ABSTRACT

Objective: The visibility of the pink ball used in day/night Test cricket has been under scrutiny, with recent research suggesting cricketers find the pink ball less visible at dusk under floodlights. With increasing interest in this match format, this study sought to investigate elite umpires' opinions pertaining to the visibility of the pink cricket ball during day/night matches.

Design: Purposeful sampling of a cross-section of elite umpires with experience adjudicating matches played using a pink cricket ball.

Method: Twenty-seven international/first-class umpires completed a questionnaire consisting of Likert scale and free text responses covering perceptions of the pink cricket ball, with a particular emphasis on visibility.

Results: The pink ball when viewed at night under floodlights was rated as being significantly more visible than the red ball during natural lighting (ps <0.050) . Umpires who actively participated in training reported a significantly higher rating of the visibility of the pink ball (mean -3.14) at night under floodlights compared to those who didn't (mean p= 0.010). No significant difference was reported in visibility in natural light or dusk under floodlights. Free text responses (n=10) revealed the following themes: use of eyewear (coverage 0.30), and adjustment to positioning (coverage 0.20) to improve visibility of the pink ball.

Conclusion: Umpires report the visibility of the pink ball is equal to the red in natural light and at dusk but is significantly better at night. Preference for the pink ball is likely due to the predominantly perceptual nature of visual tasks performed by umpires.

1. INTRODUCTION

In the lead up to India's inaugural International day/night Test cricket match, International Cricket Council (ICC) umpire Sunduram Ravi was quoted on the difficulties faced by cricket umpires when officiating in matches during dusk using a pink ball.

"*We [cricket umpires] found it slightly difficult to sight the ball during the twilight. When the floodlights are taking over. That time we would focus a little harder to sight the ball. We concentrated a little extra during that time*"[1]

A decline in the number of spectators attending Test cricket matches[2] has led to the introduction of day/night Test cricket, where play starts late in the day under natural light and continues to be played under floodlights through dusk and into the night. To increase the visibility of the ball used during the night conditions, Australian ball manufacturer Kookaburra created prototypes of different coloured cricket balls. Upon advice from television companies[3], and after gaining approval from the ICC, a (fluorescent) pink cricket ball was chosen. Following expressions of concern by some players[4,5] about player performance and safety[5,6], Kookaburra changed the colour of the seam (two rows of stitching running down the centre of the ball) from the original green/white to black[7].

A recent study investigated the opinions of cricketers with experience playing in pink ball matches[8], with the results showing that players report difficulties with the visibility of the ball in particular at dusk under floodlights, both when batting and fielding. Visibility of the pink ball was also reported to be poorer when batting against pace (faster) deliveries compared to spin (slower) deliveries. Adie and Arnold[9,10] have suggested that the visibility of the pink ball is impacted particularly at dusk due to the low luminance contrast of the ball against the sky, resulting in a reduced ability to perceive motion. The authors also presented preliminary evidence that visibility may be improved with the use of rose-tinted lenses (Oakley Prizm Golf). When batting and fielding, cricketers acquire and process visual information, with success often relying on the ability to pick-up ball-flight information as early as possible[11,12,13]. Although a high level of visual acuity may not necessarily be vital for the identification of optimal information[13,14], a high level of contrast sensitivity presumably is[9,10].

Cricket umpires officiate from two alternating positions during a cricket match, and importantly, the visual demands from those two positions differ. Umpires interchange their position after every six legal deliveries between the 'bowler's (non-striking) end' and 'square leg' (roughly 22 yards from the batsman's legs orthogonal to the direction of the pitch). Umpires at the bowler's end are, amongst other tasks, required when making leg-before-wicket decisions to make predictive judgements about whether a ball that hits the batter may have gone on to hit the stumps[15,16,17]. The role of the umpire at the square leg position differs, instead requiring them to track a ball from a side-on position to determine where the ball passes the batter, and whether the batter completes the run safely before the ball strikes the stumps. Accordingly, it is important to establish the degree to which the visibility of the pink ball is influenced when umpiring in each of those two positions.

