the sports SA literature is the lack of literature specifically investigating how SA is acquired in sports; despite many sports studies investigating how visual search behaviours, advance visual cues, and contextual cues influence cognitive skills such as anticipation and decision-making (Jackson & Morgan, 2007; Jiang et al., 2021; Loffing & Cañal-Bruland, 2017; McRobert et al., 2011; Mori & Shimada, 2013; Navia et al., 2013; Roca et al., 2018; Singer et al., 1996; Smeeton & Huys, 2011; Vaeyens et al., 2007; Williams et al., 2009; Wright & Jackson, 2014), these studies overwhelmingly do not relate these findings back to SA as a whole. The studies presented in this thesis identified two important contributing factors to SA in sports, particularly polo: gaze cueing and situational context. These findings provide insight into how experienced athletes are able to build their SA and are discussed further below. In the future, there is the potential to investigate whether the visual cues are mediators for the relationship between experience and SA; in other words, could these cues be an explanation as to why experience is a predictor of SA performance? Additionally, there would be benefits to assessing the role of these cues on SA in athletes with differing levels of experience within the same sport. Utilising these cues are arguably important for sports SA, but are those skills learned early in sport, or do they develop following more experience? This would potentially give insight into the development of cognitive skills as athletes gain experience in a sport.

6.3.1 Sports experience and the potential for Situation Awareness transfer.

An important aim of the thesis was to investigate the role of sports experience on SA performance, namely, to explore if more experience in a sport resulted in better SA performance. Additionally, the thesis aimed to investigate if sports cognitive skills, such as SA and prediction, could transfer between sports. The results of the STB and the WHN studies indicated an experience effect, where the athletes were more accurate in their respective sport. In the STB studies, polo players were more accurate in polo images, and soccer players were more accurate in soccer images. Both athlete cohorts were more accurate than control participants. Similarly, the WHN studies broadly showed that, particularly with situational context priming, polo players were more accurate than controls, and athletes (those who played team sports) were more accurate than controls. Interestingly, because the athletes who participated in team sports were more accurate than controls, there is some evidence that sports experience may aid in prediction skills transfer to a novel sport. This point is discussed further later on.

The effect of experienced/expert athletes performing better than novices or controls in perceptual-cognitive sports tasks is well-documented in the sports literature (del Campo et al., 2011; Hancock & Ste-Marie, 2013; Li & Feng, 2020; Loafing & Hagemann, 2014b; Nakamoto & Mori, 2012; Rowe et al., 2009; Runswick et al., 2020; Savelsbergh et al., 2002; Singer et al., 1996; Travassos et al., 2013; Wright et al., 2011), but there have not been empirical studies showing experience effects in sports SA studies (Ng et al., 2013). It is believed that experience drives cognitive performance in sport because prior experience in a particular sport may allow an athlete to create and continuously update mental models based on the situations encountered (Collins & Gentner, 1987), which therefore aid in the recognition of certain types of situations and can then allow an athlete to make more accurate predictions based on their previous experiences. Such an effect has also been demonstrated in driving, where experienced drivers often perform better on SA tasks (Crundall, 2016), potentially because of their developed mental models allow them to better search the road for hazardous situations (Konstantopoulos et al., 2012; Leff et al., 2015; Mourant & Rockwell, 1972; Underwood et al., 2002). In a medical trauma setting, experience was also shown to benefit SA performance, with more experienced personnel reporting more accurate decisions about a patient status (Mackenzie et al., 2023). Simply put, experience fosters higher-order cognitive skills, such as the knowledge of where to look, what to look out for, and how to react to developing situations. Therefore, it can be suggested that the sports experience allowed the athletes in this thesis to recognise and predict the outcome of both static image and dynamic situations, thus suggesting that experience plays a role in sports SA. It is also possible that athletes may possess greater domain-specific memory which allows them to tap into mental models and schema important in sports (and SA) decision-making (Kalén et al., 2021). This is an important point, as there have been limited studies which have directly investigated the role of sports experience on performance in a SA task, so the results of these studies give some evidence that there may be a link between experience and SA in sports.

6.3.1.1 Equestrian polo—similar but different: The lack of cognitive skills transfer to novel sports Situation Awareness tasks.

Sports literature has previously demonstrated that transfer of sports cognitive skills, such as play pattern recall and recognition (Abernethy et al., 2005; Smeeton et al., 2004) and decision-making (Berry et al., 2008; Causer & Ford, 2014) is possible, particularly if the sport is of a similar structure or style (Berry et al., 2008). However, there was no overwhelming evidence that prior sports experience, even in a similarly structured sport, facilitated the transfer of cognitive skills to a novel sport task. Transfer of such skills in a WHN task was demonstrated partially in Study 2.2, where team sport athletes performed better in a polo WHN task than control participants with no prior experience, but importantly, that transfer was apparent only in the defensive condition, and there was no evidence of a transfer effect in the offensive conditions. Likewise, such a transfer effect was not seen in the other studies (Study 1.1 and Study 2.1). Overwhelmingly, athletes, despite previous sporting experience, were no better than control participants in the SA tasks of this thesis.

One potential explanation for the lack of transfer is that the athletes may have experienced a higher cognitive load as they viewed a novel sport for the first time and struggled to recognise what was going on, despite the sports (*i.e.,* polo and football or other team sports) containing similar structures and characteristics. It has been suggested that learning and problem-solving concurrently may be impractical, particularly when trying to solve a problem related to a novel area; in other words, based on the Cognitive Load Theory, learners would misappropriate cognitive resources towards solving the problem, but would fail to learn (Sweller, 1988; Sweller & Chandler, 1991). It is therefore possible that the athletes, because they lacked prior knowledge and schema to help with their prediction tasks, devoted cognitive resources towards simply viewing the scene and therefore did not have enough resources to devote towards anticipation of future events (Brünken et al., 2016). Relatedly, this may have stemmed from the athletes possessing only sport-specific memory which would aid performance in their respective sport, but, as was demonstrated in both the STB and largely the WHN studies, was of no use in a novel sport. Andrew & Causer (2022) demonstrated that whilst there may be evidence for cognitive skills transfer between sports, those skills only transfer between similar domain-specific goals or components; in other words, cognitive skills such as anticipation may be sport-specific and non-transferrable. Whilst polo and the team sports in Study 2.2 are classified as 'open-style' and 'invasion' games, they are vastly different from each other, and the visual cues necessary for prediction, such as body posture and player field positioning, were simply too different for prior experience in a separate but similar sport to be of any benefit, thus increasing the cognitive load and taking up cognitive resources normally used for skills such as searching and anticipation (Runswick et al., 2018). For instance, polo players use a mallet to strike the ball, so their upper body and torso may be important postural cues when predicting the direction of a shot (Brittain & Oliver, 2018; Oliver et al., 2017, 2018a), but in soccer, players use their legs and feet to kick the ball, and the lower body is generally thought to provide the most visual information for predicting the direction of a kick (Lees & Owens, 2011; Savelsbergh et al., 2005). Therefore, the simple location and types of body postural cues may be different enough between the sports enough to nullify any advantage of prior sport experience; polo players would not normally be expected to look at lower legs for visual information, and soccer players similarly would probably not gather much information from the upper body, thus, they might not instinctively know to look to those places for guiding cues.

Future research investigating the transfer of sport cognitive skills should therefore not only account for the overall structure of the sports (open, strategic, interceptive, team, *etc*.) but also examine mechanisms behind the sports themselves. Polo is, without a doubt, multi-faceted which combines equestrian activities with traditional team ball sports; therefore, it may be too complicated of a sport to really see any potential transfer effects. Thus, the methodology used for comparing sport cognitive skills transfer should reflect the complexities of the sports examined; a sport more or less complex than the other(s) might not be an appropriate sport to include in transfer studies.

Additionally, the studies which successfully demonstrate transfer effects in sports (Abernethy et al., 2005; Berry et al., 2008; Causer & Ford, 2014; Smeeton et al., 2004) typically sample athletes of elite or near-elite status; the polo players and athletes sampled in the studies of this thesis were largely amateur—recreational participants with limited higher-level competition experience. This, naturally, may have impacted the results; it is perhaps possible that sampling a more experienced cohort of polo players and athletes would result in transfer effects, suggesting that more experienced athletes may be more likely to transfer cognitive skills to novel sports.

6.3.2 Visual cues and situational context—important in acquiring Situation Awareness or a hinderance in disguise?

It was found that the gaze and head orientation of the photographed athletes had the largest effect on STB performance, where participants regardless of sports experience were more accurate when the gaze was directed at the ball, suggesting that gaze displayed important information useful for perception in sports. Interestingly, in some cases, the control participants were able to perform just as well as the experienced athletes when the gaze was on the ball, thus suggesting that gaze cueing provides important information for perception in sports. A possible explanation for this is that gaze is generally thought to be linked to that attention, suggesting that what a person is looking at is what they are attending to (Frischen et al., 2007). Additionally, it is thought that joint attention may occur when an observer follows a person's gaze to a location or object, and thus themselves attends to the same place (Ciardo et al., 2015). It is possible that when the gaze of the photographed athletes was directed at the ball, participants in the studies could follow the line of gaze to the missing ball, and thus achieve joint attention. In sports, it has even been suggested that simple helmet orientation could be used to predict where a quarterback would throw the ball (Sawyer et al., 2015). Similarly, as has been demonstrated by Weigelt et al. (2020), a basketball head-fake is effective because of the opponent processing the head orientation, showing that head and gaze orientation are important cues for anticipation in sport.

Importantly, the polo players were better than controls when the gaze was off the ball and there was an absence of mallet information which suggests the experience kicked in when there were limited salient visual cues. Likely, the experience allowed the polo players to use other visual cues, such as body posture or kinematics, as has been demonstrated in sports before, and it has generally been shown that more experienced athletes are better than novices at information pickup stemming from body posture and kinematics (Cañal-Bruland et al., 2011; Huys et al., 2009; Lees & Owens, 2011; Smeeton & Huys, 2011; Wright et al., 2011). Without the use of any eye tracking technology in the STB studies, it can be suggested that the polo players made better use of the static visual cues in lieu of a direct gaze cue. Importantly, this finding suggests that polo players with some level of experience may be better at building SA in situations off the ball, which makes sense as sports performance is often dependent on passes to teammates, receiving passes, and intercepting offensive plays. Such situations occur off the ball as the players must search for a teammate downfield, get open for a pass, or anticipate the trajectory of the ball to intercept it. For instance, Williams et al. (1994) demonstrated that inexperienced soccer players tended to follow the ball, whereas experienced soccer players fixated on the players' positions and movements. Land & McLeod (2000) showed that elite cricket batter did not track the ball for the entirety of the bowl, and Ryu et al. (2013) showed that skilled basketball players could made accurate predictions on play outcomes, despite spending less time than lesser-skilled players looking at the ball-handler, suggesting that there are cues available off the ball that may still provide information about the environment. Therefore, the results of the STB studies suggest that gaze cueing ultimately plays a large role in sports prediction, but experience in a sport may be beneficial in predicting situations using off the ball cues.

Situational context—or providing prior information about a situation (Gray & Cañal-Bruland, 2018; Navia et al., 2013)—was also identified as an important role in sports SA. The WHN studies in Chapter 4 showed that polo players had a large discrepancy between offensive and defensive accuracy scores, where they were significantly worse in defensive situations. It was likely the polo players viewed the video clips with an offensive frame of mine despite there being an even mix of offensive and defensive situations. In other words, the polo players demonstrated an expectation bias (Loffing et al., 2015b) where they believed the clips would show an offensive play regardless of what was actually happening. As was seen in Study 2.1, this offensive expectation bias benefitted the polo players in the offensive situations but was detrimental during the defensive situations. This phenomenon has been demonstrated in sports literature where experienced athletes can fall prey to an expectation bias if they rely too heavily on it. For instance, if an outcome of a play is incongruent to what an athlete believed would happen (*e.g.,* a soccer penalty kick going to the right when the goalkeeper expected it to go left based on a kicker's preference or statistical likelihood; Navia et al. 2013), the performance would suffer. To test this offensive expectation bias, an experiment was designed which would prime the participants, or inform them of the context of the clip (whether the clip was offensive or defensive); if the polo players reported no discrepancies between the offensive and defensive situations, they were likely to have had an expectation bias. If the same discrepancies remained, they were likely to just be poor at reading defensive plays. The results of Study 2.2 showed that with priming, the discrepancy between offensive and defensive accuracy scores was nullified, thus suggesting that without priming, the polo players most likely had an offensive expectation bias. These results suggest that situational context cues may be important for—particularly in experienced athletes—building SA in sports. In sports tasks, priming has been shown to influence performance (Crognier & Fery, 2005; Jiang et al., 2021; McRobert et al., 2011; Navia et al., 2013), with congruent priming leading to improved performance, and incongruent priming leading decreased performance.

