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A systematic review of the technology-based assessment of visual perception and exploration behaviour in association football

Thomas B. McGuckian, Michael H. Cole and Gert-Jan Pepping

School of Exercise Science, Australian Catholic University, Brisbane, Queensland, Australia

ABSTRACT
To visually perceive opportunities for action, athletes rely on the movements of their eyes, head and body to explore their surrounding environment. To date, the specific types of technology and their efficacy for assessing the exploration behaviours of association footballers have not been systematically reviewed. This review aimed to synthesise the visual perception and exploration behaviours of footballers according to the task constraints, action requirements of the experimental task, and level of expertise of the athlete, in the context of the technology used to quantify the visual perception and exploration behaviours of footballers. A systematic search for papers that included keywords related to football, technology, and visual perception was conducted. All 38 included articles utilised eye-movement registration technology to quantify visual perception and exploration behaviour. The experimental domain appears to influence the visual perception behaviour of footballers, however no studies investigated exploration behaviours of footballers in open-play situations. Studies rarely utilised representative stimulus presentation or action requirements. To fully understand the visual perception requirements of athletes, it is recommended that future research seek to validate alternate technologies that are capable of investigating the eye, head and body movements associated with the exploration behaviours of footballers during representative open-play situations.

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KEYWORDS
Soccer; eye tracking; decision making; perception; vision

Introduction

It is well accepted that effective visual perception is required for prospective control of movement and appropriate goal-directed actions (Gibson, 1979; Mann, Williams, Ward, & Janelle, 2007; Van Der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008; Williams, Davids, & Williams, 1999). While the relationship between perception and action is relevant for all behaviour, its importance in fast-paced environments, such as association football,[1] may be more pronounced. In such high-stake and rapidly changing environments, a player's ability to perceive their surroundings and make the most beneficial decisions for subsequent action could be the difference between winning and losing. Therefore, understanding the specific perceptual requirements and behaviours utilised by athletes in these fast-paced environments is vital for researchers and applied practitioners who are seeking to enhance the development and performance of players. The primary aim of the current review was to synthesise the findings from research investigating the perceptual behaviours specific to football, and to compare these behaviours according to the experimental setting. Secondly, the current review aimed to synthesise the literature to compare visual perception behaviours of players with varying levels of expertise.[2] Finally, this review aimed to provide a better understanding of the types of technology that have been used to measure visual perception in football. By meeting these aims, it is expected that applied practitioners and researchers will be able to implement more informed training and experimental designs.

An abundance of research has emerged in a bid to understand the visual perception requirements of athletes in sporting contexts. Not surprisingly, research has shown that experts are better able to perceive and respond to sport-relevant cues, as evidenced by superior response accuracy and response times on perceptual-cognitive tasks (Abernethy, 1990; Helsen & Starkes, 1999; Mann et al., 2007; Wright, Pleasants, & Gomez-Meza, 1990). Additionally, this research has shown that expert performers generally utilise different perceptual behaviours than their less skilled counterparts; expert performers utilise fewer eye fixations that have a longer duration than non-expert players (Canal-Bruland, Lotz, Hagemann, Schorer, & Strauss, 2011; Helsen & Starkes, 1999; Mann et al., 2007; Savelsbergh, Onrust, Rouwenhorst, & Van Der Kamp, 2006; Savelsbergh, Williams, Van Der Kamp, & Ward, 2002).

CONTACT Thomas B. McGuckian thomas.mcguckian@acu.edu.au School of Exercise Science, Australian Catholic University, P.O. Box 456, Virginia, Queensland 4014

[1]Association football refers to the team sport commonly known as soccer in some parts of the world. For simplicity, the term "football" will be used for the remainder of this review. Additionally, although the ideas are discussed in terms of football, they may also apply to comparable, ball-based invasion team-sports such as field hockey, Australian Rules football, netball, rugby, etc.

[2]For simplicity, expertise here encompasses a range of variables commonly used by researchers to distinguish levels of ability, including more or less skill, more or less experience, successful or unsuccessful performance of skills, and experts or non-experts.

Importantly, however, these different perceptual behaviours are dependent upon the type of sport, research paradigm and stimulus presented (Mann et al., 2007). In order to fully understand the perceptual behaviours of athletes, it seems that researchers must comprehensively investigate each sport individually (Jordet & Pepping, in press), while also taking into consideration the research setting and action requirements of the task to account for the differences found between different contexts.

Proponents of representative design have long argued for the importance of maintaining organism-environment relationships while studying human behaviour (Brunswik, 1956; Dhami, Hertwig, & Hoffrage, 2004; Gibson, 1979). In particular, Brunswik (1956) insisted that the stimuli used in experimental conditions should be taken directly from the environment that the research is intended to be generalised to. Similarly, and importantly for perception in sport, Gibson (1979) argued that perception and action are inherently coupled, and that research should maintain the natural perception-action coupling if it is to understand the actual behaviours of people performing in their natural environments. In support of this, as stimuli become less representative (i.e. less similar to real-world playing environments), the superior performance of expert players over novice players becomes less evident (Shim, Carlton, Chow, & Chae, 2005), indicating there is something about the natural organism-environment and perception-action couplings that gives experts an advantage. Additionally, differences in visual perception are dependent upon the action requirements of the task (Mann et al., 2007). For example, Dicks, Button, and Davids (2010) showed that goalkeepers' eye movements were directed equally between the ball and the penalty taker's body when they were required to intercept a shot on goal. In contrast, their eye movements were directed much more toward the penalty taker's body when they were not required to intercept the ball. It also appears that the number of players involved in the task may influence the perceptual behaviours of athletes. Vaeyens, Lenoir, Williams, Mazyn, and Philippaerts (2007a), for example, found that athletes would use different visual perception behaviours in 2v1 or 3v1 offensive situations than when they were presented with 3v2, 4v3 and 5v3 offensive microstates of play. Taken together, these examples give further evidence that a particular organism-environment coupling may give rise to particular perception-action behaviours, and therefore the natural couplings should be maintained as much as possible when investigating these behaviours.

In team sports such as football, players are completely surrounded by possible opportunities for action (termed affordances; Fajen, Riley, & Turvey, 2009; Gibson, 1979), and therefore must move their head and body as well as their eyes to perceive their environment. Perceiving their environment is important in allowing the athlete to calibrate themselves relative to their surroundings (e.g. opponents, teammates) and prospectively control their actions. Given that the eyes are located within the head, which is connected to the body via the neck, the collective movements of the eyes, head and body facilitate visual perception through *exploration* behaviour (Gibson, 1966; Reed, 1996). Much of the visual perception research in sport has focussed on the movements of the eyes, which are detected with the use of eye-movement registration technology (Mann et al., 2007; Williams et al., 1999). This technology has enabled researchers to understand exactly where and when participants visually fixate on features in their environment, which has allowed conclusions to be drawn about the perceptual demands placed upon participants. However, focussing purely on the eye-movements of players only considers some of the processes involved in visual perception. In the current paper it is argued that, to fully understand the visual perception requirements of athletes, exploration behaviour through the eye/head/body system should be considered.