Umpires, just like players, also make decisions based on their identification of visual information, yet there is neuropsychological evidence to suggest that the nature of the visual information that umpires rely on might differ to that of players. The dual-pathway theory of vision[18,19] suggests that the nature of visual information relied on to control actions (information in the dorsal pathway that is highly sensitive to motion and contrast) may be different to that relied on for perceptual decisions (ventral pathway sensitive to acuity and colour). While cricketers when batting likely rely on contributions from both the ventral and dorsal pathways (i.e., respectively for initial visual cue pick-up through to the execution of an interceptive action when attempting to strike the ball), cricket *umpires* would rely solely on the perceptual pathway. More specifically, research suggests that coupled responses (subconscious) required for the completion of an interceptive action involve dorsal processing, and non-coupled (conscious) responses for perceptual actions originate from the ventral processing pathway[14,19]. Accordingly, it is possible the visual demands of players and umpires might vary, and consequently the experiences of players viewing the pink ball might differ to umpires. Another key difference between the role of players and umpires is that batters (and some fielders positioned behind the batter) view the ball as it is looming towards them whereas the umpire at the bowler's end views the ball with it looming *away* from them[20]. The complexities of the retinal image processing of motion in direction (MID) of a ball, and time to collision processing[20] are exacerbated with the inclusion of an interceptive task. The direction of the MID is a function of the ball's angular velocities and the resulting retinal images. This further highlights the importance an interceptive act plays on the processing of visual information. The umpire at the bowler's end must deal with looming of the opposite sign (away from) but without time to collision processing.

One significant visual challenge faced in cricket is the diverse set of backgrounds participants must track the ball against such as the sky, the crowd, the grass outfield, and the sight screens (white in Test cricket). Although the backgrounds remain relatively constant across all Test cricket venues, the changing light conditions alters the composition of the background. Any alteration to the illumination or colour composition to the background the ball is viewed against, will affect luminance contrast. Any change in the luminance contrast will in turn affect the visibility of the target object. Accordingly, the visual demands of players and umpires might differ, and consequently, the experiences of players viewing the pink cricket ball might differ to umpires.

The aim of this study was to investigate professional cricket umpires' opinions regarding the visibility of the pink cricket ball when adjudicating day/night cricket matches. The study explored whether, as suggested from our research on players[8] the period at dusk under floodlights is the most challenging for visibility when compared to conditions experienced during the day and at night. We hypothesized that umpires would report the pink cricket ball to be visibly more challenging than the red ball while umpiring from both positions under all three light conditions, with difficulties most pronounced when adjudicating at the bowler's end due to the complexity of the visual tasks associated with officiating from this position.

2. METHOD

A cross-sectional survey study design was used to establish umpire perceptions of the visibility of the pink cricket ball in day/night matches. The white ball used in limited (50 and 20) over matches cannot currently be used in Test match cricket. The surface integrity and colour of the ball degrades significantly prior to the 80 over life span required for use in Test cricket. The white ball offers little to no contrast against the white clothing worn by Test cricketers. For these reasons, the white ball was not considered for comparison within this study. A 27-item questionnaire was initially developed by two researchers (PA, LW) based on previous experience conducting a similar survey on elite cricketers[8]. The full research team (including cricket coach [JJ] and umpire [JA]) then reviewed the survey in an iterative process with further modifications made to the wording to make it suitable for umpires. The survey went through two stages of review to establish validity prior to commencement of the study proper. Individuals with knowledge of the sport (sports researchers, and cricket administrators) reviewed the survey to ensure face validity and interpretability. Modifications were made

before the second stage, where the survey was sent to two elite umpires to determine whether the questionnaire was sufficiently clear and straightforward to complete. They confirmed that the length of the questionnaire was acceptable and that they experienced no difficulties with the format or comprehensibility of the questions. The survey was available to the umpires for one month and took between 15-20 minutes to complete. The study adhered to the tenets of the Declaration of Helsinki. Ethical approval was obtained from the Faculty Research Ethics Panel of Anglia Ruskin University.