6.3.3 What makes an expert? Potential insights into the experience effects of sports Situation Awareness.

Throughout the thesis, experience in a sport has been shown to be a predictor in sports SA performance, with experienced athletes performing better in both the STB and WHN tasks. However, what is not abundantly clear is why that is the case—why are experienced athletes better at these tasks? It is important to note that, while this section discusses 'expertise' (outstanding performers in their sport), the STB and WHN tasks only sampled those with sport experience—they had prior experience and familiarity but were not considered experts. Even still, even a slight amount of experience and familiarity still resulted in better performance in the tasks. It seems painfully obvious at a first glance; of course, people with more experience would have better SA, that is just how it goes. However, beneath the surface, there may be interesting cognitive processes at play which allow experience to drive SA performance. One potential explanation is that the experienced athletes may have had a better memory of sport-specific situations which led to a superior performance compared to those without experience. Prior experience in a sport has been suggested as a precursor to creating mental models and schema, which are then used for acquiring SA (Endsley, 1995b). These mental models may then influence the higher-order cognitive processes such as scanning, anticipation, or decision-making (Collins & Gentner, 1987; Filho et al., 2015). So, could memory be a contributing factor to expertise in a sport?

Perhaps the most well-known study investigating expert problem-solving strategies was conducted by Chase & Simon (1973) who demonstrated that chess Grand Masters could recall and reconstruct a chess board (constructed using chess board positions taken from a Masters game) with a high level of accuracy after only viewing it for five seconds, whereas the weaker players (intermediates and novices) could not. Interestingly, the Grand Masters struggled to recreate the board when the pieces were randomly placed on the board. This led to the theory that the Grand Masters had better chess-specific memory, but not overall better memory. The authors posited that the Grand Masters had a better domain-specific LTM that gave them an advantage. This suggests that the Grand Masters' expertise in chess may stem from their superior memory and recall of specific patterns and positions seen in their play and practice (Chase & Simon, 1973; de Groot, 1978).

In sports, Eccles (2020) suggested that expertise followed a pathway where practice led to domain-specific mental models and memory systems, which led to a more efficient processing of domain-specific information, which then resulted in superior performance. McPherson (1999b) showed that high-level tennis players found solutions to tennis problems by accessing their memories from playing the game over time; it was suggested that experienced athletes maintained two memory profiles: current event (keeping up with information about the past, present, and future events) and an action plan (general rule-based plans stored in the long-term memory (LTM) where the current situation was matched with an appropriate response). Additionally, Furley & Memmert (2013) demonstrated that in basketball players, working memory (WM) influenced decision-making, with decision options associated with WM representations chosen more frequently. The authors suggested that an athlete's attention may be guided towards teammates (or locations) that were similar to those held in internal representations, or mental models. Therefore, it is possible that the experience effects seen in the thesis were the result of the experienced athletes having a better sport-specific memory which allowed them recall mental models and schema and thus perform better on the SA tasks. Of course, this suggestion is only that—a suggestion. Future research could investigate if there is a causal mechanism of domain-specific memory on experience and SA performance.

6.4 Can Situation Awareness be trained in complete novices?

The last main goal of the thesis was to explore if SA could be trained in sports. Theoretically, improving SA could lead to an improvement in performance; this has been demonstrated with driving Hazard Perception (HP) training which largely focusses on improving the HP, the sensitivity to hazards on the road, in novice drivers (McDonald et al., 2015; Walker et al., 2009; Wetton et al., 2013). The goal of such training is to teach novice drivers the cognitive skills, such as visual search behaviours and anticipation (McDonald et al., 2015) necessary for safe driving, and not so much the physical skills required for vehicle control. By training such cognitive skills, new drivers could be able to learn how to search their environment like experienced drivers, and better anticipate roadway hazards, thus leading to overall safer drivers. In sports, visual search and anticipation skills have been linked to SA (Hadlow et al., 2018), and better skills generally lead to improved performances (Loffing & Cañal-Bruland, 2017). Therefore, the study in Chapter 5 investigated two training interventions aimed at training polo SA in completely novice participants (no prior polo experience) by guiding their attention and gaze to relevant areas of the field that would allow them to make better predictions about the conclusion of a play. The ultimate goal of the training study was to develop a SA training programme to safely teach absolute beginner players the ins and outs of polo, the flow of the game, and strategies in a safe manner (off the field, off the horse). Here, visual cueing, where brightly coloured cues were superimposed onto polo video clips to draw attention to important features of the environment, and expert commentary, where a Subject Matter Expert (SME) gave commentary about where, when, and why to look at certain locations, were used as training methods. Participants were tested using a WHN test to investigate the effectiveness of the training interventions. Likewise, the eye movement behaviours of the participants were recorded before and after training to see if the interventions promoted a shift towards relevant locations.

The results showed no evidence that the training interventions worked for improving SA in a WHN task. There were no changes in WHN accuracy scores between the pre-training and post-training tests, suggesting that the interventions did not provide enough information to successfully train the participants. It is also possible that the information that was provided in the interventions may have been largely meaningless to the participants, who had no such prior knowledge or experience of polo. Importantly, in the SA training literature, there was no study which trained true novices; all participants had some level of prior experience to build upon (Bolstad et al., 2010; Burkolter et al., 2010; Chauvin et al., 2009; Lehtonen et al., 2017; Walker et al., 2009). It has been suggested that experience in a domain makes learning easier because there would be a foundation already established, and individuals would have a better understanding because they would have been exposed to more situations (Castro et al., 2016). Therefore, it is possible that at least some level of prior experience is necessary for SA training to be effective. Additionally, it was possible that more sessions were required to see any training effect, a point argued for by Chauvin et al. (2009), who suggested that to get a full training benefit, multiple exercises should be conducted over time.

Eye movement behaviours showed that the participants largely focussed on the ball, demonstrating fewer fixations of longer durations towards the ball and ball-handler. Interestingly, although the training interventions were designed to promote off-ball searching, the participants actually searched the environment less following the training. Ultimately, this suggests that the participants experienced a higher cognitive load and longer processing time (Falkmer et al., 2008) as they attempted to follow the ball and tried to work out what was happening. It is possible that the polo stimuli were so novel that the participants devoted immense cognitive resources towards simply figuring out what was happening and failed to achieve any learning or build schema for later problem-solving (Wickens et al., 2013). In other words, the simple act of trying to understand what was going on during the polo plays interfered with the training instructions, thus reducing learning. It has been suggested that in order to successfully solve a new problem (or in this case, anticipate the outcome of a polo play), there should be existing schema and mental models to help guide those problem-solving skills (Sweller, 1988; Sweller & Chandler, 1991; Wickens et al., 2013).

This overwhelming focus on the ball may have then led to the participants not being able to see (and thus pick up) information contained off the ball, such as players moving into position. Incidentally, the training actually promoted a shift towards a narrower search, as the average dispersion area shrank following training. This suggests that the training actually encouraged participants to find and follow the ball. While such a narrow focus is potentially different than what an experienced player would exhibit, it still shows that there was some learning that took place. Participants, even inadvertently, were perhaps better at finding the ball than before the training. In a full-circle moment, this can perhaps be related to the results of the STB studies, which showed that experienced athletes were more accurate at finding the ball. One could thus argue that the training, while ineffective at improving prediction abilities or shifting attention to a wider search, still allowed the participants to begin building a mental model of polo. Ultimately, however, to properly train SA in athletes, there should be some level of prior knowledge or experience to build upon; training interventions should take a more scaffolded approach and account for participants' experience level.

6.5 Conclusion

Equestrian polo is a highly dynamic sport which requires a combination of physical and cognitive skills during play, and Field Awareness has been thought of as a polo player's guide to staying safe and performing well. Field Awareness could conceivably be equated to Situation Awareness (SA), which is essentially, knowing what is going on around you. However, the existing body of literature investigating SA in sports settings is generally underdeveloped, descriptive, and retroactive, leading to many inconsistencies in the field. The overall aim of the thesis was to explore SA abilities in polo players and answer the following questions: 1) What are objective methods used for assessing SA in polo, 2) what is the role of polo experience on SA performance, and 3) can polo SA be trained? There are several general conclusions that can be drawn from the results of the study. First, the 'Spot the Ball' and 'What Happens Next?' methods for assessing SA discriminate sports experience and thus, are sensitive enough measures to tap into the perception and anticipation skills associated with SA. It can be suggested that these methods are therefore appropriate for inferring SA in sports settings. Second, the results show that sports experience plays a role in SA performance, with experience allowing a polo player to construct mental models useful in recognising situations and making predictions about how those situations will progress. However, experience may also be a detriment if the polo player has an expectation bias or incorrectly views a situation. Lastly, SA training is difficult and may require a base level of knowledge or at least some prior experience to build upon. Complete novices with no prior experience may experience a heavy cognitive load as they struggle to understand what is going on, which may in turn shrink their visual search area, thus leading to a decrease in SA performance. With the experiments presented in this thesis, strides hopefully have been made towards better understanding the SA abilities, and how they are acquired, of polo players. Potentially, the studies may aid in understanding sports

SA in general, and perhaps will contribute to a new interest in exploring the sport of equestrian polo…it has been around for at least 2000 years, so maybe it is time to give it some attention.

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Chapter 7 Appendices

7.1 Approach towards conducting a scoping review of Situation Awareness in sports.

Chapter 1 presented an adaptation of the work: *Situation Awareness in sports: a scoping review* published in Psychology of Sport and Exercise (Huffman et al., 2022). The methodology of conducting a scoping literature search was removed for the purpose of the thesis chapter but is presented below.

7.1.1 Sources of information.

The literature search was carried out using seven internet-based databases: ScienceDirect, Google Scholar, Nottingham Trent University Library OneSearch Pro, Web of Science, PsycInfo, PubMed, and SCOPUS. These databases are available to the authors through institution subscriptions or are freely available search engines. Table 7.1 shows the databases used, how to access them, and their accessibility.

Table 7.1 *Databases searched, their web addresses, and availability.*

Database	Web Address	Accessibility
ScienceDirect	sciencedirect.com	Institutional
Google Scholar	scholar.google.com	Open
NTU Library OneSearch Pro	llr.ntu.ac.uk/choose-los	Institutional
Web of Science	apps.webofknowledge.com	Institutional
PsycInfo	search.proquest.com/psycinfo/advanced	Institutional
PubMed	pubmed.ncbi.nlm.nih.gov	Open
SCOPUS	scopus.com	Institutional

7.1.2 Search terms & delimiting.

The following parameters were used to search the databases for relevant literature. Search keywords included "situation(al) awareness", AND "sport(s)", OR "athlete(s)", OR "player(s)", OR "coach(es)", OR "trainer(s)", OR "referee(s)", OR "official(s)", OR "umpire(s)".

7.1.3 Selection criteria employed.

To narrow down the number of papers included for this review, certain selection criteria were employed to ensure the papers were relevant. Figure 7.1 shows the PRISMA flow diagram for the screening and selection process. To be included in the review, papers were required to be peer-reviewed articles, sports and situation awareness-related, and written between the years 2000 – 2020. The searches were up to date as of December 2020. Initial searches of "situation awareness" AND "sports" revealed no articles pre-2000. Papers were excluded if they did not contain the phrase "situation awareness" in either the title, abstract, or the listed keywords, if they did not pertain to a sporting context, or were not written in English. From our initial search, it was found that there were many duplicates of papers as well as irrelevant articles (*i.e.,* papers on the topic of SA but not pertaining to sports).

The selection criteria for this review made it necessary for papers to explicitly describe situation awareness in sports contexts. While many sports papers investigate cognitive skills, such as visual search behaviours or anticipation, only papers that mentioned or directly linked those cognitive skills to situation awareness were included. More than preserving focus, this criteria also removes our own author subjectivity in categorizing whether a cognitive skill *could* be related to SA.