This systematic review of literature had a number of aims. Primarily, as visual perception behaviours appear to be dependent upon the environmental context and action requirements of the task (Mann et al., 2007), this review aimed to synthesise and discuss the findings from research according to the representativeness of the experimental setting and microstates of play. Additionally, this review aimed to compare the visual perception behaviour of footballers with varying levels of expertise. Finally, due to the complex environment that football provides, this review aimed to gain an understanding of the types of technology that have been used, and how they have been used, to quantify the visual perception and exploration behaviours of football players. As the type of sport moderates the visual perception behaviours of athletes, this review focussed only on research investigating visual perception in a football context, with the intention of giving a more informed understanding of the demands specific to this particular organism-environment coupling (Jordet & Pepping, in press). With a greater understanding of the specific visual perception behaviours of footballers, and the methods of quantifying these behaviours, this review will better equip applied practitioners to provide the training and rehabilitation requirements that are necessary for athletes to obtain optimal performance.

Methods

Search strategy

Following the PRISMA recommendations for completing and reporting the findings of systematic reviews (Liberati et al., 2009), an electronic database search was completed in February 2017 using five relevant databases; SPORTDiscus, PsychINFO, PubMed, Web of Science and EMBASE. The search was completed for title and abstracts to identify articles that used technology to measure visual perception and exploration behaviour in football. The search included three groups of search terms which related to: i) the context (team sport OR field sport OR sport OR football OR soccer); ii) the outcome (exploration OR perception action OR perception-action OR percept* OR fixation OR visual search OR gaze OR head check OR vision OR affordance OR calibrat* OR decision making OR decision-making); and iii) the use of technology (eye track* OR eye movement OR eye-movement OR sensor OR acceler* OR gyroscope OR wearable OR observation OR technology OR video). In addition to the database search, the bibliographies of relevant articles identified via the review process were manually searched to identify additional studies for inclusion. The full search strategy and protocol for the systematic review is included in Appendix 1.

Selection criteria

Full-text articles with versions available in English and published any time before February 2017 were eligible for inclusion in this review. Articles were only included if they: i) investigated association football players; ii) utilised technology to quantify exploration behaviour; iii) presented at least one quantitative outcome measure of exploration behaviour; iv) were a full-length original research article; and v) were written in English. The titles and abstracts of studies identified via the initial search were screened for eligibility by the first author (TBM) and were excluded if they were deemed not to meet the inclusion criteria. Any articles that could not confidently be excluded by the reviewer were included for the next level of screening. The full-text of those papers that were considered potentially relevant following title and abstract screening were retrieved and assessed for eligibility following full-text review. For any full-text articles that could not be confidently excluded, an assessment was made by the second (MHC) and third (GJP) authors, and the article discussed until consensus was reached. A PRISMA flow diagram of the selection process is provided in Figure 1.

Quality assessment

Once articles had been selected, an assessment of each article's quality of reporting was performed using the Crowe Critical Appraisal Tool (CCAT)(Crowe, Sheppard, & Campbell, 2012). The CCAT was selected as it can accommodate a wide range of study designs and consists of eight independently-scored categories that include; Preamble, Introduction, Design, Sampling, Data Collection, Ethical Matters, Results, and Discussion. Each category received a score ranging from 0–5, with 0 being the lowest possible score and 5 being the highest. The scores for each category were then summed giving a total score, which was divided by the maximum score of 40 and multiplied by 100 to give an overall percentage value. Each of the eight categories contributed equally to the overall score of each paper, and points were only given based on what was reported by the authors.

To limit the risk of bias in the scoring performed by the first author, 10% of papers were randomly selected and appraised by the second and third authors. Where there was evidence of one or more of the criteria being assessed more or less harshly by one of the assessors, the authors discussed these scores until a consensus was reached. Together, these measures ensured that the first author scored each paper fairly, giving an accurate representation of the paper's reporting quality.

The range of possible scores was divided into quintiles to allow each paper to be categorised based on the level of detail that it presented. Using the overall scores, each paper was subsequently classified as having either very low (<20%), low (≥20% but <40%), moderate (≥40% but <60%), high (≥60% but <80%), or very high (≥80%) reporting quality. Further assessment of the quality of each paper may be attained by viewing the individual scores for each category. The overall percentage scores and individual scores for each of the CCAT's eight categories are provided in Appendix 2.

Data extraction

Details about the number and age of participants, the technology used, outcome measures of exploration behaviour, the experimental setting, action requirements of participants, microstates of play and major findings were extracted and collated from each of the included articles. Furthermore, definitions of each of the visual perception outcomes used in the included studies were extracted and have been summarised in Table 1 to assist with the analysis and interpretation of the findings.

As the experimental settings varied between many of the studies included in the review and to assist with the synthesis of the findings, each paper was assigned to one of five categories relating to the representativeness of the setting; controlled laboratory, open laboratory, laboratory in-situ, controlled in-situ and open in-situ. The controlled laboratory category included studies which required the participants to be sitting or standing with limited movement, and used non-live stimuli such as static images, video footage or point-light display. Furthermore, the studies included in this category required responses that were not representative, such as pressing a button or verbally responding to the stimuli. The open laboratory category included studies that allowed participants some degree of movement, used non-live stimuli, and required limited movement responses (e.g. moving arms to indicate a direction). Studies assigned to the laboratory in-situ category included studies that allowed the participants free movement, used non-live stimuli, and required responses representative of the task (e.g. physically passing a ball). Controlled in-situ studies allowed participants to move freely in the environment, involved live stimuli (e.g. a goal keeper or penalty kicker), and required responses that were representative of the task (e.g. kicking or catching a ball). Studies categorised as open in-situ were those that investigated an open-play situation (i.e. a real match) where players' responses were influenced by the constraints of the game.