Purposeful sampling was used towards the end of the 2018 English county cricket season to recruit elite male cricket umpires (from the UK and internationally) who had experience adjudicating pink ball cricket matches. The study consisted of 30 elite (international and first-class) umpires recruited via the England and Wales Cricket Board (ECB), Cricket Australia (CA), and the International Cricket Council (ICC). The data for the UK-based umpires were collected at the ECB umpires' end of season meeting in paper form or using an online questionnaire (Qualtrics). The international data were collected using the online questionnaire circulated by an ICC elite panel member via email, and Australian umpires were invited via the CA match officials' manager. Participants answered a combination of Likert scale and closed questions, with free text comments allowing participants to expand on their responses. The survey can be found in Appendix A1.

The final survey consisted of 4 sections, as follows:

Section A, addressing participant characteristics, contained questions about the participants' officiating experience in matches and/or training with a pink ball. Further questions required information regarding self-disclosure of any vision problems along with a personal rating of their own distance vision (1 = very poor, to 10 = excellent).

Section B assessed *visibility of the pink ball under different lighting conditions,* with participants asked to rate, on a 15-point Likert scale, the visibility of the pink ball under natural light, dusk under floodlights, and night under floodlights when compared to the visibility of the red ball in normal daylight conditions (control condition). Visibility was rated while umpiring from the bowlers' end, and from the square leg position. Negative values (down to -7) indicated better visibility with the pink ball while positive values (up to +7) indicated better visibility with the red ball. A zero response indicated no difference in the visibility between the pink and red cricket balls. Internal consistency for the Likert-scale questions was high (Cronbach's alpha = 0.766). An example question in this section:

> "On a scale from -7 (pink ball much easier to see) to +7 (red ball much easier to see), with zero representing no difference, how visible is the pink ball compared to the red ball while umpiring at THE BOWLER'S END in NATURAL AFTERNOON LIGHT?"

Section C evaluated *Approaches to umpiring with the pink ball* using a similar 15-point Likert scale. Participants were asked to compare the visibility of the pink ball when umpiring pace and spin bowling. An example question in this section:

> "On a scale from -7 (pace bowling much more difficult) to +7 (spin bowling much more difficult), with zero representing no difference, is the visibility of the pink ball more difficult against PACE BOWLING or SPIN BOWLING?

Negative responses (down to -7) indicated better visibility with pace bowling, with positive responses (up to +7) indicating better visibility with spin bowling. Responses of 0 indicated no difference in visibility between pace and spin bowling. Participants were asked if visibility improves with time (yes/no/don't experience), and whether visibility of the pink ball differs between delivery types (full length, bouncers, slower balls, and normal length). Umpires were also asked whether they made any changes to their umpiring style to accommodate the pink cricket ball. Opinions were sought regarding the future direction of pink ball cricket, including the potential use of an alternative ball colour, coloured clothing, and coloured sight screens.

Section D provided the opportunity for participants to offer any relevant information that had not been covered in the survey.

Quantitative data were analysed using Statistical Package for Social Sciences (SPSS) version 26.0 (IBM Corp, 2019). Likert scale responses were treated as non-parametric ordinal data and summarised using the median. A one-sample Wilcoxon signed-rank test was used to determine whether values differed from zero. A paired-sample Wilcoxon signed-ranks test with Bonferroni corrected *p* values (revised *p*-value of 0.025) was used to identify whether ratings differed between lighting conditions. Categorical variables (yes/no) regarding acceptance of the pink ball were described using frequencies.

To analyse the free text responses, content was initially analysed inductively to produce themes that could then be used for categories in a content analysis[8,21]. To become familiar

with the data the responses were first read and reread by the lead researcher with initial observations noted. Next, features of the data were labelled and compiled to allow themes to be identified. For content analysis, participant responses were broken into clauses, and each clause was coded based on the themes generated. The five emergent themes generated were: *(i) difficulties tracking pace deliveries due to ball speed, (ii) eyes do adjust with time, (iii) continue with the pink ball, (iv) limited exposure makes it difficult to evaluate, (v) slight adjustments made to positioning.* The coverage of each theme (the number of times the codes associated with that theme appeared in the free text comments) was calculated; a maximum possible coverage value being 1.0 (if all free text comments were to be associated with that one theme). Themes with low coverage (less than 0.10) were not reported. This process was conducted for each question by three members of the research team, with multiple codes possible per response, for example a participant may mention both lighting conditions and the background when asked about whether visibility differs facing different delivery types. To ensure inter-rater reliability, the data were coded by the lead researcher and by an independent researcher to reduce bias[22]. A Cohen's K was run to determine the level of agreement between researchers, revealing a high level of agreement (K=0.667, p<.001).