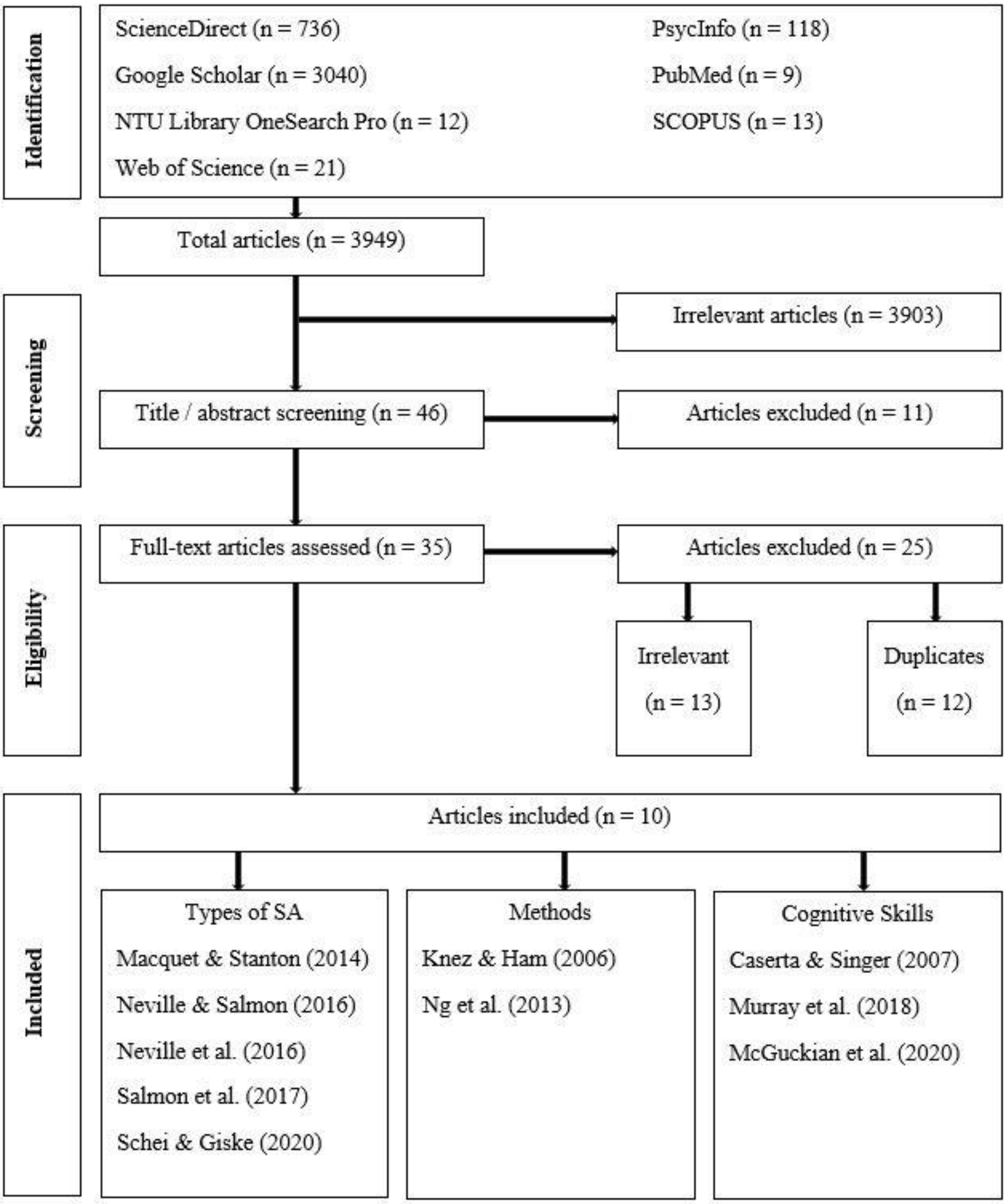

Figure 7.1 *PRISMA flow diagram for the screening and selection process of reviewed papers.*

7.2 Global Polo Entertainment permissions grants for polo video use as experimental stimuli

The video stimuli used in Chapters 4 and 5 were provided with permission from Global Polo Entertainment for the use in the experiments of this thesis. The permission grants for the use of video footage from the 2021 USPA Gold Cup Final and the 2021 C.V. Whitney Final are provided below.

GLOBAL POLO TV

This memo is to confirm that Global Polo Entertainment grants permission to Samantha Huffman the use of game footage found on globalopolo.com for her PhD Candidacy investigation regarding Situational Awareness.

Global Polo TV does not grant the rights of use of this game footage in any use outside of this investigation. This footage may not be used in any commercial capacity or in any other distribution beyond the "What Happens Next" PhD investigation made by Huffman at Nottingham Trent University.

Footage Chosen for this project includes:

- 2021 USPA Gold Cup Final

X Shannon Stilson
Shannon Stilson
Date: July 26, 2021
Asst. Vice President Marketing
USPA Global Licensing/Global Polo TV

X S Huffman
Samantha Huffman
Date: July 26, 2021
PhD Candidate
Nottingham Trent University

GLOBAL POLO

This memo is to confirm that Global Polo Entertainment grants permission to Samantha Huffman the use of game footage found on globalopolo.com for her PhD Candidacy investigation regarding Situational Awareness.

Global Polo TV does not grant the rights of use of this game footage in any use outside of this investigation. This footage may not be used in any commercial capacity or in any other distribution beyond the "What Happens Next" PhD investigation made by Huffman at Nottingham Trent University.

Footage Chosen for this project includes:

2021 C.V. Whitney Final

x

Shannon Stilson
Date: April 13, 2022
Asst. Vice President Marketing
USPA Global Licensing/Global Polo TV

x

Samantha Huff Date:
Date: April 13, 2023
PhD Candidate
Nottingham Trent University

7.3 Descriptions of Chapter 4: Study 2.1 What Happens Next? (WHN) video stimuli

Table 7.2 describes the What Happens Next? (WHN) video stimuli used for Chapter 4: Study 2.1. It includes a brief description of the play, the total length of the play (ms), the time of the play onset (ms), the multiple-choice question (MCQ) answer choices, and the correct answer. Note, the total length of the play does not include the 20,000ms added to display the WHN MCQs.

Table 7.2 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.1.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
1	Offense	Knock-In from the End Zone: Green 4 passes the ball to Green 3 on the outside of Red 3.	6080	5000	a) G4 passes to G3 on the outside of R3 b) G4 takes the ball to the right c) R3 intercepts the ball d) G4 passes to G3 on the inside of R3	A
2	Offense	Knock-In from the End Zone: Red 4 leaves the ball for Red 2.	8090	8000	a) G2 intercepts the ball b) R4 leaves the ball for R2 c) G3 intercepts the long hit d) R4 takes the ball with him	B
3	Offense	Throw-In from the Centre: Green 3 passes the ball to Green 4.	21110	21000	a) R3 intercepts the ball b) R4 intercepts the ball c) G3 passes to G4 d) G3 takes the ball to the inside	C

Table 7.2 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.1.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
4	Offense	Knock-In from the End Zone: Red 4 takes the ball to the right of Green 2.	9220	9000	a) R4 passes to R2 b) R4 takes the ball to the left c) G2 intercepts the ball d) R4 takes the ball to the right	D
5	Offense	Knock-In from the End Zone: Green 4 passes to Green 3.	6200	6000	a) G4 passes to G3 b) R2 intercepts the ball c) G4 hits downfield towards the right d) R3 intercepts the ball	C
6	Offense	Field Play: Red 2 takes possession of the loose ball.	8010	7000	a) G2 takes possession of the ball b) R2 takes possession of the ball c) R3 takes possession of the ball d) G2 hooks R3	B

Table 7.2 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.1.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
7	Offense	Knock-In from the End Zone: Green 3 leaves the ball for Green 4.	13180	13000	a) G3 passes to G2 b) R2 hooks G3 c) G3 leaves the ball for G4 d) G3 takes the ball with him	C
8	Offense	Knock-In from the End Zone: Green 3 turns the ball to the right.	10000	9000	a) G3 turns the ball to the right b) G3 passes to G2 c) R2 intercepts the ball d) R3 intercepts the ball	A
9	Offense	Throw-In from the Centre: Green 3 takes out Red 4 and leaves the ball for Green 4.	13210	12000	a) G3 shoots towards goal b) G3 leaves the ball for G4 c) R4 intercepts the ball d) R3 intercepts the ball	B

Table 7.2 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.1.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
10	Defence	Field Play: Green 3 has possession of the ball. Red 2 bumps Green 3 to gain possession.	3060	2000	a) R2 bumps G3 b) R2 turns the ball to the right c) G3 makes a pass downfield d) G3 hooks R2	A
11	Defence	Field Play: Green 3 has possession of the ball. Red 3 bumps Green 3 to gain possession.	29070	27000	a) R4 hooks G3 b) R3 bumps G3 c) G3 leaves the ball for G4 d) G3 takes the ball with him	B
12	Defence	Field Play: Red 2 has possession of the ball. Green 3 hits a backshot away from Red 2.	16130	16000	a) R2 takes the ball with him b) R2 leaves the ball for R3 c) G3 hits a backshot d) G2 hits a backshot	C

Table 7.2 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.1.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
13	Defence	Throw-In from the Centre: Green 4 has possession of the ball. Red 4 hits a backshot away from Green 4.	20290	20000	a) R4 passes to R3 b) G4 leaves the ball for G2 c) G4 takes the ball with him d) R4 hits a backshot	D
14	Defence	Throw-In from the Centre: Red 4 has possession of the ball. Green 3 hits a backshot away from Red 4.	19190	19000	a) G3 hits a backshot b) G4 hooks R4 c) R4 takes the ball with him d) R3 takes the ball with him	A
15	Defence	Field Play: Green 3 has possession of the ball. Red 3 intercepts the ball.	9130	9000	a) G3 passes to G2 b) G3 hits downfield to the right-side boards c) R3 intercepts the ball d) R1 intercepts the ball	C

Table 7.2 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.1.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
16	Defence	Throw-In from the Centre: Green 3 has possession of the ball. Red 4 intercepts the ball.	17290	17000	a) G3 leaves the ball for G2 b) G3 passes to G1 c) R4 intercepts the ball d) R2 intercepts the ball	C
17	Defence	Field Play: Red 3 has possession of the ball. Green 4 intercepts the ball.	4240	4000	a) G3 intercepts the ball b) R3 leaves the ball for R1 c) G4 intercepts the ball d) R3 hits the ball downfield	A
18	Defence	Knock-In from the End Zone: Red 4 has possession of the ball. Green 4 intercepts the ball.	9050	7000	a) G3 backs the ball b) R3 picks up the ball c) G4 picks up the ball d) R2 picks up the ball	C

7.4 Descriptions of Chapter 4: Study 2.2 and Chapter 5: Study 3 post-training What Happens Next? (WHN) video stimuli

Table 7.3 describes the What Happens Next? (WHN) video stimuli used for Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test. It includes a brief description of the play, the total length of the play (ms), the time of the play onset (ms), the multiple-choice question (MCQ) answer choices, and the correct answer. Note, the total length of the play does not include the 10,000ms added to display the WHN MCQs.

Table 7.3 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
1	Offense	Knock-In from the End Zone: Green 4 passes the ball to Green 3 on the outside of Red 3.	6080	5000	a) G4 passes to G3 on the outside of R3 b) G4 takes the ball to the right c) G4 takes the ball to the left d) G4 passes to G3 on the inside of R3	A
2	Offense	Knock-In from the End Zone: Red 4 leaves the ball for Red 2.	8090	8000	a) R4 passes to R3 b) R4 leaves the ball for R2 c) R4 takes the ball with him to the left d) R4 takes the ball with him to the right	B
3	Offense	Throw-In from the Centre: Green 3 passes the ball to Green 4.	21110	21000	a) G3 takes the ball to the outside b) G3 passes to G2 c) G3 passes to G4 d) G3 takes the ball to the inside	C

Table 7.3 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
4	Offense	Knock-In from the End Zone: Red 4 takes the ball to the right of Green 2.	9220	9000	a) R4 passes to R2 b) R4 takes the ball to the left c) R4 takes the ball down the centre d) R4 takes the ball to the right	D
5	Offense	Knock-In from the End Zone: Green 4 passes to Green 3.	6200	6000	a) G4 passes to G3 b) G4 passes to G2 c) G4 hits downfield towards the right d) G4 hits downfield towards the left	C
6	Offense	Field Play: Red 2 takes possession of the loose ball.	8010	7000	a) R1 takes possession of the ball b) R2 takes possession of the ball c) R3 takes possession of the ball d) R1 passes to R3	B

Table 7.3 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
7	Offense	Knock-In from the End Zone: Green 3 leaves the ball for Green 4.	13180	13000	a) G3 passes to G2 b) G3 takes the ball with him to the left c) G3 leaves the ball for G4 d) G3 takes the ball with him to the right	C
8	Offense	Knock-In from the End Zone: Green 3 turns the ball to the right.	10000	9000	a) G3 turns the ball to the right b) G3 passes to G2 c) G3 turns the ball to the left d) G3 passes to G4	A
9	Offense	Throw-In from the Centre: Green 3 takes out Red 4 and leaves the ball for Green 4.	13210	12000	a) G3 shoots towards goal b) G3 leaves the ball for G4 c) G4 passes to G3 d) G4 shoots towards goal	B

Table 7.3 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
10	Defence	Field Play: Green 3 has possession of the ball. Red 2 bumps Green 3 to gain possession.	3060	2000	a) R2 bumps G3 b) R2 turns the ball to the right c) R2 hooks G3 d) R2 hits a backshot	A
11	Defence	Field Play: Green 3 has possession of the ball. Red 3 bumps Green 3 to gain possession.	29070	27000	a) R4 hooks G3 b) R3 bumps G3 c) R4 bumps G3 d) R3 hooks G3	B
12	Defence	Field Play: Red 2 has possession of the ball. Green 3 hits a backshot away from Red 2.	16130	16000	a) G3 bumps R2 b) G2 bumps R2 c) G3 hits a backshot d) G2 hits a backshot	C

Table 7.3 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
13	Defence	Throw-In from the Centre: Green 4 has possession of the ball. Red 4 hits a backshot away from Green 4.	20290	20000	a) R3 intercepts the ball b) R1 hits a backshot c) R4 bumps G4 d) R4 hits a backshot	D
14	Defence	Throw-In from the Centre: Red 4 has possession of the ball. Green 3 hits a backshot away from Red 4.	19190	19000	a) G3 hits a backshot b) G4 hooks R4 c) G3 takes the ball with him to the right d) G4 bumps R3	A
15	Defence	Field Play: Green 3 has possession of the ball. Red 3 intercepts the ball.	9130	9000	a) R2 intercepts the ball b) R2 hooks G3 c) R3 intercepts the ball d) R1 intercepts the ball	C

Table 7.3 *Descriptions of the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
16	Defence	Throw-In from the Centre: Green 3 has possession of the ball. Red 4 intercepts the ball.	17290	17000	a) R2 hooks G3 b) R4 bumps G3 c) R4 intercepts the ball d) R2 intercepts the ball	C
17	Defence	Field Play: Red 3 has possession of the ball. Green 4 intercepts the ball.	4240	4000	a) G3 intercepts the ball b) G4 bumps R3 c) G4 intercepts the ball d) G3 bumps R3	A
18	Defence	Knock-In from the End Zone: Red 4 has possession of the ball. Green 4 intercepts the ball.	9050	7000	a) G3 hits a backshot b) G4 bumps R2 c) G4 intercepts the ball d) G3 bumps R2	C

7.5 Descriptions of Chapter 5: Study 3 Pre-Training What Happens Next? (WHN) video stimuli

Table 7.4 describes the What Happens Next? (WHN) video stimuli used for the Chapter 5: Study 3 pre-training test. It includes a brief description of the play, the total length of the play (ms), the time of the play onset (ms), the multiple-choice question (MCQ) answer choices, and the correct answer. Note, the total length of the play does not include the 10,000ms added to display the WHN MCQs.