Results

The initial database search returned 3,508 results to be considered for inclusion in the systematic review. Of these results, 940 were excluded as duplicates, 596 were not full-length original research articles (e.g. books and theses), 108 were not available in English, and 43 were meta-analyses or review articles. The remaining 1,821 results were screened for inclusion based on the title and abstract. During this stage, 1,683 results were excluded based on the title, and 99 results were excluded based on the abstract. The remaining 39 papers were further evaluated via full-text review, which resulted in an additional nine manuscripts being excluded. Of these nine exclusions, four were deemed ineligible as they did not investigate a football context, two had no quantitative outcome measure of exploration behaviour, one did not

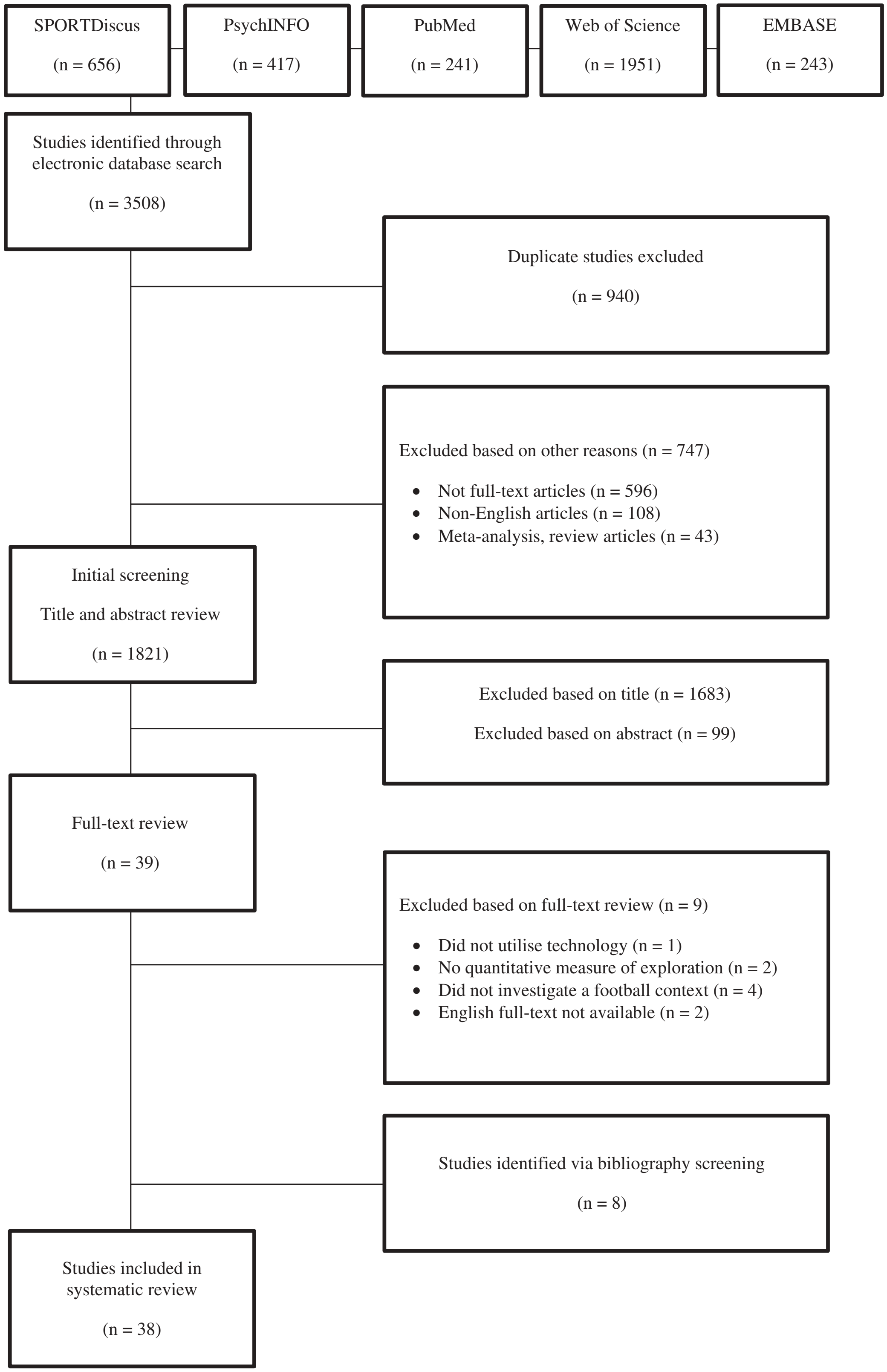

Figure 1. PRISMA flow diagram outlining the implementation of the systematic search strategy and review process.

utilise technology to quantify exploration behaviour, and two were not available in English. The reference lists of the remaining 30 papers were manually searched to identify any potentially-relevant papers that were not identified via the systematic search procedures. This process highlighted a further eight papers that met the inclusion criteria and resulted in a total of 38 papers being included in this systematic review.

Table 1. Definitions of each of the outcome variables used in each of the included studies.