3. RESULTS

Section A - Umpire characteristics

Participants (n=27; age 50.9, SD = 8.1yrs; range 32-57yrs) had all officiated in first-class or International pink-ball matches (mean matches = 3.7, SD = 3.3, range 1-15) and so had experience of umpiring under the full variety of lighting conditions. When asked if they had previously undertaken any specific training in preparation for pink-ball matches, 11 umpires (41%) reported no specific training and 16 umpires (59%) reported that they had attended practice ('net') sessions using the pink ball in preparation for matches. Participants were asked to rate their distance vision on a scale from 1 (very poor) to 10 (excellent); a mean rating of 9.5 (SD = 0.6) was recorded. One umpire reported having "mild colour blindness" (non-specified self-reported CVD), although the participant passed the pre-season ECB vision screening assessment.

Section B - Visibility of the pink ball under different lighting conditions

The median values of the umpires' ratings of the visibility of the pink cricket ball under different lighting conditions (Figure 1) indicated that the visibility of the pink ball when viewed in natural light and at dusk was no different to that when viewing the red ball under natural lighting (pink ball in natural light, bowlers end median = 0, z=-0.87, p=0.930; pink ball at dusk, bowlers end

median 0, z=-0.88, p=0.382; pink ball in natural light, square leg median = 0, z=-0.26, p=0.793; pink ball in natural light, square leg median = +1, z=0.22, p=0.828). However, the pink ball when viewed at night under floodlights was rated as being more visible than the red ball is during natural lighting (bowler's end median = -3, z=-2.40, p=0.016; square leg median = -3, z=-2.17, p=0.030).

INSERT FIGURE 1 AROUND HERE

A paired samples Wilcoxon signed-ranks test revealed the pink ball to be more visible at night under floodlights (median = -3) than at dusk under floodlights when viewed from the square leg position (median +1, z=-2.537, p=0.013). No significant differences were found between viewing at night under floodlights and in natural light for either viewing position (p=>0.025; Bonferonni corrected), or between any of the lighting conditions from the bowler's end.

An umpire's experience of using a pink ball did not alter their rating of the visibility of the pink ball from either the bowler's end (h=3.066, p=0.38) or from square leg (h=3.58, p=0.31).

Section C - Approaches to umpiring with the pink ball

The pink ball was rated as being significantly less visible during the umpiring of pace bowling when compared to umpiring spin bowling (median value=0, mean=-1.23, z=-2.00, p=0.046). When asked to expand on the Likert responses, the main theme related to difficulties tracking pace deliveries due to the speed of the ball (n=20, coverage 0.35). Responses relating to pace bowling included:

> "Spin bowling is obviously a lot slower, therefore easier to pick up and track" (Participant 19), and "The ball moves faster so therefore more difficult to pick up!" (Participant 22).

Participants were asked whether visibility improved over time if the pink ball was difficult to see. From the responses received (n=23), six participants (26%) responded 'yes' that the pink ball becomes gradually easier to see, eight (35%) responded 'no', and nine (39%) didn't experience any problems seeing the pink ball. Free text responses (n=14) highlighted the following theme: no problems experienced (coverage 0.29). Example responses included:

263 “I never really noticed a big difference with the pink ball” (Participant 24), “the pink ball
264 is a bright pink, it’s not a dull colour, so I didn’t notice any real change” (Participant 9).