Table 7.4 *Descriptions of the What Happens Next? (WHN) video stimuli used in the Chapter 5: Study 3 pre-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
1	Offense	Knock-In from the End Zone: Blue 3 leaves the ball for Blue 2.	6160	5000	a) B3 leaves the ball for B2 b) B3 passes to B1 c) B3 passes to B4 d) B3 takes the ball to the right	A
2	Offense	Knock-In from the End Zone: Red 4 passes the ball to Red 2.	4020	4000	a) R4 takes the ball to the left b) R4 passes to R2 c) R4 passes to R1 d) R4 takes the ball to the right	B
3	Offense	Field Play: Red 2 leaves the ball for Red 4.	7200	7000	a) R2 makes a long pass downfield b) R2 takes the ball to the right of G2 c) R2 takes the ball to the left of G2 d) R2 leaves the ball for R4	D

Table 7.4 *Descriptions of the What Happens Next? (WHN) video stimuli used in the Chapter 5: Study 3 pre-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
4	Offense	Knock-In from the End Zone: Red 4 takes the ball to the right.	5130	5000	a) R4 passes to R3 b) R4 passes to R1 c) R4 takes the ball to the left d) R4 takes the ball to the right	D
5	Offense	Knock-In from the End Zone: Blue 3 passes the ball to Blue 2 on the outside of Red 3.	2240	2000	a) B3 takes the ball to the right b) B3 passes to B2 on the inside of R3 c) B3 takes the ball to the left d) B3 passes to B2 on the outside of R3	D
6	Offense	Knock-In from the End Zone: Blue 4 leaves the ball for Blue 3.	22040	21000	a) B4 shoots towards the goal b) B4 leaves the ball for B3 c) B4 passes to B3 d) B4 keeps the ball with him	B

Table 7.4 *Descriptions of the What Happens Next? (WHN) video stimuli used in the Chapter 5: Study 3 pre-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
7	Offense	Knock-In from the End Zone: Red 2 backs the ball to Red 4.	20070	20000	a) R2 passes to R1 b) R2 hits down the centre c) R2 backs the ball to R4 d) R2 takes the ball to the right	C
8	Offense	Knock-In from the End Zone: Red 4 passes the ball to Red 2.	5210	5000	a) R4 passes to R3 b) R4 passes to R2 c) R4 takes the ball to the left d) R4 takes the ball to the right	B
9	Offense	Knock-In from the End Zone: Red 4 passes the ball to Red 3.	2280	2000	a) R4 passes to R3 b) R4 passes to R2 c) R4 takes the ball to the right d) R4 takes the ball to the left	A

Table 7.4 *Descriptions of the What Happens Next? (WHN) video stimuli used in the Chapter 5: Study 3 pre-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
10	Defence	Field Play: Blue 3 hits a backshot away from Red 2.	18000	17000	a) B2 hits a backshot b) B2 bumps R2 c) B3 bumps R2 d) B3 hits a backshot	D
11	Defence	Field Play: Red 2 bumps Blue 2 and steals the ball.	15180	13000	a) R2 bumps B2 and steals the ball b) R2 hooks B2 and leaves the ball for R3 c) R2 hits a backshot to the left to R3 d) R2 hits a backshot to the right to R4	A
12	Defence	Field Play: Red 3 hits a backshot away from Blue 4.	15210	15000	a) R1 bumps B4 b) R3 hooks B4 c) R3 hits a backshot d) R1 turns the ball to the right	C

Table 7.4 *Descriptions of the What Happens Next? (WHN) video stimuli used in the Chapter 5: Study 3 pre-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
13	Defence	Field Play: Blue 2 hits a backshot to Blue 4 on the outside of Red 4.	10170	9000	a) B2 turns the ball to the left b) B2 turns the ball to the right c) B2 passes to B4 on the inside of R4 d) B2 passes to B4 on the outside of R4	D
14	Defence	Field Play: Blue 4 hooks Red 3.	6050	5000	a) B4 bumps R3 b) B4 intercepts the ball and passes to B2 c) B4 hits a backshot to the right d) B4 hooks R3	D
15	Defence	Throw-In from the Centre: Blue 2 has possession of the ball. Red 2 intercepts the ball.	20180	19000	a) R3 hooks B2 b) R3 bumps B2 c) R3 intercepts the ball d) R2 intercepts the ball	D

Table 7.4 *Descriptions of the What Happens Next? (WHN) video stimuli used in the Chapter 5: Study 3 pre-training test.*

Clip No.	Clip Type	Description	Total Length (ms)	Play Onset (ms)	MCQ Answers	Correct Answer
16	Defence	Throw-In from the Centre: Red 2 has possession of the ball. Blue 2 intercepts the ball.	11220	9000	a) B2 hits a backshot to B3 b) B2 turns the ball to the left c) B2 turns the ball to the right d) B2 intercepts the ball and takes it forward	D
17	Defence	Field Play: Blue 2 hits a backshot.	8040	7000	a) B4 hits a backshot b) B2 hits a backshot c) B4 bumps R3 d) B1 hooks R4	A
18	Defence	Field Play: Blue 4 hooks Red 2's mallet.	13040	11000	a) B4 bumps R2 b) B2 hits a backshot c) B4 hooks R2 d) B4 passes to B2	C

7.6 Descriptions of Chapter 5: Study 3 training stimuli

Table 7.5 describes the What Happens Next? (WHN) video stimuli used for the Chapter 5: Study 3 training stimuli. It includes a brief description of the play, the total length of the play (ms), and the times of the video pauses (ms).

Table 7.5 *Descriptions of the What Happens Next? (WHN) training stimuli used in Chapter 5: Study 3.*

Clip No.	Clip Type	Description	Total Length (ms)	Pause 1 (ms)	Pause 2 (ms)	Pause 3 (ms)	Pause 4 (ms)
1	Offense	Knock-In from End Zone: Red 4 passes to Red 3.	150000	9000—55000	57000—80000	82000—100000	102000—139000
2	Offense	Knock-In from End Zone: Red 4 runs to the right.	169000	11000—60000	65000—89000	92000—117000	118000—156000
3	Offense	Knock-In from End Zone: Red 4 passes to Red 3	153000	7000—57000	58000—82000	84000—105000	106000—143000
4	Offense	Knock-In from End Zone: Red 4 runs to the left.	163000	8000—57000	60000—84000	86000—112000	113000—152000
5	Offense	Field Play: Red 2 leaves the ball for Red 4.	211000	20000—74000	86000—121000	125000—153000	155000—187000
6	Defence	Field Play: Red 4 hits a neckshot to the right.	157000	14000 – 74000	82000—104000	106000—138000	n/a
7	Defence	Field Play: R3 intercepts the ball.	153000	14000—76000	82000—99000	100000—134000	n/a
8	Defence	Field Play: R2 intercepts the ball and hits a backshot	173000	18000—81000	82000—98000	101000—119000	121000—154000
9	Defence	Field Play: Blue 2 intercepts the ball.	222000	23000—84000	95000—141000	144000—161000	165000—197000
10	Defence	Field Play: Red 4 blocks a goal shot with a backshot.	164000	7000—65000	67000—119000	121000—155000	n/a
11	Control	Steve Thompson Polo—Top 10 Polo Tips	920000	n/a	n/a	n/a	n/a

7.7 YouTube links for Chapter 4: Study 2.1 What Happens Next? (WHN) video stimuli

Table 7.6 lists the YouTube links for the What Happens Next? (WHN) video stimuli used for the Chapter 4: Study 2.1. Clip numbers 1—9 are offensive clips, and clip numbers 10—18 are defensive clips.

Table 7.6 *YouTube links for the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.1.*

Clip No.	YouTube Link	Clip No.	YouTube Link
1	https://youtu.be/M3APb6VlDdc	10	https://youtu.be/lRM6CMU9oJc
2	https://youtu.be/qNmiBvWeams	11	https://youtu.be/AHhoCszr5bs
3	https://youtu.be/omdisomFlog	12	https://youtu.be/7OWDbg3J1kk
4	https://youtu.be/mkGpLEFxp48	13	https://youtu.be/HSkyfcCF3Ts
5	https://youtu.be/MPBFczHba3o	14	https://youtu.be/x63eJ39AG2U
6	https://youtu.be/bQf14srXqqs	15	https://youtu.be/2wosxrbB7js
7	https://youtu.be/cSTs4uXMv_g	16	https://youtu.be/PPY4w59Euk0
8	https://youtu.be/P-f4bb4O-7g	17	https://youtu.be/oD89_X8yQ4s
9	https://youtu.be/QW0Hf8etc2U	18	https://youtu.be/YsY5h6fLlO8

7.8 YouTube links for Chapter 4: Study 2.2 and Chapter 5: Study 3 Post-Training What Happens Next? (WHN) video stimuli

Table 7.7 lists the YouTube links for the What Happens Next? (WHN) video stimuli used for the Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test. Clip numbers 1—9 are offensive clips, and clip numbers 10—18 are defensive clips.

Table 7.7 *YouTube links for the What Happens Next? (WHN) video stimuli used in Chapter 4: Study 2.2 and the Chapter 5: Study 3 post-training test.*

Clip No.	YouTube Link	Clip No.	YouTube Link
1	https://youtu.be/ywQftuJshOg	10	https://youtu.be/P9Ve8k78Cw8
2	https://youtu.be/tzwa48a0A9o	11	https://youtu.be/WB9LqWYRtHw
3	https://youtu.be/e9NchqDGwSc	12	https://youtu.be/HtFSm-qjN7U
4	https://youtu.be/LehjSIvNuzQ	13	https://youtu.be/U3Ws2plsYSA
5	https://youtu.be/OeBS92wEcuM	14	https://youtu.be/Fq_WRmQE0B8
6	https://youtu.be/J94V9Cl5jPc	15	https://youtu.be/CWIKER9K5t4
7	https://youtu.be/LAoZEaKYEt8	16	https://youtu.be/bSiiqo_KZdI
8	https://youtu.be/Ei5JyubjgzM	17	https://youtu.be/1512pmXsCXE
9	https://youtu.be/boEG73c-VWY	18	https://youtu.be/Ug4xx4XVQps

7.9 YouTube links for Chapter 5: Study 3 Pre-Training What Happens Next? (WHN) video stimuli

Table 7.8 lists the YouTube links for the What Happens Next? (WHN) video stimuli used for the Chapter 5: Study 3 pre-training test. Clip numbers 1—9 are offensive clips, and clip numbers 10—18 are defensive clips.

Table 7.7 *YouTube links for the What Happens Next? (WHN) video stimuli used in the Chapter 5: Study 3 pre-training test.*

Clip No.	YouTube Link	Clip No.	YouTube Link
1	https://youtu.be/qr4ijRL9Woo	10	https://youtu.be/vJZLktaBLBs
2	https://youtu.be/X3zzaXA49ao	11	https://youtu.be/05J1dhLwUpI
3	https://youtu.be/eYH9TArwVLM	12	https://youtu.be/WHk6tBK38Es
4	https://youtu.be/DClEJWcygO8	13	https://youtu.be/ZTeSxUKGrt4
5	https://youtu.be/_EjFJG78MBk	14	https://youtu.be/wruGB4-g95A
6	https://youtu.be/k_MCugYX8RM	15	https://youtu.be/yPOPkPc-cRU
7	https://studio.youtube.com/video/oXZ-EnF0FY4/edit	16	https://youtu.be/AwIDx1amKBM
8	https://youtu.be/xcc6ZXp_j9I	17	https://youtu.be/su4raFhVqeM
9	https://youtu.be/kNBB0DzP0Q0	18	https://youtu.be/LtkeXPVUR54

7.10 YouTube links for Chapter 5: Study 3 training video stimuli

Table 7.9 lists the YouTube links for the What Happens Next? (WHN) video stimuli used for the Chapter 5: Study 3 training. Clip numbers 1—5 and 11—15 are offensive clips, and clip numbers 6—10 and 16—20 are defensive clips. The control training stimuli used "Steve Thompson Polo—Top 10 Polo Tips" obtained from Steve Thompson Polo, with open access availability on YouTube (https://www.youtube.com/watch?v=SzrzB44fxM0).