Outcome Measure	Definition of Outcome Measure	Article
Fixation	Not defined	Abellan et al. (2016); Canal-Bruland et al. (2011); Wilson et al. (2009); Woolley et al. (2015)
	When the eye remains in a stationary position for a period equal to or greater than 40ms	Van Der Kamp (2011)
	When the eye remains in a stationary position for a period equal to or greater than 100ms	Bertrand and Thullier (2009); Binsch et al. (2010a); Binsch et al. (2010b); Horn et al. (2002); Kim and Lee (2006); Nagano et al. (2006); Noel and Van Der Kamp (2012); Piras and Vickers (2011); Poulter et al. (2005); Vater et al. (2015)
	When the eye remains in a stationary position for a period equal to or greater than 116.67ms	Vaeyens et al. (2007b); Vaeyens et al. (2007a)
	When the eye remains in a stationary position for a period equal to or greater than 120ms	Bakker et al. (2006); Button et al. (2011); Dicks et al. (2010); Mann et al. (2009); North et al. (2009); Roca et al. (2011, 2013); Savelsbergh et al. (2002); Savelsbergh et al. (2005); Savelsbergh et al. (2006); Timmis et al. (2014); Williams et al. (1994); Williams and Davids (1997, 1998); Wood and Wilson (2010); Wood and Wilson (2011)
	When the eye remains in a stationary position for a period equal to or greater than 140ms	Helsen and Starkes (1999)
	The period between the end of one saccade and the onset of the next saccade	Krzepota et al. (2016)
Mean number of fixations	The average number of fixations for each condition	Bertrand and Thullier (2009); Button et al. (2011); Canal-Bruland et al. (2011); Dicks et al. (2010); Helsen and Starkes (1999); Horn et al. (2002); Krzepota et al. (2016); Roca et al. (2011, 2013); Savelsbergh et al. (2002); Savelsbergh et al. (2005); Savelsbergh et al. (2006); Vaeyens et al. (2007b); Vaeyens et al. (2007a); Vater et al. (2015); Williams et al. (1994); Williams and Davids (1997, 1998); Wood and Wilson (2010); Woolley et al. (2015)
Mean number of fixations per second	The average number of fixations for each condition, expressed per second	Mann et al. (2009); North et al. (2009)
Total number of fixations	The total number of fixations for each condition	Bishop et al. (2014); Wilson et al. (2009)
Mean number of fixations per location	The average number of fixations on a categorised area of the display	Nagano et al. (2006)
Total number of fixations per location	The total number of fixations on a categorised area of the display	Binsch et al. (2010b); Poulter et al. (2005)
Percentage of fixations per location	The number of fixations to an area of interest, expressed as a percentage of the total number of fixations per trial	Timmis et al. (2014); Woolley et al. (2015)
Mean fixation duration	The average duration (ms) of each fixation for each condition	Bertrand and Thullier (2009); Bishop et al. (2014); Button et al. (2011); Canal-Bruland et al. (2011); Dicks et al. (2010); Helsen and Starkes (1999); Horn et al. (2002); Kim and Lee (2006); Krzepota et al. (2016); Mann et al. (2009); North et al. (2009); Roca et al. (2011, 2013); Savelsbergh et al. (2002); Savelsbergh et al. (2005); Savelsbergh et al. (2006); Vaeyens et al. (2007b); Vaeyens et al. (2007a); Vater et al. (2015); Williams et al. (1994); Williams and Davids (1998); Woolley et al. (2015)
Fixation time rate	The rate of total fixation time relative to total performance time	Kim and Lee (2006)
Mean fixation duration per location	The average duration (ms) of fixations according to each categorised area of the display	Bertrand and Thullier (2009); Nagano et al. (2006); Piras and Vickers (2011)
Relative fixation duration per location	Not defined	Piras and Vickers (2011)
Relative fixation time per location	The amount of time spent fixating each categorised area of the display	Horn et al. (2002)
Total fixation duration per location	The total duration of all fixations on a categorised area of the display	Binsch et al. (2010b); Wilson et al. (2009)
First fixation mean duration	The average duration of the first ocular fixation on each categorised areas of the display	Bertrand and Thullier (2009)
Initial fixation duration	The duration of the initial fixation on a categorised area of the display	Binsch et al. (2010a)
Final fixation duration	The average duration of the final fixation on a categorised area of the display	Binsch et al. (2010a); Wood and Wilson (2010); Woolley et al. (2015)
Mean number of fixation locations	The average number of locations fixated according to the categorised areas of the display	Button et al. (2011); Dicks et al. (2010); Horn et al. (2002); Krzepota et al. (2016); North et al. (2009); Roca et al. (2011, 2013); Savelsbergh et al. (2002); Savelsbergh et al. (2005); Vater et al. (2015)
Mean number of fixation locations per second	The average number of locations fixated according to the categorised areas of the display, expressed per second	North et al. (2009)
Fixation location	The location of fixations according to the categorised areas of the display	Bishop et al. (2014); Helsen and Starkes (1999); Kim and Lee (2006); Mann et al. (2009)
First fixation location	The location of the first ocular fixation on the display	Bakker et al. (2006); Bertrand and Thullier (2009)
Final fixation location	The location of the final fixation, represented as the mean distance (cm) from the centre of the goal	Wood and Wilson (2010)
Final fixation location	The location of the final fixation according to the categorised areas of the display	Woolley et al. (2015)

(*Continued*)

Table 1. (Continued).

Outcome Measure	Definition of Outcome Measure	Article
Percentage viewing time per fixation location	Total time spent fixating categorised areas of the display, expressed as a percentage of total trial length	Dicks et al. (2010); Krzepota et al. (2016); Noel and Van Der Kamp (2012); North et al. (2009); Roca et al. (2011, 2013); Savelsbergh et al. (2002); Savelsbergh et al. (2005); Savelsbergh et al. (2006); Savelsbergh et al. (2010); Timmis et al. (2014); Vaeyens et al. (2007b); Vaeyens et al. (2007a); Van Der Kamp (2011); Vater et al. (2015); Williams et al. (1994); Williams and Davids (1997, 1998); Woolley et al. (2015)
Mean percentage of viewing duration per location	Not defined	Nagano et al. (2004); Poulter et al. (2005)
Percentage of time fixating temporal periods	The percentage of time fixating an area in relation to the total time of the temporal period. Temporal periods defined as the time before foot-ball contact and the flight time of the ball before goalkeeper movement	Abellan et al. (2016)
Number of changes in fixation location	Not defined	Woolley et al. (2015)
Onset of initial fixation	The time at which the initial fixation on the goalkeeper occurred from the beginning of the trial	Binsch et al. (2010a)
Onset of final fixation	The time at which the final fixation on open goal space occurred from the beginning of the trial	Binsch et al. (2010a)
Fixation order	The average frequency that fixations alternated between the player with the ball, somewhere else on the display, then back to the player with the ball	Roca et al. (2011); Vaeyens et al. (2007b); Vaeyens et al. (2007a); Williams et al. (1994); Williams and Davids (1997, 1998)
Fixation transition	The ocular displacement between two fixations	Bertrand and Thullier (2009)
Number of fixation transitions per second	The number of times fixations occur between two predefined location, expressed per second	Mann et al. (2009); North et al. (2009)
Mean number of fixation transitions	Not defined	Piras and Vickers (2011)
Slow tracking fixation	A fixation which maintains a fixated object in central vision as the object moves for a period of at least 140ms	Helsen and Starkes (1999)
Time to first fixate	Not defined	Bishop et al. (2014)
Time to first fixate goalkeeper	The time (s) taken to first orient a fixation to the goalkeeper from the onset of a trial	Wilson et al. (2009)
Interfixation distance	The distance between subsequent fixations, calculated in degrees of visual angle	Vaeyens et al. (2007b); Vaeyens et al. (2007a)
Interfixation duration	The time between the end of one fixation and the start of the next fixation	Vaeyens et al. (2007b); Vaeyens et al. (2007a)
Interfixation rate	Represents the tempo of successive fixations. Calculated by dividing the interfixation distance by the interfixation duration.	Vaeyens et al. (2007b); Vaeyens et al. (2007a)
Overall dwell time	Not defined	Bishop et al. (2014)
Quiet Eye	The final fixation prior to the goalkeeper's hop phase on the ball for a minimum of 100ms*	Piras and Vickers (2011)
Mean quiet eye duration	The average duration of the quiet eye period	Nagano et al. (2006); Piras and Vickers (2011)
Quiet eye duration – prior to run-up	The duration of the last fixation prior to the initiation of the penalty kick run-up	Wood and Wilson (2011)
Quiet eye duration – final ball fixation	The duration of the last fixation on the ball during the execution phase of the kick	Wood and Wilson (2011)
Quiet eye location – prior to run-up	The location of the final fixation prior to initiation of the penalty kick run-up, expressed as the mean distance (cm) from the centre of the goal	Wood and Wilson (2011)
Saccade	An eye movement with velocity exceeding 30°/s and acceleration exceeding 8,000°/s^2	Bishop et al. (2014)
Saccadic amplitude	Not defined	Bishop et al. (2014)
Saccadic latency	Not defined	Bishop et al. (2014)
Saccadic velocity – peak	Not defined	Bishop et al. (2014)

*This is an operational definition provided by the authors. A more general definition of quiet eye is the final fixation or tracking gaze which is initiated before the start of the final movement of an action (Vickers, 2007).