265

266 Participants were asked if, when umpiring under floodlights, the visibility of the pink ball varied
267 depending on the delivery type. From the responses received (n=26), 11 participants (42%)
268 replied that visibility did depend on the delivery type, 15 participants (58%) responded that it
269 did not. Free text responses (n=12) provided the following themes: short deliveries being more
270 difficult (coverage 0.33); and full deliveries more difficult (coverage 0.25). Example responses
271 included:

272 “Short pitched deliveries are more difficult to pick up” (Participant 19), “Short balls are
273 often more difficult from side on as the angles are more steep” (Participant 22), and “I
274 believe that fuller deliveries are more difficult to pick up by both batsmen and umpires”
275 (Participant 13).

276

277 Participants were then asked if they have changed anything about the way they go about their
278 umpiring to accommodate the pink ball. From the responses (n=26), six reported that they did
279 make changes to accommodate the pink ball (23%), and 20 reported they did not make any
280 changes (77%). Free text responses (n=10) revealed the following themes: use of eyewear to
281 help (coverage 0.30), adjustment to positioning (coverage 0.20), and not enough exposure to
282 warrant changing anything (coverage 0.20). Responses included:

283 “I wear Oakley prism glasses” (Participant 15), “Ball tracking as mentioned above.
284 Standing back a bit further at dusk” (Participant 8), “I came closer at square leg to try
285 and pick the ball up better from side on” (Participant 17), and “We do very few games
286 so why would I change my routines?” (Participant 22), “Not yet - don’t have enough
287 pink ball experience yet to figure out what the best solution would be” (Participant 15).

288

289 When asked if a different coloured ball would be preferable to using the pink ball in day/night
290 matches (n=24), nine participants responded yes (38%), with 15 answering no (62%). Free
291 text responses (n=18) highlighted two main themes/suggestions; Continue with the pink ball
292 (coverage 0.39), and white is more visible under artificial lighting (coverage 0.22). Example
293 responses include:

Pink I believe to be excellent for myself" (Participant 15), "Pink ball is very easy to see" (Participant 6), and "White is still better to umpire" (Participant 14), "The white ball is easier to see" (Participant 12).

Participants were asked if it would be better if cricketers wore coloured clothing whilst playing in pink-ball matches. From the responses received (n=23), five participants responded yes (22%), and 18 responded no (78%). The associated free text comments (n=10) identified the following themes: coloured clothing would be harder (coverage 0.40). Responses included:

"Coloured clothing would make it harder. Coloured clothing and a coloured ball....no thank you!" (Participant 9), "you get a good contrast between white and pink, other colours might be harder to see ball" (Participant 14).

When asked if an alternative colour sight screen would aid visibility (as opposed to the white screen currently used), 12 (46%) of the responding participants (n=26) answered yes, and 14 (54%) responded no. Participants elaborating on their answers highlighted the following theme: black would aid visibility (coverage 0.71). Example responses included:

"Black is a clear background and easy to pick the ball out of" (Participant 28), "Black screen, better contrast", and "Black screens would aid visibility" (Participant 21).

The final question asked whether there were any playing grounds in which umpires found the pink ball easier to see. Of the responding participants (n=19), five answered yes (26%), and 14 answered no (74%). Free text responses did not provide any meaningful themes.

Section D – Further information

The responses provided in this free text option (n=11) did not provide any additional information to that supplied in sections A-C.

Responses throughout the survey for one participant who self-reported as having mild CVD highlighted the difficulties that an umpire with a CVD may find with the visibility of the pink ball. That umpire rated the visibility from the bowlers' end at dusk under floodlights as being worse than the red ball under natural conditions (+5 reported), as when viewing the pink ball at night under floodlights (+3 reported), at square leg at dusk under floodlights (+5 reported), and square leg at night under floodlights (+3 reported).

4. DISCUSSION

Anecdotally, some cricket umpires have reported that they find it difficult to see the pink cricket ball during dusk[1]. This study sought to empirically investigate these reports using a cross-sectional survey with a purposeful sample of elite cricket umpires. Findings fail to support the anecdotal observations, with the visibility of the pink ball at dusk (and in the daytime) rated as being no different to that of a red cricket ball during natural daylight. In fact, elite umpires considered the visibility of the pink ball at night under lights to be significantly *better* than that of the red ball during daylight hours. There are key differences between the red and pink balls when considering them as visual stimuli. Unlike the red ball, the pink ball is fluorescent, meaning the relative luminance, when viewed against a non-fluorescent background, will be lowest when the exciting wavelengths are reduced. This would be particularly prevalent in direct sunlight just before the onset of dusk.