Table 7.9 *YouTube links for the training video stimuli used in Chapter 5: Study 3.*

Clip No.	Training Type	YouTube Link	Clip No.	Training Type	YouTube Link
1	Cueing	https://youtu.be/R1M0fvt-QPI	11	Commentary	https://youtu.be/1RdOnKvFnTM
2	Cueing	https://youtu.be/lbKAVmm9QPk	12	Commentary	https://youtu.be/_wBTxVtZsU0
3	Cueing	https://youtu.be/0ag8hIA6yz4	13	Commentary	https://youtu.be/kTYBPnEihlg
4	Cueing	https://youtu.be/pVcxbsMQ-tI	14	Commentary	https://youtu.be/AQH7c6-MHmY
5	Cueing	https://youtu.be/Jfjq2zt3U7A	15	Commentary	https://youtu.be/-I6AiwikKZ8
6	Cueing	https://youtu.be/7F30fhzQvjM	16	Commentary	https://youtu.be/CDRoFhIAEnw
7	Cueing	https://youtu.be/kFuWU-KBNOk	17	Commentary	https://youtu.be/nsdsaCm4ZRk
8	Cueing	https://youtu.be/NGEvP2gG6BY	18	Commentary	https://youtu.be/jw3u-TUZc0Q
9	Cueing	https://youtu.be/1jVrkvzOzTo	19	Commentary	https://youtu.be/h9735LthC08
10	Cueing	https://youtu.be/O5DM4oa65BA	20	Commentary	https://youtu.be/G_athz5EuB4

7.11 Published materials

A portion of the literature review presented in Chapter 1 was adapted from the work: *Situation Awareness in sports: a scoping review* published in Psychology of Sport and Exercise. The full citation is as follows:

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Review

Situation Awareness in sports: A scoping review

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ABSTRACT

Situation Awareness (SA) has been studied in many dynamic environments such as aviation.

transportation, and medicine, but has not been extensively applied to sporting environments. Research from other areas suggests that SA is an important aspect of successful performance. The objectives of this scoping review were to identify what types of SA frameworks are used in sports, what methods are used to directly assess SA in sports, and what are the cognitive skills that have been linked to SA in sports. Seven databases were searched for peer-reviewed papers examining SA in a sporting context. The literature search revealed a scarcity of studies that directly describe SA within a sporting context. The most common frameworks described in the sporting literature were the three-level framework and Distributed Situation Awareness. The direct methods of measuring SA in sports varied and included the Situation Awareness Global Assessment Technique (SAGAT), Cognition Self-Assessment Tool (CSAT), and Random Number Cognition Test (RANCT) tools. Lastly, the cognitive skills linked to SA in sports included visual behaviours, anticipation, and decision-making. After evaluating the research, we argue there is potential benefit in applying SA to a sporting context but there are, currently, issues of validity and reliability in how SA is described and assessed in sports. Suggestions are made for how we might advance in this field of research.

1. Introduction

Researchers have investigated how cognitive skills such as visual search (Loffing et al., 2015; McGuckian et al., 2020; Sors et al., 2017) or anticipation (Smeeton & Huys, 2011) contribute to sporting performance. While isolating and assessing cognitive skills is important in sports research, it is also necessary to explore how cognitive skills are combined to influence overall awareness of the sporting environment; awareness that may aid in sporting performance. Situation Awareness (SA) is a popular construct that arguably captures these elements holistically during complex dynamic tasks (Hulme et al., 2019). Endsley (1995b) describes SA as "the perception of the elements in the environment [...], the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995b, p. 36). SA has been studied in a variety of highly dynamic environments including aviation (Muehlethaler & Knecht, 2016), transportation (Jackson et al., 2009; Schömig & Metz, 2013; Underwood et al., 2011), and medicine (Chapman et al., 2020; Dishman et al., 2020; Hunter et al., 2020). Within a sports setting, some researchers have argued that SA is necessary for an athlete to achieve high-level performance (Hadlow et al., 2018), yet few studies have examined the role of SA in sports (Ng et al., 2013). This is interesting considering the cognitive skills associated with SA are widely studied in sports (Hadlow et al., 2018). This paper aimed to therefore provide a reconnaissance of information related to SA in sport and focused on identifying the frameworks labelled as SA in a sporting context, the methods used to assess SA in sports and the cognitive skills directly associated with SA in sports.

While many researchers agree that SA is important for safety and performance in dynamic environments (Salmon & Stanton, 2013), there is no universally accepted framework (Salmon et al., 2009). However, the three-level framework by Endsley (1995a) is arguably the most cited and validated definition of SA (Salmon et al., 2009). In this framework, perception (Level I SA) is the detection of surrounding elements and provides the base for an individual's overall SA. Comprehension (Level II SA) is identifying the importance and understanding the meaning of the perceived elements, and projection (Level III) SA involves predicting what may happen in the near future (Jackson et al., 2009). It is important to recognize that SA is not decision making nor is decision making encompassed within the three-level framework. But arguably SA will influence, in part, decision making where good SA can subsequently

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contribute to better decision making. SA does not always guarantee good performance as there are many factors which influence performance, and SA is just one of those factors (Endsley, 1995b). As an example of this three-level framework in a sporting context, a soccer player may perceive another player running with the ball (Level I SA). The soccer player must now comprehend (Level II SA) if the player is a teammate or opponent and understand what their role is (*e.g.*, that they are an opponent attacking with the ball). The soccer player combines their perception of the elements (a player running with the ball) with the comprehension of the elements (the player is an opponent attacking with the ball) and now may make a prediction (Level III SA) on what the perceived player intends to do; will the opposing player take on the defence, or do they pass, and if so, to whom?

1.1. *Research questions and rationale*

There are few studies that specifically and directly investigate SA in sports, certainly relative to the volume of SA studies in other domains such as driving and aviation. This scoping review aims to provide a summary of the research related to three specific research questions:

1) What are the different types of frameworks labelled as situation awareness in sports?
2) What methods are used to directly assess situation awareness in sports?
3) What are the cognitive skills that have been explicitly linked to a situation awareness framework in sports?

Scoping reviews are relatively new research tools but are useful for determining the capacity of literature and its overall scope in the domain (Munn et al., 2018). We believe the exploratory nature of the scoping review to be initially more important than a systematic review in a less established area of research. A systematic review would be required to answer a more specific or set of specific research questions in a more established research area using literature as the data (*i.e.*, "*a review on the effect of x on y*"). With this review, we hope to provide a reconnaissance of the theoretical underpinnings, methodological issues, and potential future directions of SA in sports.

In our first research question, we asked: what are the different types of frameworks labelled as SA used in sporting contexts? Because SA is not universally defined (Salmon et al., 2009), researchers have posited different types of frameworks that measure different components. Therefore, we aim to identify which SA frameworks are used in sporting contexts and how these frameworks attempt to capture the varied elements across sports (*e.g.*, individual vs team). The three-level SA framework (Endsley, 1995b) is typically applied at an individual level within other domains and is likely also relevant within a sporting context, but many sports are team-orientated and there may be benefits to having a framework that captures team-wide awareness.

In our second research question, we asked: what are the methods to directly assess SA in sporting contexts? There have been several methods employed by other domains which assess an individual's SA. For instance, offline freeze-probes such as the Situation Awareness Global Assessment Technique (SAGAT; Endsley, 1995a) and What Happens Next (WHN; Jackson et al., 2009) involve simulations or freeze-frame video techniques, and participants must answer queries that target their SA (Endsley, 1995a). These techniques have been used in aviation (Endsley, 1995a; 2000a), air traffic control (Endsley, 2000b), driving (Jackson et al., 2009), and medical studies (Wright et al., 2004). Real-time online probes such as the Situation Present Assessment Method (SPAM; Durso & Gronlund, 1999) presents queries during a simulation, and participants may choose when to answer the queries based on their workload (Salmon et al., 2009). This has been used in air traffic control (Bacon & Strybel, 2013) and submarine track management (Loft et al., 2013). For a recent review that compares the SAGAT and SPAM methods see Endsley (2021). Lastly, subjective rating tools such as Situation Awareness Rating Technique (SART; Taylor, 1990) measure an individual's perceived SA through a series of post-simulation questionnaires (Salmon et al., 2009), and has been used in aviation (Endsley, 1988), air traffic control (Durso et al., 1999), and military planning (Salmon et al., 2009). Because there are a variety of methods that directly assess SA in other domains, we aim to identify which SA methods are used in a sporting context.

In our third research question, we asked: what are the cognitive skills linked to a SA framework in a sporting context? Endsley's (1995b) three-level hierarchal framework, for example, necessitates certain cognitive skills such as visual search skills (*i.e.*, for Level I SA) and anticipation (*i.e.*, for Level III SA; de Winter et al., 2019; Endsley, 1995b; Salmon et al., 2009). We aim to identify which cognitive skills have been directly associated with SA or mentioned in relation to SA within a sports context. Although note, reviewing more generally the literature of cognitive skills (*e.g.*, visual search) that could simply be implied to relate to SA or an element of SA exceeds the aim of this scoping review. Our focus is on those pieces of research that directly make mention to SA. For examples of reviews targeting certain cognitive skills in sport more generally, see McGuckian et al. (2018) for visual search and Loffing and Cañal-Bruland (2017) for anticipation.

2. Approach

2.1. *Sources of information*

The literature search was carried out using seven internet-based databases: ScienceDirect, Google Scholar, Nottingham Trent University Library OneSearch Pro, Web of Science, PsycInfo, PubMed, and SCOPUS. These databases are available to the authors through institution subscriptions or are freely available search engines. Table 1 shows the databases used, how to access them, and their accessibility.

2.2. *Search terms & delimiting*

The following parameters were used to search the databases for relevant literature. Search keywords included "situation(al) awareness", AND "sport(s)", OR "athlete(s)", OR "player(s)", OR "coach(es)", OR "trainer(s)", OR "referee(s)", OR "official(s)", OR "umpire(s)".

2.3. *Selection criteria employed*

To narrow down the number of papers included for this review, certain selection criteria were employed to ensure the papers were relevant. Figure 1 shows the PRISMA flow diagram for the screening and selection process. To be included in the review, papers were required to be peer-reviewed articles, sports and situation awareness-related, and written between the years 2000–2020. The searches were up to date as of December 2020. Initial searches of "situation awareness" AND "sports" revealed no articles pre-2000. Papers were excluded if they did not contain the phrase "situation awareness" in either the title, abstract, or the listed keywords, if they did not pertain to a sporting context, or were not written in English. From our initial search, it was found that

Table 1
Databases for literature search.

Database	Web Address	Accessibility
ScienceDirect	sciencedirect.com	Institutional
Google Scholar	scholar.google.com	Open
NTU Library OneSearch Pro	llr.ntu.ac.uk/choose-los	Institutional
Web of Science	apps.webofknowledge.com	Institutional
PsycInfo	search.proquest.com/psycinfo/advanced	Institutional
PubMed	pubmed.ncbi.nlm.nih.gov	Open
SCOPUS	scopus.com	Institutional

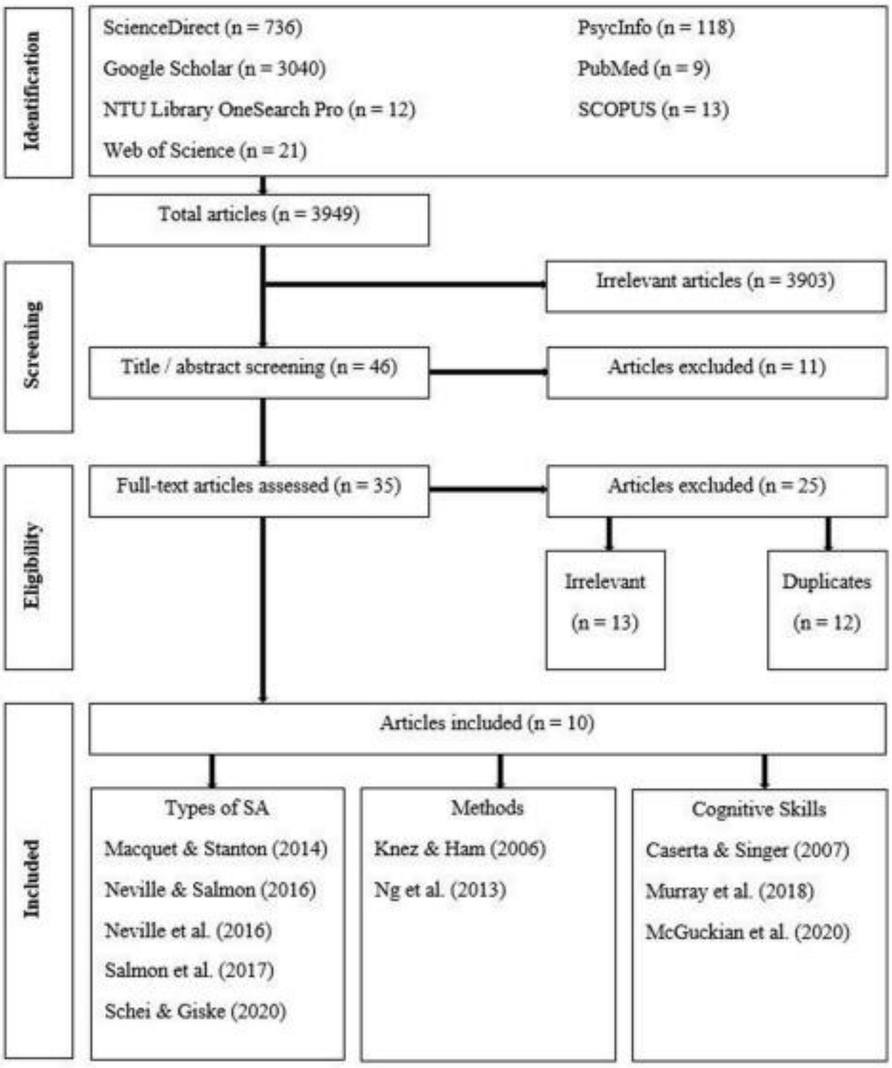

Fig. 1. PRISMA flow diagram for literature screening and selection.

there were many duplicates of papers as well as irrelevant articles (*i.e.*, papers on the topic of SA but not pertaining to sports).