Methodological quality assessment

According to the quality assessment completed for each paper, five (13%) papers were classified as having low reporting quality (range = 22.5% to 37.5%), eight (21%) papers were classified as having moderate reporting quality (range = 42.5% to 57.5%), 20 (53%) papers were classified as having high reporting quality (range = 60% to 77.5%), and five (13%) papers were classified as having very high reporting quality (range = 80% to 87.5%). Papers generally scored poorly on the Sampling (M = 1.4) and Ethical Matters (M = 2.4) categories. Specifically, those papers that scored poorly for the Sampling category generally gave a descriptive summary of the sample (e.g. age, gender, playing experience or level) but did not report any information regarding the sampling method, suitability of the sample size or inclusion/exclusion criteria. The average scores for the other categories ranged from 3.2 for the Results section to 4.1 for the Introduction section.

Research paradigm

Representativeness of the experimental setting

According to the previously described criteria for each category, 15 (39%) studies utilised a controlled laboratory setting, four (11%) utilised an open laboratory setting, six (16%) utilised a laboratory in-situ setting, and nine (24%) utilised a controlled in-situ setting (Table 2). Four (11%) utilised a combination of the above settings, and there were no studies that utilised an open in-situ setting. The included studies used various types of stimuli; 21 (55%) studies used a video stimulus, nine (24%) used a live stimulus, three (8%) used a static image stimulus, two (5%) used both point-light display and video stimuli, two (5%) used both video and live stimuli, and one (3%) used both video and static image stimuli. With respect to the amounts of movement permitted by participants; 17 (45%) studies allowed the participants to move freely, eight (21%) had the participants standing, eight (21%) had the participants sitting, three (8%) had a combination of participants able to move freely and standing, one (3%) had a combination of participants standing and sitting, and one (3%) did not report information regarding the position of the participants.

The included studies required the participants to perform various actions in response to stimuli. In total, 15 (39%) studies required the participants to respond by performing a representative action (such as taking a penalty kick or tackling an opponent), four (11%) required participants to respond by performing a partially representative action (such as taking a step in the anticipated direction of a pass), six (16%) required the participants to respond verbally, three (8%) required the participants to press a button, two (5%) required the participants to move a joystick, one (3%) required the participants to place a marker on a schematic board, four (11%) required participants to use a combination of the above responses, and three (8%) either did not require a response or the response was not clearly reported.

Microstates of play

The included studies reported investigating visual perception and exploration behaviours in various microstates of play. Penalty kick microstates accounted for 17 (45%) of the studies, nine (24%) of which investigated penalty kickers and eight (21%) investigated goalkeepers. Of the remaining studies, 10 (26%) investigated defensive situations, seven (18%) investigated offensive situations, and four (11%) did not clearly fit into either defensive or offensive situations. Of the studies investigating defensive microstates, four (11%) studies investigated 1v1 defensive situations, one (3%) investigated 1v1 and 3v3 defensive situations, one (3%) investigated 3v3 and 11v11 defensive situations, and four (11%) investigated 11v11 defensive situations. Of the studies investigating offensive situations, two (5%) investigated 4v4 offensive situations, two (5%) investigated 11v11 offensive situations, and three (8%) investigated various offensive microstates of play ranging from 2v1 to 5v5 offensive situations (Table 2).

Visual perception and exploration behaviours in football

According to the representativeness of the experimental setting

Of the included studies, five (14%) specifically investigated differences in visual perception behaviours according to the representativeness of the experimental setting. Of these five, two compared outcome measures when participants responded using non-representative actions to a video stimulus with situations that required participants to respond using representative actions to a live stimulus, two compared outcomes when participants viewed video stimuli and point-light display stimuli, and one compared outcomes when participants viewed video stimuli from aerial and player perspectives. From these studies, some differences were found in the outcome measures according to how representative the stimuli and responses were. The two studies that investigated fixations while viewing video and point-light display stimuli had conflicting findings. One study found no difference in the number or duration of fixations between video and point-light display stimuli (Horn, Williams, & Scott, 2002). In contrast, the other study found that when participants viewed a video stimulus they used more fixations to more locations than when they viewed a point-light display stimulus (North, Williams, Hodges, Ward, & Ericsson, 2009). When viewing a video stimulus from an aerial perspective, participants used more fixations of shorter duration and spent more time fixating open space than when viewing a video stimulus from a player perspective (Mann, Farrow, Shuttleworth, & Hopwood, 2009). Finally, when responding to live stimuli with representative movement, goalkeepers utilised more fixations of shorter duration to fewer locations than when viewing video stimuli (Button, Dicks, Haines, Barker, & Davids, 2011), and also fixated the ball earlier and for longer than in conditions which required non-representative actions (Dicks et al., 2010).

According to microstates of play

Of the 38 included studies, three (8%) utilised various microstates of play, however only two (5%) specifically investigated the differences in outcome measures across various microstates of play. Both studies found that while making decisions in 2v1 and 3v1 offensive situations, footballers used fewer fixations of longer duration and fixated more on the ball and the player with the ball than when making decisions in 3v2,

Table 2. Data extraction table outlining the experimental groups, type of technology used, outcome measures, experimental setting, action requirements, microstate of play, and major findings of each of the studies included in this review.