In a recent study[8], elite cricketers reported the visibility of the pink ball to be poorer at dusk, under floodlights, both when batting and fielding, compared to the red ball in natural light. Collectively, the results from the current study and previous work[8] present contrasting views on the visibility of the pink ball, raising interesting questions about the unique demands (visual processing, enhanced concentration, adaptation) posed by the pink cricket ball on each of the respective roles of umpires and cricketers. Research suggests the ventral and dorsal streams are driven by retinocortical visual projection which is organised by at least three major pathways (magnocellular – dorsal, parvocellular – ventral, and the koniocellular - dorsal). The parvocellular cells manifest red-green opponency, the magnocellular cells are non-colour opponent, while the koniocellular cells show yellow-blue opponency. The koniocellular pathway appears likely to sustain some visual behaviours in the absence of either magnocellular or parvocellular input. The ventral and dorsal pathways are responsible for processing information pertaining to vision for action (dorsal), and vision for perception (ventral)[18]. Therefore, the predictive element (pre-ball release information) requires processing from the ventral stream, with the movement and action (post-ball release interception) element processed by the dorsal stream. A batter will utilise both streams whilst executing a shot or in the outfield, moving to intercept the ball. However, an umpire will predominantly utilise the ventral stream for their predictive response. Findings from this study add further support to research suggesting that information processed through the dorsal stream is affected by the change or reduction in contrast luminance[23], thus accounting for the differing opinions around the visibility of the pink ball.

An alternative explanation for the umpires not perceiving a difference in visibility between the pink ball at dusk under floodlights and the red ball during regular daylight conditions may be linked to the anecdotal report by ICC umpire Sunduram Ravi[1]. Ravi stated that conditions with (potentially) poorer visibility cause umpires to increase their levels of concentration. This increased concentration may (subconsciously) nullify any visual difficulties experienced. It is relevant to note that a study by Mann et al., (2007)[13] found that low levels of induced blur did not negatively affect cricket batting performance, with the authors suggesting that an increase in concentration may be one of the factors mitigating against a decrement in performance. Similarly, Wilkins & Appelbaum (2019)[24] proposed that one of the mechanisms of stroboscopic visual training (a type of training where individuals perform actions under intermittent visual conditions) may be that it leads to increased attention and effort. Thus, the idea that individuals may mitigate impoverished visual conditions by increasing concentration could also be applicable in the current study. This, however, does not explain why previous research[8] has shown cricket players to perceive the pink ball as having reduced visibility, particularly as they would arguably have an even greater incentive to increase their concentration than the umpires.

It is possible that the difference between current findings and the previous player-based research[8] could be due to the changes made by umpires in their positioning (coverage 0.20) and equipment used (coverage 0.30), which provided comparable visibility to traditional conditions as highlighted from the free text responses:

> "I wear Oakley prism glasses" (Participant 15), "Standing back a bit further at dusk" (Participant 8), and "I came closer at square leg to try and pick the ball up better from side on" (Participant 17).

The use of sports eyewear to improve the visibility of the pink ball was discussed by Adie & Arnold[10]. They suggest the use of rose-tinted lenses may help to counter the effects of any change in luminance contrast when observing a pink ball at dusk under floodlights. In previous research[8], whilst some players commented on changes to their playing style, 92% reported no changes in batting style and 91% reported no changes in fielding style in order to accommodate for their perceived reduced visibility with the pink ball.

Although the re9sults indicate that experience does not directly impact on the visibility of the pink ball at either the bowler's end ($h=3.066$, $p=0.38$) or square leg ($h=3.58$, $p=0.31$) positions,

it is unclear if attending and participating in training sessions with a pink ball does. Within the participant cohort, a section of umpires (n=11) reported attending and participating in training (net) sessions. A subsidiary analysis on the effect participating in a training session had on umpire's perceptions of the pink ball revealed that umpires who actively participated in training reported a significantly higher rating of the visibility of the pink ball (mean -3.14, SD = 3.45) at night under floodlights compared to those who didn't (mean -0.67, SD = 3.39: u=181, p=0.010). Also, of interest is that the free text responses relating to changes in positioning made by umpires came from umpires within the training-initiated group:

> "At square leg, I will actively go to the other side if I think I will get a better contrast so that I can track the ball better" (Participant 11), and "Apart from always standing on the offside. When the ball is pulled on the leg side it is very difficult to see" (Participant 23).