The selection criteria for this review made it necessary for papers to explicitly describe situation awareness in sports contexts. While many sports papers investigate cognitive skills, such as visual search behaviours or anticipation, only papers that mentioned or directly linked those cognitive skills to situation awareness were included. More than preserving focus, this criteria also removes our own author subjectivity in categorizing whether a cognitive skill *could* be related to SA.

3. Findings & discussion

3.1. Situation Awareness frameworks in sports

The findings of our literature search revealed that Distributed Situation Awareness (DSA) and Endsley's (1995b) three-level frameworks were the overwhelming SA frameworks discussed in a sporting context. Four articles described Endsley's (1995b) three-level framework (Caserta & Singer, 2007; Knez & Ham, 2006; Murray, 2018; Ng et al., 2013). Four articles employed the framework of DSA to a variety of sports which included research on athletes, coaches, and officials (Macquet & Stanton, 2014; Neville et al., 2016; Neville & Salmon, 2016;

Salmon et al., 2017). However, Neville and Salmon (2016) was a review article on SA in officials and will not be discussed explicitly in this paper. One article employed a Shared Situation Awareness (SSA) framework to athletes and their coaches (Schei & Giske, 2020). One article (McGuckian et al., 2020) did not describe a specific framework, but mentioned SA.

3.1.1. Three-level framework

Endsley's (1995b) three-level framework was described in four papers investigating SA in cyclists (Knez & Ham, 2006), tennis players (Caserta & Singer, 2007), basketball players (Ng et al., 2013), and squash players (Murray, 2018). As mentioned previously, Endsley's (1995b) three-level framework contains hierarchal levels of perception, comprehension, and projection. The first level is the ability of an individual to perceive the elements in the environment. The second level, comprehension, is when that individual identifies the importance and understands the meaning of the elements in the environment. The third level, projection, is when the individual makes a prediction about what may happen in the near future (Endsley, 1995b). The three-level framework describes how individuals use mental models established through experience and training to effectively perceive their environment and predict the future state of the environment (Endsley, 1995b; Salmon et al., 2009). While the four papers above mentioned the three-level framework of SA, their main objective related to our other research questions more closely and, as such, will all be discussed individually in subsequent sections.

3.1.2. Distributed Situation Awareness

Distributed Situation Awareness (DSA; Stanton, 2016; Stanton et al., 2006) suggests SA is applied across systems or environments and describes how SA is obtained via the interaction between human and non-human agents. It argues that SA is within both the individual and the context of the environment (Macquet & Stanton, 2014). With DSA, researchers and practitioners may describe how interactions within a system determine the overall performance (Neville & Salmon, 2016). DSA therefore describes what unique SA information is necessary for each individual agent within a system. Once the unique SA information is identified, agents can exchange that information when and where it is required. Within DSA, SA is a combination of the individuals' and technical agents' SA models. However, the actions of each individual are still based on their own understanding of their SA. DSA has been suggested to be a more accurate representation of a team's SA (Stanton, 2016), and has been described in many environments such as military control, healthcare, transportation, and sports (Neville & Salmon, 2016). DSA has been argued as an appropriate method for describing SA within sports because of the cooperative nature of sports with multiple individuals each with different relationships and tasks (Macquet & Stanton, 2014; Neville et al., 2016). Many sports create an environment in which individuals and teams of people compete for the same goal, so while a sport may be labelled as "individual", there is still a team of coaches, trainers, and other athletes that influence training, competition, and ultimately SA.

Salmon et al. (2017) used a DSA approach to examine the SA networks in elite women's cycling. In elite cycling, athletes form a "peloton" or pack of cyclists. In these pelotons, athletes must remain aware of their teammates' and opponents' movements in order to successfully strategize how to win as well as to avoid collisions. There is also substantial communication during a race between teammates and coaches. In their research, Salmon et al. (2017) video-recorded a cycling race, recorded the verbal communications during team race planning meetings, conducted post-race Critical Decision Method (CDM) interviews, and audio recorded post-race team debriefs. Following the interviews, each participant completed a social network analysis diagram to show who and what they interacted with during the race. The interviews were transcribed verbatim and categorized into three networks based on the Event Analysis of Systematic Teamwork (EAST) framework. EAST is an ergonomics framework designed for analysing complex systems – in this case, a sociotechnical system (a system with both human and digital agents) – and describing the activities within. Networks are identified using network analysis principles where important nodes and paths are identified based on certain metrics (*e.g.*, number or density of connections; Lane et al., 2019). The three thematically identified networks were the: 1) Task, 2) Social, and 3) SA networks. The Task Network revealed there was a range of subtasks involved - both at an individual and team-level. The relationship between each subtask can be used to identify which are important to team success. The Social Network showed that the "protected rider" (the leader of the peloton) and "domestique rider 2" (support rider in the peloton) were the most connected with incoming/outgoing communications. These two riders also had more frequent communications with other agents. Importantly for this research, the network analysis revealed, with the SA Network, that SA was distributed across the team, peloton system, and between human and non-human agents. As an example, information presented on the bike-mounted computer and handlebar screen was used in conjuction with verbal transactions within the peloton and was important to inform decisions; for example, when to attack. This research was exploratory in nature and, like much of the DSA research, simply offered a description of the elements that may be related to situation awareness or performance.

The athlete is not the only performer in a sports context. The coach is also an important member of the team in many ways. The coaching process is composed of training, competition, and organization, which is highly cognitive in nature (Debanne & Chauvin, 2014). They must have an awareness of how their team and the opposition are performing to make quick decisions. Coaches often have different vantage points of the situation in comparison to the athlete, therefore they may interpret the situation differently (Macquet & Stanton, 2014). Macquet and Stanton (2014) used a DSA approach to determine if the athletes' and coaches' SA matched each other. Six elite athletes (two male and two female hammer throwers, and one male and one female rower) and three coaches (one hammer throwing and two rowing) were observed and recorded during training sessions. Video recordings of the athletes' behaviour, athletes' and coaches' communication, and verbalizations from post-training interviews were analysed for behavioural and contextual data. Participants watched their videos during interviews with the researchers and described their activity and thoughts during a course of action. The data identified what the authors called "meaningful units", which were verbalizations relating to or that described the athlete's behaviour, focus, feelings, and the situation (Macquet & Stanton, 2014). It was suggested that if the content of the units described by the player and coach matched or were "compatible", then this would aid performance. The authors then thematically organized the content of the meaningful units into broader categories. They identified that the content of the meaningful units could be themed as relating to "Technical Elements", "Athlete's Psychological States", "Organization and Safety", "Performance", and "Athlete's Experience". They report that the meaningful units themed within Technical Elements were reported to have the highest number of compatible matches. Meaningful units themed within the Athlete's Experience were reported to having the least number of compatible matches. What we can take from this research, and what the authors suggest then, is that coaches and athletes' SA may often overlap but not always. How this relates to performance, however, is unclear.

Officials are a vital part of all sports and can be classified as interactors (*e.g.*, basketball referees), reactors (*e.g.*, line judges), or monitors (*e.g.*, gymnastics judges; Neville & Salmon, 2016). Officials are required to have significant awareness of the unfolding play and make rapid decisions that may be influenced by a variety of factors (Burnett et al., 2017). Therefore, it can be argued that officials must have SA during competitions to ensure correct and fair calls or judging. Neville et al. (2016) applied a DSA framework to officials in sport (OiS). Game video recordings and audio commentaries between referees were provided by the Australian Football League (AFL). Each game was transcribed and coded for DSA using the EAST method. The authors described how SA is distributed within an OiS sociotechnical system with six tenets (Neville et al., 2016), where the OiS sociotechnical system is defined by the network of both human referees and non-human technical agents (e.g., video review and goal-line technology). Tenet 1 described that the OiS SA is held by both human and non-human agents. Video review systems and goal-line technologies facilitated the SA held by officials. Tenet 2 stated that the agents have different perspectives on the game due to positions and roles, and these different views are combined to make an appropriate decision. The authors report that the system could not function if the officials' SA are not compatible with each other, or in other words do not align towards a similar goal or decision. Tenet 3 described the overlapping of SA between agents and suggests that overlapping of SA occurs and is only important when the goals of the agents are similar or the same. Tenet 4 stated communication between agents could be verbal and non-verbal. The use of hand signals and flags were used by officials as non-verbal SA transactions in the OiS system. Tenet 5 described how SA holds loosely coupled systems together, but also that coupling can shift dynamically throughout the duration of a game. The officials interacted with the game differently depending on play situation. Officials were more loosely coupled during general play, and field umpires did not interact as much with boundary and goal umpires. However, during set shot for goal and out of bounds situations, the umpires interacted much more with each other. Lastly, Tenet 6 described that one agent may compensate for the degradation of SA in another. For example, video review for uncertain plays and goals compensates for an on-field official's initial ruling. Overall, Neville et al. (2016) suggested that SA in officials is activated and updated through transactions in the system either through verbal or non-verbal communication. They also argued that DSA can contribute to the understanding and enhancement of complex sociotechnical systems performance.

While DSA has been described as appropriate for assessing SA in sports (Macquet & Stanton, 2014; Neville et al., 2016; Neville & Salmon, 2016; Salmon et al., 2017), we propose that this method merely describes the thoughts and actions of the performers and identifies relevant knowledge that other actors have. Ultimately, DSA appears vague and unquantifiable. It offers no obvious way of creating a standardized test that can be compared across studies, trials, and sports. There is also no discernible in-depth measurement of performance with DSA that states whether or not a performer has good or adequate SA required for their tasks, nor does DSA allow one to identify where mistakes were made during a performance or how to correct those mistakes. One could propose that DSA is simply a way to describe that the overall SA model is an outcome of the combination of all others' SA models. Related, but perhaps not a limitation given the nature of DSA, DSA does not provide insight into the importance of an individual's SA – particularly in sports where communication between coaches during gameplay is minimal (e.g., racquet sports). Even in team sports, one still operates at an individual level, and as such it would be still be useful to explore individual SA in team sports. We discuss a potential measurable method to accomplish this in the General Discussion. It should be noted, however, that DSA is still in its infancy and has not been extensively studied and applied as other measures of SA (Stanton, 2016).

3.1.3. Shared Situation Awareness

Shared Situation Awareness (SSA) promotes the idea that team performance will be optimal if players on the same team have a shared understanding of the environment, the agents within the environment, and how to execute the current task (Jonker et al., 2010; Salas et al., 1994). SSA appears to be very similar in nature to DSA (both in terms of construct and measures of) and has been defined as a shared understanding of a situation (Kurapati et al., 2012). It is argued that each team member has their own pre-existing knowledge and experience that differs from the other members. However, the members often must have good SA of their specific components as well as those shared by the team (Gillespie et al., 2013). Success of a task depends on the members' shared strategic knowledge and mental models which allows the team to have common definitions of tasks, assessments of the situation, and expectations of the task requirements (Salas et al., 1994). Communication amongst team members is argued to be the most important aspect of SSA as it affects the flow of information and ultimately the decision making of the team (Seppänen et al., 2013). Researchers believe that through SSA, teams become coordinated, and members are able to anticipate the actions of the other members (Salas et al., 1994), which is important for sports teams (Loffing & Cañal-Bruland, 2017).

Schei and Giske (2020) examined the SSA between soccer players and their coaches to determine if athletes and coaches are coordinated in their views of the game. Ten elite soccer players and their coach watched 12 videos of a soccer match in which the players participated, and they were interviewed following each video. Participants were asked to "describe what you perceive in this video" along with follow-up questions. Each interview was transcribed and analysed to determine similarities and differences amongst the players and coach. Situational descriptions, such as the theme, terminology, positions, and pitch area, as well as the situational solutions were used to evaluate the similarities and differences in statements. The authors revealed that in seven of the game situations, the players and coach shared coordinated views, but in five of the situations, they had contradictory views. The contradictory views would arguably have a negative effect on SSA, and therefore team coordination (Schei & Giske, 2020). The authors suggested that SSA requires players (and coaches) to continuously update their views of the situation for the team to be cohesive. They also argued that SSA in a team is a collective endeavour, and that teams should watch game footage to express their opinions to improve their shared knowledge skills, and thus SSA (Schei & Giske, 2020).