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
Abellan et al. (2016)	*10/22 (17.55 ± 0.8)*	Eye-Movement Registration (ASL Mobile-Eye)	% time fixating kicker during run-up, % time fixating ball during flight	Controlled in-situ	Physically move to catch ball during flight	Corner kick GK defence	Greater % time fixating ball in flight than % time fixating kicker during run-up. No difference in % time fixating between interceptions and non-interception
Bakker et al. (2006)	Experiment 1 = 7/7 (20.9 ± 1.77) Experiment 2 = 10/10 (21.2 ± 2.10)	Eye-Movement Registration (ASL 501)	Location of first fixation (4 areas)	Lab in-situ	Physically kick foam ball to score goal according to condition	1v1 penalty kick	First fixation directed at GK more often when instructed not to look at the GK compared to when instructed to look at open space. Penalty kicks more successful when first fixation is toward open space.
Bertrand and Thullier (2009)	Experienced Defenders = 8/8 (20.8 ± 2.6) Experienced Attackers = 7/7 (20.8 ± 2.4) Less Experienced Defenders = 7/7 (21.8 ± 4.5) Less Experienced Attackers = 7/7 (21.5 ± 2.5)	Eye-Movement Registration (ASL 5000SU)	Mean no. fixations, mean fixation duration, fixation location (4 areas), first fixation duration, first fixation location, fixation transition	Controlled lab	Predict direction of dribble (method of prediction not reported)	1v1 defensive situations	All groups showed more fixations in more complex situations. Experienced defenders had more fixations of shorter duration, fixated more on the trunk and non-kicking leg, and transitioned between these locations more than experienced attackers and less experienced players.
Binsch et al. (2010a)	*13/32 (24.2 ± 7.4)*	Eye-Movement Registration (ASL 501)	Total fixation duration on GK	Lab in-situ	Physically kick foam ball to score goal according to condition	1v1 penalty kick	Instructions for "not-keeper" and "pass-keeper" conditions had longer fixation duration on GK than "accurate" condition. Fixating on the to-be-avoided area (GK) mediated ironic effects to kick toward that area.
Binsch et al. (2010b)	32/32 (21.8 ± 2.1)	Eye-Movement Registration (ASL 501)	Onset and duration of initial fixation on GK, onset and duration of final fixation on open goal space	Lab in-situ	Physically kick foam ball to score goal according to condition	1v1 penalty kick	Final fixation on open space shorter when ironic effects occur compared to when ironic effects do not occur. No difference in duration of initial fixation on GK between groups or condition.
Bishop et al. (2014)	**Experiment 1**: Male = 26/26 (21.0 ± 1.7), Female = 14/14 (21.4 ± 2.0) **Experiment 2**: Male = 20/20, Female = 26/26 (19.5 ± 1.2)	Eye-Movement Registration (SR Research EyeLink 1000)	Saccades, area of interest (4 areas), overall dwell time, total no. fixations, time to first fixate, mean fixation duration, mean saccadic amplitude, mean saccadic latency, mean peak saccade velocity	Controlled lab	Press computer key to predict direction of dribble	1v1 defensive situations	Time to initiate a saccade to the ball the only predictor of decision-making efficiency. Instructing novices to first saccade to the ball did not improve decision-making efficiency over group instructed to first saccade to the head or control group.
Button et al. (2011)	8/8 (22.8 ± 4.1)	Eye-Movement Registration (ASL Mobile-Eye)	Mean no. fixations, mean fixation duration, mean no. fixation locations (10 areas)	Controlled lab Controlled in-situ	VSM (move joystick to predict direction of kick) ISM (side-step and direct arms to predict direction of kick) ISI (physically move to intercept kick)	1v1 penalty defence	Less fixations of longer duration in VSM condition than ISM and ISI. ISI fixated fewer areas than VSM and ISM conditions. ISI more likely to fixate head of kicker then the ball than VSM and ISM conditions.

(*Continued*)

Table 2. (Continued).

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
Canal-Bruland et al. (2011)	Skilled = 21/21 (26.0 ± 4.4) Less Skilled = 21/21 (25.8 ± 2.2) Control = 14/14 (24.8 ± 2.8)	Eye-Movement Registration (SR Research EyeLink II)	Mean no. fixations, mean fixation duration	Controlled lab	Press keyboard spacebar and move mouse to indicate when the target player was detected	10–17 players total, offensive, defensive and unstructured situations	No difference in number of fixations or fixation duration between skilled and less skilled. Skilled had fewer fixations of longer duration than controls.
Dicks et al. (2010)	8/8 (22.8 ± 4.1)	Eye-Movement Registration (ASL Mobile-Eye)	Mean no. fixations, mean fixation duration, mean no. fixation locations, % viewing time at fixation locations (10 areas)	Controlled lab Controlled in-situ	VSV (verbally identify direction of kick) VSM (move joystick to predict direction of kick) ISV (verbally identify direction of kick) ISM (side-step and direct arms to predict direction of kick) ISI (physically move to intercept kick)	1v1 penalty defence	Performance in ISM and ISI better than in VSV, VSM and ISV. GKs fixated for longer on penalty kicker's body than the ball in limited movement conditions, but fixated the ball earlier and for longer in ISI condition compared to all other conditions.
Helsen and Starkes (1999)	Expert = 14/14 (26.3 ± NR) Intermediate = 14/14 (22.5 ± NR)	Eye-Movement Registration (NAC-V)	Mean no. fixations, mean fixation duration, fixation locations (4 areas), slow tracking fixations	Controlled lab Lab in-situ	Verbally state optimal offensive move. Physically kick ball to either shoot, pass or dribble	Up to 11v11 offensive situations	Experts fixed fewer times than intermediates, but no difference in fixation duration or fixation location. Number and duration of fixations different for shooting, dribbling and passing situations.
Horn et al. (2002)	21/21 (22.2 ± 4.7)	Eye-Movement Registration (ASL 4000SU)	Mean no. fixations, mean fixation duration, fixation duration per location (3 areas), number of fixation locations (12 areas)	Controlled lab	No response when viewing stimuli	Performing "chip" kick	No difference between video and point-light display for number of fixations or fixation duration. Non-bodily areas fixated more in point-light display condition.
Kim and Lee (2006)	6/6 (NR)	Eye-Movement Registration (NAC Eye Mark Recorder-8)	Mean fixation duration, fixation location (9 areas)	Controlled lab	Press computer key to predict direction of kick	1v1 penalty defence	Longer fixation duration on shoulders and area between ball and non-kicking leg for successful predictions.
Krzepota et al. (2016)	Experienced = 8/8 (22.2 ± 3.5) Less Experienced = 8/8 (23.5 ± 4.1) Non-Players = 8/8 (23.2 ± 4.0)	Eye-Movement Registration (SensoMotoric Instruments ETG 2w)	Mean no. fixations, mean fixation duration, mean no. fixation locations (7 areas), % fixation duration per location	Controlled lab	No response required	1v1 defensive situations	No difference in number of fixations or fixation duration between three groups. Experienced group fixated fewer areas and fixated more towards the ball/foot area than non-player group.

(Continued)

Table 2. (Continued).