From these results, it seems reasonable that umpires who attended training sessions benefited from an increase in confidence in the visibility of the pink ball and offers the opportunity to make potentially important adaptations to the elements of their on-field application and/or concentration.

The pink ball may be particularly difficult for participants who are colour vision deficient (CVD)[25], with some first-class players even withdrawing from pink-ball matches[26] because of concerns about their own performance and safety[6]. One participant in this study self-reported a CVD. When the responses of this participant were excluded, the results did not change meaningfully and so their responses were included for all analyses. This participant also passed the pre-season ECB visual screening assessment. These findings along with reported perceptions of CVD cricketers[6,8], suggest the perceived visibility difficulties with the pink ball may be exacerbated for CVD participants. Further research is required to explore the effect on CVD cricketers, and how, if at all, the impact differs between different CVDs.

It is important to recognise the following limitations of the study. With the number and frequency of day/night cricket matches using a pink ball being low, the exposure to matches using a pink ball of the participants recruited is so-far relatively low. There is a possibility that some of the responses given are due to inexperience or lack of exposure to the pink ball. Additionally, the comparison between the pink ball under different lighting conditions with the red ball under natural daylight conditions may have been difficult because the red ball is not normally used during play under floodlights. Due to the geographical spread in both the

participants of the survey, and the locations in which pink ball Test cricket has been played, a number of uncontrollable variables within the survey should be considered. The conditions in which the day/night matches have been played may vary by country, overhead conditions/weather, the time of year, and the make of the ball used. The aforementioned uncontrollable variables may produce different responses from umpires officiating in different countries/climates. This study provides an overview of the perceptions of pink ball visibility in world cricket. Future research should consider introducing an experimental design to mathematically model the visibility of both the pink and red balls under different lighting conditions to empirically demonstrate whether there is any difference in the visibility between the red and pink balls.

5. CONCLUSION

Elite cricket umpires reported no difference in the visibility of the pink ball and the red ball when umpiring from both the bowler's end and square leg positions under natural light and at dusk under floodlights. The pink ball was reported to be *more* visible at night than the red ball under regular daylight conditions when umpiring from both the bowler's end and square leg, with a significant increase in visibility compared to dusk when positioned at square leg. These findings differ from previous research with elite cricketers[8] on the same topic who reported difficulties with the visibility of the pink ball particularly at dusk. The key distinction in the task of umpires and batters/fielders is whether they need to intercept the ball or not. A batter must act to intercept the ball (vision-for-action) in order to preserve their wicket (not be given out) and to accumulate/score runs. The key task for the umpire is to complete the complex series of (visual) tasks to make decisions, including predictive decisions about where the trajectory of the ball would have continued if the interception had not taken place (vision-for-perception)[18]. The looming sign for the umpire is opposite to that faced by the batter and close fielders (directly behind the batter)[20]. With that in mind, it is suggested that the contrasting perspectives of umpires and players with regards the visibility of the pink ball may be due to the differences in the information processing required.

PRACTICAL IMPLICATIONS

- This systematic investigation of elite cricket umpires' opinions suggests that the visibility of the pink cricket ball is equal to or better than the red ball in traditional conditions.
- The results of this study suggest that the visibility of the pink ball is significantly better at night under floodlights from both bowler's end and square-leg positions, and significantly better at night than at dusk from the square-leg position.
- The results indicate that the pink ball is suitable for day/night Test matches from an umpire perspective.

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Figure 1. Participant ratings of visibility of the pink ball, when compared to the red ball in natural daylight, in three different light conditions officiating from (A) the bowler's end and (B) square leg positions. The solid line within each boxplot represents the median response and the circle represents an outlier**.**

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