While SSA does address the communication and coordinated information required for successful teams, it arguably fails to explain how the individuals obtained their information, whether that information gave them "good" or "bad" SA, or how to improve their overall SA, which is often the goal of researchers (Patrick & Morgan, 2010). Therefore, it appears the major shortcomings of SSA and DSA are that these frameworks are only descriptive in nature, do not provide an in-depth measurement of SA, and lack the ability to be empirically tested and trained over different trials with different participants.

3.2. Direct methods of assessing Situation Awareness in sports

The results of our literature search revealed only two papers where the authors used direct methods to assess SA in athletes. Ng et al. (2013) used the Situation Awareness Global Assessment Technique (SAGAT) alongside several other general cognitive tests in basketball players, while Knez and Ham (2006) used a subjective Cognition Self-Assessment Tool (CSAT) and objective Random Number Cognition Test (RANCT) to measure SA in cyclists. The other studies reviewed did not use a direct measurement of SA.

3.2.1. Situation Awareness Global Assessment Technique (SAGAT)

Arguably the most popular and validated objective method is the Situation Awareness Global Assessment Technique (SAGAT; (de Winter et al., 2019; Endsley, 1995a, 2021). It has been reported that SAGAT scores are indicative of performance in a simulation, which validates the measurement of SA (Endsley, 2000a). The SAGAT test was designed alongside the three-level framework of SA proposed by Endsley (1995b). It is an offline, freeze-probe objective measurement taken during a task that queries participants' knowledge of task-specific elements and how they are likely to act in the future (Orique & Despins, 2018). The questions then target a participant's SA through their perception, comprehension, and projection (Dishman et al., 2020). Once the participant answers the questions, the simulation or video resumes. The questions may be scored binarily as "correct" or "incorrect" (Endsley, 1995a) or the response time may be used to assess SA (Bacon & Strybel, 2013). Upon the completion of the simulation or video, the points are summed to give an SA score (Endsley, 1995a). The higher the score or lower the response time, the better the participant's SA. The SAGAT test has been shown to be a reliable method for measuring an individual's SA in a variety of environments (Crozier et al., 2015; Dishman et al., 2020; Endsley, 2000a; Ikuma et al., 2014; Jannat et al., 2018; Joffe & Wiggins, 2020; Kaber et al., 2016; Lavoie et al., 2016).

To assess how cognitive skills and SA influence basketball performance, Ng et al. (2013) tested teenage (14–16 years) basketball player's level of anxiety, short-term memory, and SA. They also tested the players' knowledge of basketball rules and concepts, their ability to learn and set plays, and their physical fitness level. Twenty-five basketball players completed a SAGAT test and several other cognitive tests in conjunction. The SAGAT and cognitive tests were taken twice during the study—once at the beginning of the season before the first game and once at the end of the season following the last game. In the SAGAT test, players were shown a 5 – 7-min professional basketball video that was paused three times. At each pause, the players answered 4–5 multiple choice questions that targeted their perception, comprehension, and anticipation abilities. Alongside the SAGAT test, the basketball players completed a Competitive State Anxiety Inventory-2 (CSAI-2) test to measure cognitive and somatic anxiety plus self-confidence. They completed a Corsi block-tapping task to measure short-term spatial memory, in which participants were shown a pattern of randomized block taps and were required to replicate the pattern, with the patterns increasing in length for each trial. Participants also completed a multiple-choice basketball knowledge test, a basketball recall-and-recognize learning video task, and a standardized physical fitness test. The authors compared scores of the SAGAT, cognitive tests, and fitness test with the players' performance results in the basketball games. Ng et al. (2013) reported that the fitness test score can best explain the variance in basketball performance, followed by basketball learning ability, basketball knowledge, short-term spatial memory, competitive anxiety, and lastly SA, which was not a significant predictor. Within the cognitive skills tests (Corsi block-tapping and CSAI-2), the short-term spatial memory (Corsi block-tapping test) had the largest coefficient for predicting basketball performance, which the authors suggested was indicative of players' abilities to find open spaces on the basketball court to score points.

SA, measured through the SAGAT test, was not a significant predictor of the variance in performance scores across the players (Ng et al., 2013). Players averaged 54.2% on the perception questions, 33.3% on the comprehension questions, and 46.9% on the anticipation questions. However, the players were least consistent when responding to the anticipation questions, with scores ranging from 0 to 100%. The authors argued SA may not explain basketball performance as well as the other skills because basketball performance is often influenced by other players. They reasoned that a player may have good SA and pass the ball to a teammate, but if that teammate does not have the same SA and catch the ball, the performance is ultimately affected. Ng et al. (2013) explained that performance statistics are also often dependent on the opposing team. One of the important takeaways from this piece of research therefore is that SA may not relate to performance directly. SA is not performance itself. It is a mental awareness that may aid in performance, but good SA cannot guarantee good performance. Where this distinction is likely to be most salient is in the execution of technical motor skills. Whilst an individual may have a good level of SA, and then subsequently make the correct decision, they may, for example, be inaccurate in their pass.

However, some limitations remain in the Ng et al. (2013) study, particularly with regards to the attempt to relate SA and performance. This research did not take into account the importance of measuring different experience levels of players. The players sampled in the study were all of similar ages (14–16 years) and played on the same team, so it is possible the variability of SAGAT scores and basketball performance was small due to the similarities of the players. It would be beneficial to sample players of differing experience (*i.e.*, experts and novices) to provide a greater variability in SA performance measures. This is often seen in driving SA studies where experts and novices are compared (Kroll et al., 2020). It is also worth noting that the low SAGAT scores in all three levels suggest that the questions were perhaps too difficult for the level of the players, or that the questions focused on elements that the players did not consider relevant to their next move. It should also be noted that Ng et al. (2013) only averaged the SAGAT scores of the players and did not look at the individual scores themselves. It would be beneficial to see if individuals with higher SAGAT scores had better basketball performance scores. This would potentially show a link between better SA and better performance, often seen in other domains such as driving (Crundall, 2016; Kroll et al., 2020). Ultimately, we argue that whilst SA may not explain all the variance in performance, we suggest that further studies better targeting this relationship using the SAGAT method is warranted.

3.2.2. *Cognition Self-Assessment Tool (CSAT) and Random Number Cognition Test (RANCT)*

Knez and Ham (2006) examined the effects of fatigue on elite cyclists' subjective and objective SA during a Time Trial 30 km (TT_{30}) cycling race. Physical factors such as fatigue and psychological factors such as boredom, anxiety, and pressure have been known to affect SA in individuals (Endsley, 1995b; Sneddon et al., 2013). The measures identified to assess SA were 1) the Cognition Self-Assessment Tool (CSAT) and 2) the Random Number Cognition Test (RANCT). The CSAT is a subjective self-report measure that asks questions related to the degree to which participants would be able to carry out specific cognitive tasks. Tasks such as the ability to plan race lines, develop race strategy, judge distance, etc. The RANCT is a common measure for visual search and detection performance. In this study participants were presented with a 6 × 6 grid containing numbers 1–36 and were asked to sequentially score out the numbers. Whilst the CSAT may seem somewhat related to assessing SA, it is more difficult to connect performance in the RANCT with overall SA. At best, perhaps it might relate to Level I of the three-level framework (Perception), but it is unclear how it might relate to a general awareness where one is able to make predictions or make decisions. The authors reported that the maximal physical effort during a TT_{30} race resulted in a significant increase in performance in the RANCT, suggesting that high-exertion exercise benefits visual search/detection. In contrast, it was reported that high exertion also resulted in greater perceived difficulty to maintain SA during the race, which were reflected in the scores of the CSAT.

Knez and Ham (2006) suggested that CSAT and RANCT have a high reliability to give consistent measures of visual perception and detection skills, as well as measures of cognitive function. The authors also suggested these tools may be used to help manage an athlete's perception of fatigue and arousal levels, the contributing factors to fatigue and arousal, and their own SA abilities (*i.e.*, recognizing key elements and making correct and timely decisions). While Knez and Ham (2006) argued that the CSAT and RANCT are reliable measures of SA, it should be addressed that crossing out sequential numbers through the RANCT makes no connection to the athlete's awareness of their surrounding sporting environment. While the RANCT is useful in assessing general cognitive functions and visual search tasks (Knez & Ham, 2006), this is not necessarily the same as SA. One could make the argument that RANCT is not a valid measurement of SA but only an arbitrary method to examine visual scanning and cognitive function. Knez and Ham (2006) noted the increase in perception of difficulty through the CSAT was inconsistent with the 'objective' measurement of SA through the RANCT. They suggested athletes perhaps underestimate their level of SA. Self-reported SA assessments have been criticized as being unable to accurately report SA (Salmon et al., 2009) because they are thought to be influenced by an individual's performance or memory and not on a participant's actual SA (Endsley, 1995b). However, it is still important for athletes to know if they are over- or underestimating their SA abilities. This knowledge may allow them to alter their behaviour to better suit their environment and performance (Knez & Ham, 2006).

3.3. Cognitive skills associated with Situation Awareness in sports

The results of our literature search showed the cognitive skills of visual search, anticipation, and decision making were directly linked to SA in a sports context. McGuckian et al. (2020) examined the visual search behaviours of soccer players, Caserta and Singer (2007) studied how anticipation, decision making, and SA influenced tennis performance, and lastly Murray (2018) isolated the effect of SA on decision making in elite squash players. As a reminder, whilst a plethora of sporting research will investigate and report on these elements, only those that specifically discuss these in relation to SA were included in the review (this point is addressed later in the discussion).

3.3.1. Visual search behaviours

Perception—the first level in Endsley's (1995b) framework of SA—is heavily influenced by an individual's ability to efficiently and effectively use vision to monitor their environments. Perception (Level I SA) errors are notably the most common amongst SA errors, particularly due to the failure to recognize or see important environmental elements (Mason, 2020). Therefore, visual behaviours are important in acquiring SA. Each athlete has different perceptions and roles in their environment based on their past experiences, coaching, and positions played (Richards et al., 2009). Playing positions, offense or defence, positions on the pitch, and the flow of the game can all impact an athlete's visual perception and ultimately SA.

McGuckian et al. (2020) examined how SA and decision making (DM) via visual search behaviours is affected based on an athlete's pitch position, role on the team, and phase of play. Twenty-two teenage Australian National Premier League youth players competed in two separate 11 v 11 training matches. The players' head movements and pitch position were recorded. The authors examined data regarding pitch zone, ball possession, phase of play, head turn frequency, and head turn excursion for each player. McGuckian et al. (2020) reported the ball possession, phase of play, location on the pitch, and playing role constrained the way players visually explored their environment. They found players explored more extensively when they were in possession of the ball in comparison to when they were not. The authors suggested players were not searching as much prior to ball possession and thus compensated and searched more when they received possession. In a defensive or attacking area on the pitch, players explored more than they did in central or neutral areas despite being surrounded by teammates and opponents in the central areas which offered an abundance of visual information. McGuckian et al. (2020) proposed that players should develop their visual searches in the central pitch areas. The players also searched more when their team had possession of the ball compared to when the opposing team had possession and transition phases when there was no clear possession. McGuckian et al. (2020) suggested there may be less searching in transition phases due to the uncertainty of the situation and the increased task demands. The authors also reported that players were only in possession roughly 2% of the playing time, and they argued that players should develop their searching abilities outside of ball possession. McGuckian et al. (2020) suggested that perception—and the visual behaviours that underly it—forms the base of a person's SA, therefore it is important that players are able to increase their searching abilities in times outside of possession to increase their SA.

Yet, despite this mention, this study did not measure the relationship between visual search behaviours and SA explicitly. Because perception (Level I SA) is the foundation for good SA (Endsley, 1995b), sports studies investigating SA should ideally explore the relationship between visual behaviours. Other domains, such as driving, have extensively identified visual search strategies and their effect on SA (Haupt et al., 2015; Scott et al., 2013; Underwood et al., 2003). Generally, more experienced drivers exhibit more effective search strategies and also have better driving performance and SA (Konstantopoulos et al., 2010; Mackenzie & Harris, 2015). In sports, many studies have examined gaze behaviours (Binsch et al., 2009, 2010; Panchuk et al., 2017; Panchuk & Vickers, 2006; Vickers, 1996), but few have related those behaviours to SA. Therefore, we argue that it is important to examine how sports participants use perception and visual behaviours to achieve SA within a sporting domain.

3.3.2. Anticipation

Anticipation has long been investigated within sporting contexts (Loffing & Cañal-Bruland, 2017; Williams & Jackson, 2019). Projection (Level III SA) is often seen as the ability to anticipate or predict what may happen next in the environment (Jackson et al., 2009). Therefore, it can be argued that anticipation and SA are highly related. Information from athletes' bodies, kinematics, and equipment is often used to anticipate shot direction (Cañal-Bruland et al., 2011), movement (Loffing et al., 2015), and deceptive actions (Wood et al., 2017), which affect sports performance.

