Situation Awareness in sports: a scoping review

This article was accepted for publication in Applied Ergonomics on Aug 3, 2021. At the time of writing, this article is considered to be ‘in press’. Should you wish to cite this article, please update the following reference with the journal volume number and pages numbers once they become available: Huffman, S., Crundall, D., Smith, H., & Mackenzie, A. (2022). Situation Awareness in sports: A scoping review. *Psychology of Sport and Exercise*, (59). https://doi.org/10.1016/j.psychsport.2021.102132

1.0 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, pp. 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, Endsley's (1995) three-level framework 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 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, particularly when compared 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? 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 addition, one could argue that the advent of sophisticated technology in sports might also aid in developing SA. For example, side-line video playback reviews have been widely integrated in a variety of sports (Can et al., 2011; Neptune et al., 2009) and can provide players and coaches (and officials) with alternative points of perspective or in-game opportunities to study the players to aid prediction and subsequent decision making. 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).

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 & Cañal-Bruland (2017) for anticipation.

2.0 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 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.

3.0 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 & 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). 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 we can take from this research, and 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), 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 & 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 & 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-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. 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 & Ham (2006) examined the effects of fatigue on elite cyclists' subjective and objective SA during a Time Trial 30km (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 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.,* recognizing key elements and making correct and timely decisions). While Knez & 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 & 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 & 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, 2017). 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 & 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 & 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.

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).

4.0 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 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.

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 SynchSA. 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).

5.0 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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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

Figure 1. PRISMA flow diagram for literature screening and selection