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
Mann et al. (2009)	*13/19 (18.0 ± 0.4)*	Eye-Movement Registration (ASL Eye-Trac 6000)	Mean no. fixations, mean fixation duration, fixation locations (9 areas), fixation transitions (4 categories)	Controlled lab	Verbally state action they would take	2v1, 3v2, 4v3, 4v4, 5v4, 5v5 offensive situations	More fixations of shorter duration, and more time spent fixating open space when viewing aerial video compared to player perspective video.
Nagano et al. (2004)	Expert = 4/4 (21.3 ± 0.5) Novice = 4/4 (20.5 ± 0.6)	Eye-Movement Registration (NR)	% fixation time on locations (7 areas)	Controlled in-situ	Physically tackle opponent to stop the ball	1v1 defensive situation	Ball fixated the most overall, but experts fixate toes, knees and hips more than novices.
Nagano et al. (2006)	*6/8 (20.6 ± 0.5)*	Eye-Movement Registration (NAC Eye Mark Recorder-8B)	Mean no. fixations per location, mean fixation duration per location, mean quiet eye duration	Controlled in-situ	Physically kick a ball to hit a target	Performing kick to hit a target	No difference in number of fixations between high and low score groups. High score group had longer quiet eye duration and fixated on the target for longer, while the low score group fixated for longer on the ball.
Noel and Van Der Kamp (2012)	*GK independent = 10/10 (26.0 ± 2.5) GK dependent = 8/10 (26.2 ± 2.4)*	Eye-Movement Registration (ASL Mobile Eye)	Fixation location (5 areas)	Controlled in-situ	Physically kick soccer ball to goal according to condition	1v1 penalty kick	No effect of anxiety on performance or fixation locations. More time spent fixating area inside goal and the ball in GK independent strategy than GK dependent strategy. GK independent strategy had better performance.
North et al. (2009)	*Skilled = 8/11 (20.6 ± 3.1) Less Skilled = 10/15 (25.8 ± 4.7)*	Eye-Movement Registration (ASL 5000)	Mean no. fixations per second, mean fixation duration, mean no. fixation locations per second, % fixation duration per location (5 areas), fixation transitions (3 categories)	Controlled lab	Place marker on schematic board to anticipate destination of ball. Press button to indicate if clip is recognised or not.	11v11 offensive situation	No difference in no. or duration of fixations, but skilled fixated more locations than less skilled. More fixations to more locations when viewing film stimulus compared to point-light display stimulus.
Piras and Vickers (2011)	7/7 (18.7 ± 2.4)	Eye-Movement Registration (ASL Mobile Eye)	Mean and relative fixation duration per location (5 areas), fixation transitions (between 5 areas), quiet eye duration	Controlled in-situ	Physically move to save penalty shot	1v1 penalty defence	Longer fixation duration on visual pivot, quiet eye located on visual pivot, and fewer fixation transitions when shots saved compared to goals scored.
Poulter et al. (2005)	*39/48 (20.5 ± 4.65)*	Eye-Movement Registration (ASL 5000)	No. fixations and % viewing time per location (6 areas)	Controlled lab	Verbally state direction of penalty kick	1v1 penalty defence	Explicit learning group had fewer fixations, spent more time fixating the legs and less time fixating the torso, ball and space post-test.

(*Continued*)

Table 2. (Continued).

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
Roca et al. (2011)	Skilled = 10/10 (23.6 ± 3.8) Less skilled = 10/10 (24.3 ± 2.4)	Eye-Movement Registration (ASL Mobile Eye)	Mean no. fixations, mean fixation duration, mean no. fixation locations, % viewing time per location (5 areas), fixation order	Controlled lab	Verbally state what the player in possession of the ball was going to do	11v11 defensive situation	Skilled group used more fixations of shorter duration and to more locations than less skilled group. Skilled group fixated attacking players and free space more than less skilled group, who fixated the ball and player with the ball more.
Roca et al. (2013)	Skilled = 12/12 (23.1 ± 3.7) Less skilled = 12/12 (24.1 ± 2.2)	Eye-Movement Registration (ASL Mobile Eye)	Mean no. fixations, mean fixation duration, mean no. fixation locations, % viewing time per location (5 areas)	Controlled lab	Verbally state what the player in possession of the ball was going to do	Near and far 11v11 defensive situation	Skilled group used more fixations of shorter duration and to more locations than less skilled group. Skilled group spent more time fixating teammates, opponents and free space in the far task, and spent more time fixating the player with the ball in the near task.
Savelsbergh et al. (2006)	19/19 (22.2 ± 3.0)	Eye-Movement Registration (ASL 4000SU)	Mean no. fixations, mean fixation duration, % viewing time per location (8 areas)	Open lab	Physically move to the expected destination of the pass	4v4 offensive situation	High score group had longer fixations than low score group, but no difference in number of fixations. As viewing time increased, passing player fixated for the longest.
Savelsbergh et al. (2010)	*16/20 (11.8 ± NR)*	Eye-Movement Registration (ASL 5000SU)	% viewing time per location (6 areas), % viewing time per location on passing player (3 areas)	Open lab	Physically move to the expected destination of the pass	4v4 offensive situation	High score group fixated for longer on the ball area, low score group fixated for longer on the player with the ball and other players. In the last second, high score group fixated for longer on the legs of the player with the ball and the low score group fixated for longer on trunk and head of the player with the ball.
Savelsbergh et al. (2005)	16/16 (25.7 ± 7.1)	Eye-Movement Registration (ASL 4000SU)	Mean no. fixations, mean fixation duration, mean no. fixation locations, % viewing time per location (4 areas)	Controlled lab	Move a joystick to predict the direction of penalty kick	1v1 penalty defence	No difference in number of fixations, fixation duration or number of fixation locations between successful and non-successful experts. Successful experts spent longer fixating the non-kicking leg and unclassified area than non-successful experts.
Savelsbergh et al. (2002)	Expert = 7/7 (29.9 ± 7.1) Novice = 7/7 (21.3 ± 1.4)	Eye-Movement Registration (ASL 4000SU)	Mean no. fixations, mean fixation duration, mean no. fixation locations, % viewing time per location (9 areas)	Controlled lab	Move a joystick to predict the direction of penalty kick	1v1 penalty defence	Expert GKs had fewer fixations of longer duration to fewer locations than novice GKs. No difference in number, duration or location of fixations between successful and non-successful trials.
Timmis et al. (2014)	12/12 (20.1 ± 1.4)	Eye-Movement Registration (SensoMotoric Instruments iViewETG)	% no. fixations and % viewing time per location (4 areas)	Controlled in-situ	Physically kick soccer ball to goal according to condition	1v1 penalty kick	Players fixated the GK more often when executing a power kick and the edges of the goal more often when executing a placement kick. Ball fixated for the longest for both types of kick.

(*Continued*)

Table 2. (Continued).