Caserta and Singer (2007) investigated how anticipation and SA training in tennis influenced performance on a tennis-related video task (identify where to position oneself to return a shot). Training was instruction-based and, depending on the experimental condition, informed participants about: the most important cues to attend to (visual), the meaning of those cues (understanding), how to use this information to anticipate shots (anticipation) and how to respond effectively (decision making). After training, each participant viewed several tennis video clips and were required to choose a location to return a shot by manually pressing buttons that represented areas of a tennis court. The results were that, overall, the training groups responded faster than the control group (no instructional training) but there was no difference in accuracy (Caserta & Singer, 2007). The training had perhaps enhanced the awareness of strategies, court positioning, and shot tendencies and thus allowed the training groups to make faster decisions (Caserta & Singer, 2007). The authors proposed that athlete performance can be improved with training SA, anticipation, and DM skills rather than years of developing physical skills. Importantly, Caserta and Singer (2007) argued that training perceptual skills should go beyond isolating anticipation and DM and should instead combine the skills associated with SA to provide athletes with a complete set of perceptual tools. The results of Caserta and Singer (2007) lend credence to the idea that SA is important in dynamic sports contexts, and that training SA and anticipation skills may be effective in assisting athletes' DM processes.

3.3.3. Decision making

The decision making (DM) abilities of athletes have long been explored by researchers and practitioners. Researchers generally accept that SA is an important foundation for DM and ultimately performance (Mason, 2020). Many also agree that DM in complex environments, such as sports competitions, requires extensive domain expertise that is acquired through many hours and years of practice and experience (Hutton & Klein, 1999; Macquet & Fleurance, 2007). In a SA context, DM is influenced by an individual's ability to take in all relevant sources of environmental information, combine that information using knowledge from past experiences, and physically respond to that information (Murray, 2018). Researchers also argue that SA is an important precursor to DM (Endsley, 1995b), meaning that better SA may lead to better decisions.

Murray (2018) investigated how SA influenced the decision of which shot to play in expert squash players. Over 40 squash matches were recorded, and player shot type, player position and movement, and ball position were tracked using squash game tracker technology. Based on these quantifiable aspects of play, the authors conducted a cluster analysis to identify categories of shot-outcome. The analysis revealed six, what the authors termed, "SA clusters" that related to the shot the player decided to play. For example, an "attempted winner", was revealed as a cluster that often resulted from when the player identified the opponent was out of position and the player was facing low pressure (*i.e.*, more time to play the shot). Conversely, a "defensive" cluster was identified, and this was a shot outcome that would result from when the player was facing high pressure (*i.e.*, where the distance they would have to travel to make the shot was large or the time they had to make the shot was short). The authors suggest this method and the results allowed for a fine-grained analysis into the reasons for differences in behaviour and decision making within expert-level players. And this is an important addition to the field, where much of the research into differences in behaviours within sports addresses the differences between expert groupings (novice/amateur/professional).

We would argue the terminology of "SA cluster" is somewhat misleading as it seems these clusters are categorized as decision making outcomes rather than SA itself. SA is arguably more related to the analysed components that fed into the corresponding cluster (*i.e.*, having awareness of an opponent's position or awareness of how long one has to make a shot). The authors make an inference that the players had SA related to these parameters that then may have influenced the decision of which shot to play, but there was no measure of SA per se. Successful decision making is likely, at least in part, a result of successful SA (Endsley, 1995b) but is not the same as SA. This distinction is not made particularly clear in the research by Murray (2018).

4. General Discussion

This scoping review examined SA in sports, focusing on three research questions: Within sports, 1) What are the different types of frameworks labelled as SA? 2) What methods are used to directly assess SA? 3) What are the cognitive skills that have been explicitly linked to an SA framework? Our results confirmed there is a paucity of sources which report studies of SA within sporting contexts. In this section, we will discuss the key findings, implications, and present suggestions for future studies of SA in sports.

4.1. *Issues with description in frameworks*

Perhaps one of the more surprising findings in this review is the scarcity of using the more tangible three-level SA framework in a sporting context. It has been investigated in other domains such as aviation and driving and is able to provide quantifiable insights into the nature of SA and how it might link to sporting performance. As such, one would argue this is an appropriate starting point for investigating SA in sports. Yet, in much of the research described, analyses relating to SA frameworks have been somewhat retroactive. That is, games have been recorded and then researchers make inferences based on the behaviour observed (Knez & Ham, 2006; Murray, 2018). Whilst this approach has benefits such as being able to analyse naturalistic behaviour, it often results in very descriptive research; research that appears to provide only surface level observations of what information a human or digital agent may hold. From our literature search, we ultimately found a lack of testability and replicability in SA frameworks used in sports, namely with the Distributed Situation Awareness (DSA) and Shared Situation Awareness (SSA) frameworks. The descriptive nature of these frameworks makes it difficult to compare results across the studies and draw conclusions on the importance of SA in sports. While DSA and SSA acknowledge the importance of team communications and technological agents in SA, they do not provide a reliable and/or valid method of measurement. Nor do they provide an in-depth measure of performance or decision-making or indicate the sufficiency of SA. There is no discernible component to DSA and SSA which allows one to conclude if a person's SA is good or bad, and there are no performance measures described to correlate with the SA. Consequently, the implications for training and assessment become limited, which are aspects that are often targeted in sports cognition (Caserta & Singer, 2007; McGuckian et al., 2020; Patrick & Morgan, 2010). If SA in sports is to be trained as a means to aid performance, as it has been in other domains (Mason, 2020; Salehi et al., 2018), including driving (Horswill et al., 2013; Wetton et al., 2013; Young et al., 2017), and aviation (Muehlethaler & Knecht, 2016), then we argue for the importance of quantifiable measures of assessment in SA frameworks.

4.2. *Underdeveloped methods assessing SA and the potential for a synchronized SA framework*

Providing individual assessment of SA in sports is hugely important as 1) many sports are individual based (*e.g.*, squash) and 2) even in team sports, team performance is (usually) a culmination of individual performances. As demonstrated in other domains, Endsley's (1995a) SAGAT method appears reliable for assessing individual SA (Crozier et al., 2015; Dishman et al., 2020; Endsley, 2000a; Ikuma et al., 2014; Jannat et al., 2018; Joffe & Wiggins, 2020; Kaber et al., 2016; Lavoie et al., 2016) given its link to the three-level framework. As such this is likely again a good starting point in assessing SA in sport. Other methods identified as providing assessment (or claiming to) for individual SA included the Cognition Self-Assessment Tool (CSAT) and Random Number Cognition Test (RANCT; Knez & Ham, 2006). There were issues relating to the validity of SA measurements in sport which was most salient with the RANCT which appeared to assess visual search/identification and not SA. Beyond this, no research that we are aware of had demonstrated a level of validity in their tool (including SAGAT) by comparing performance between, for example, novices and experienced, 'more expert' sports players, or even winning and losing teams. One could argue that identifying performance differences across these groups would identify expertise effects suggesting a level of validity in the tool (if, of course, the more experienced or expert players perform better than novices). We see this type of comparison in What Happens Next (WHN) tools in driving, for example, Kroll et al. (2020) have shown that emergency response drivers outperformed control drivers in a WHN task based on the SAGAT.

The reviewed studies also gave conflicting results regarding the relationship between physical performance and SA, with Ng et al. (2013) stating no relationship between actual performance and Knez and Ham (2006) stating the opposite. Given the scarcity of research it is difficult to make any claims here linking 'adequacy of SA' and sporting performance. Developing more quantifiable and sensitive measures of SA would benefit the field whereby one might be better able to identify the link between SA and sporting performance. These measures might also identify the possible disconnect between level of SA and sporting performance where, for example, an avid soccer viewer has high level of SA but is physically unable to perform.

Whilst continuing research into methods of assessing SA at an individual level is warranted, perhaps there is opportunity to also better investigate the interaction between individual SA and team performance. One such possibility would be to use the more promising SAGAT method of assessment to capture SA at the individual level and compare this across the team. It is possible that the successful teams have increased synchronicity across probe questions. Rather than there being an absolute correct answer for SAGAT probe questions, it might be the case that what is important is the synchronicity in the answer across the team where players are interpreting cues in a similar way to arrive at the same answer. And this is despite players having different perspectives and positions. This would allow players on the same team to make decisions regarding the current state of play, safe in the knowledge that their teammates were likely thinking the same thing. We are terming this concept Synchronized SA (SyncSA).

This concept of SyncSA would combine the team elements of DSA with the individualized measurement of a SAGAT probe technique to determine how the overlap of SA in individual team members can influence the effectiveness of a team. Rather than this being a new framework of SA, it takes the principles of the three-level framework, assesses these principles at an individual level using the SAGAT probe-like method and then compares the synchronicity of answers across the team as a measure of SyncSA. The first hypothesis to test is whether increased levels of SyncSA relates to more team wins. The second hypothesis to test would be to investigate the relative importance of SyncSA compared to performance on a more traditional there-is-always-a-correct-answer SAGAT probe task. To this end, we will explore the possibilities of a SyncSA model in future research and encourage others to do so as well.

4.3. *Cognitive skills and SA, and general limitations*

The cognitive skills directly linked to SA in sports were visual behaviours, anticipation, and decision-making (Caserta & Singer, 2007; McGuckian et al., 2020; Murray, 2018). The three-level framework of SA acknowledges that these cognitive skills contribute to SA or, in the case of decision making, is a potential product of SA (Endsley, 1995b). Many sports studies have alluded to the importance of SA, but either only isolate a particular cognitive skill to study (Macquet & Fleurance, 2007; Macquet, 2009), or in the case of McGuckian et al. (2020), do not demonstrate how the cognitive skill (visual search) relates to SA. What is arguably missing here is 1) a body of research that better links cognitive skills to SA and 2) a body of research that investigates the interaction between these cognitive skills and their relation to SA. Perhaps what is needed initally however is a larger review on the potential cognitive skills (within and across perception, comprehension and anticipation) that could, in principle, link to an individual's SA, despite not being explicitly termed SA (or an element of). We acknowledge that there is an extensive body of research that investigates cognitive skills (such as visual search) in sports that were not reviewed in this paper. The scope of this review was to identify research that made direct mention of or links between cognitive skills in relation to SA. We direct the readers to example reviews that directly focus on some of the cognitive skills in sports highlighted here more generally and outside the context of SA *e.g.*, visual search (McGuckian et al., 2018) and anticipation (Loffing & Cañal-Bruland, 2017), however a wider, holistic, and in-depth review of a range of cognitive skills that could relate to SA in sports is warranted.

Owing to the vague descriptive nature of the Distributed Situation Awareness (DSA) and Shared Situation Awareness (SSA) frameworks one might question if the role of cognitive skills is supported by or indeed relevant to DSA/SSA. We argue that the role of cognitive skills in acquiring DSA/SSA is currently unclear rather than them not being important. One of the advantages of the three-level framework is the potential to identify how SA can be acquired by means of the individual, yet interacting, components including the cognitive skills. Research into the possible cognitive skills that would be related to DSA/SSA would be warranted. Where, for example, in the case of DSA, visual search would likely be very important for sports officials in aiding in the decision of the legality of a play.

It is also important to highlight a general limitation to some SA in sport studies where studies are conducted in laboratory settings with simulations or video displays (*e.g.*, Loffing & Cañal-Bruland, 2017; Smeeton et al., 2013; Williams & Jackson, 2019; Wright et al., 2011). Lab-based studies are important building blocks in cognitive research in general but often do not consider the importance of *in situ* environments where variables that are otherwise controlled for influence behaviour in a meaningful way (Kingstone et al., 2008). There is also a lack of research into whether the lab-based behaviours transfer to the field (Williams et al., 2003). Although there is some suggestion of transference (Gabbett et al., 2009), there is evidence that certain behaviours, (*e.g.*, eye movement strategies) often differ between passive lab-based methods and their more active "real-world" counterparts (Foulsham et al., 2011; Mackenzie & Harris, 2015; Risko & Dunn, 2015). We believe that it is important for sports researchers to also investigate SA abilities or elements of SA on the field during real game play (*e.g.*, Aksum et al., 2021).

5. Conclusion

The purpose of this review was to answer the research questions: Within sports, 1) What are the different types of frameworks labelled as SA? 2) What methods are used to directly assess SA? 3) What are the cognitive skills in an SA framework? We conducted a scoping review of the current literature of SA in sporting environments. We found that Endsley's (1995b) three-level framework and Distributed Situation Awareness (DSA) were the most mentioned frameworks of SA in sports, while the methods used to directly assess SA in sports varied across studies and sports. Lastly, the cognitive skills of visual behaviours, anticipation, and decision-making were directly linked with SA in sports. We ultimately conclude that in order to advance the field of SA in sports, researchers: might find advantage in grounding their research within the three-level framework (at least initially), identify quantifiable ways to assess individual and team SA and, importantly, identify how significant SA or the elements of SA are in relation to performance in naturalistic contexts.

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Authors' contributions

The authors declare that this submission is approved by all authors.

S.H. contributed to the conceptualization, methodology, investigation, writing—original draft, and writing—review & editing. D.C. contributed to the conceptualization, writing—original draft, writing—review & editing, and supervision. H.S. contributed to the writing—review & editing and supervision. A.M. contributed to the conceptualization, methodology, writing—original draft, writing—review & editing, and supervision.

Declaration of competing interest

Declarations of interest: none.

The authors declare that this submission follows the ethical guidelines of the APA manual.

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