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
Vaeyens et al. (2007a)	Elite = 21/21 (14.7 ± 0.5) Sub-elite = 21/21 (14.6 ± 0.3) Regional = 23/23 (14.6 ± 0.6) Control = 22/22 (14.5 ± 0.4)	Eye-Movement Registration (ASL 5000)	Mean no. fixations, mean fixation duration, fixation location (9 areas), fixation order, interfixation duration, interfixation distance, interfixation rate	Lab in-situ	Physically move with ball by passing, shooting or dribbling to indicate tactical decision	2v1, 3v1, 3v2, 4v3, 5v3 offensive situations	No difference in number of fixations or fixation duration between groups, but elite group had higher fixation order. In 2v1 and 3v1 microstates, players used fewer fixations of longer duration and fixated more on the player with the ball and the ball than in 3v2, 4v3 and 5v3 microstates.
Vaeyens et al. (2007b)	***Analysed*** *Successful = 13 (NR)* *Less successful = 15 (NR)* ***Recruited*** *Elite = 21 (14.7 ± 0.5)* *Sub-elite = 21 (14.6 ± 0.3)* *Regional = 23 (14.6 ± 0.6)*	Eye-Movement Registration (ASL 5000)	Mean no. fixations, mean fixation duration, fixation location (9 areas), fixation order, interfixation duration, interfixation distance, interfixation rate	Lab in-situ	Physically move with ball by passing, shooting or dribbling to indicate tactical decision	2v1, 3v1, 3v2, 4v3, 5v3 offensive situations	No difference in fixation duration between successful and less successful. Successful had more fixations, higher fixation order and fixated on the player with the ball more than less successful players. In 2v1 and 3v1 microstates, players used fewer fixations of longer duration and fixated more on the player with the ball and the ball than in 3v2, 4v3 and 5v3 microstates.
Van Der Kamp (2011)	*High skilled = 7/8 (26.0 ± 4.0)* *Low skilled = 8/8 (22.0 ± 1.5)*	Eye-Movement Registration (ASL 501)	% viewing time per location (7 areas)	Lab in-situ	Physically kick foam ball to score a goal	1v1 penalty kick	From the start of run-up to the moment of foot-ball contact, fixations moved from the GKs upper and lower body, to lower body, to open goal areas immediately before contact with the ball.
Vater et al. (2015)	*Higher skilled = 10/11 (18.55 ± 2.8)* *Lower skilled = 10/11 (22.91 ± 4.51)*	Eye-Movement Registration (ASL, model not reported)	Mean no. fixations, mean fixation duration, mean no. fixation locations, % viewing time per location (4 areas)	Controlled lab	Verbally state what the player in possession of the ball was going to do	11v11 defensive situations	More time spent fixating opponents, teammates and free space in the far condition and in the higher skilled group. More time spent fixating the ball in the near condition and in the lower skilled group. Fewer fixations and fewer fixation locations in the near condition than the far. Higher skilled players had fewer fixation locations under high anxiety than low anxiety compared to lower skilled players.
Williams and Davids (1997)	**Experiment 1**: Experienced = 10/10 (20.8 ± 1.5) Less Experienced = 10/10 (20.6 ± 2.1) **Experiment 2**: Experienced = 12/12 (24.0 ± 4.1) Less Experienced = 12/12 (23.3 ± 4.0)	Eye-Movement Registration (ASL 4000SU)	Mean no. fixations, % viewing time per location (3 areas), fixation order	**Experiment 1**: Controlled lab **Experiment 2**: Open lab	**Experiment 1**: Verbally state the direction of the pass **Experiment 2**: Physically move left, right, forward, or backward in response to the stimulus	**Experiment 1**: 11v11 defensive situations **Experiment 2**: 3v3 defensive situations	**Experiment 1**: No difference in search rate, but experienced spent less time fixating the player making the final pass than the less experienced group. **Experiment 2**: No difference between experienced and less experienced groups for fixation order, number of fixations or fixation location. Verbal reports indicate experienced attended to sides of screen more the less experienced.

(*Continued*)

Table 2. (Continued).

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
Williams and Davids (1998)	Experienced = 12/12 (24.0 ± 4.1) Less Experienced = 12/12 (23.3 ± 4.0)	Eye-Movement Registration (ASL 4000SU)	**Experiment 1A**: Mean no. fixations, mean fixation duration, % viewing time per location (5 areas), fixation order **Experiment 1B**: Mean no. fixations, mean fixation duration, % viewing time per location (3 areas), fixation order	Open lab	**Experiment 1A**: Physically move left, right, forward, or backward to simulate intercepting pass **Experiment 1B**: Physically move left or right to anticipate tackling the opponent	**Experiment 1A**: 3v3 defensive situations **Experiment 1B**: 1v1 defensive situations	**Experiment 1A**: No difference in any exploration variables. Players fixated the lower body of the opponent the most. **Experiment 1B**: Experienced players had more fixations of shorter duration than less experienced players. Players fixated the lower body of the opponent the most.
Williams et al. (1994)	*Experienced = 10/15 (21.1 ± 1.7)* *Inexperienced = 10/15 (20.7 ± 2.3)*	Eye-Movement Registration (ASL 4000SU)	Mean no. fixations, mean fixation duration, % viewing time per location (3 areas), fixation order	Controlled lab	Verbally state the anticipated location of the pass	11v11 defensive situations	Experienced players had more fixations of shorter duration, to more locations and with higher fixation order than inexperienced players.
Wilson et al. (2009)	14/14 (20.4 ± 1.1)	Eye-Movement Registration (ASL Mobile Eye)	Total no. fixations, total fixation duration (2 areas), time to first fixate GK	Controlled in-situ	Physically kick ball to score a goal	1v1 penalty kick	In high threat condition, players had more total fixations, fixated the GK faster and fixated the GK for longer than in the low threat condition.
Wood and Wilson (2010)	12/12 (20.3 ± 1.2)	Eye-Movement Registration (ASL Mobile Eye)	No. fixations, final fixation location, final fixation duration	Controlled in-situ	Physically kick ball to score a goal	1v1 penalty kick	No difference in number of fixations between KD, KI and OI strategies. KD strategy used most often.
Wood and Wilson (2011)	Placebo = 10/10 (20.3 ± 1.16) QE training = 10/10 (20.0 ± 1.25)	Eye-Movement Registration (ASL Mobile Eye)	QE location prior to run-up, QE duration prior to run-up, QE duration of final ball fixation	Controlled in-situ	Physically kick ball to score a goal	1v1 penalty kick	QE training group had longer and wider final fixation before run-up, and longer final fixation on the ball than placebo group in retention tests. QE training group did not perform better than placebo group in a penalty shootout.
Woolley et al. (2015)	GK = 17/17 (21.6 ± 2.6) Field players = 20/20 (21.2 ± 2.1) Control = 20/20 (20.5 ± 2.1)	Eye-Movement Registration (ASL Mobile Eye XG)	Mean no. fixations, mean fixation duration, no. changes in fixation location, QE duration, QE location, % viewing time per location (9 areas)	Open lab	Physically move arm to indicate anticipated direction of kick	1v1 penalty defence	GKs had fewer fixations of longer duration, longer QE duration and fewer changes in fixation location than controls. GKs QE location predominantly on stance foot of kicker and the ball.

*A number of studies were unable to analyse data from all recruited participants. The number of participants used for analysis (n) and the total number of participants recruited (N) are reported. Studies that did not analyse data from all participants are reported in italics.

Abbreviations: NR (Not reported), ASL (Applied Science Laboratories), Lab (Laboratory), GK (Goalkeeper), VSV (Video Simulation Verbal), VSM (Video Simulation Movement), ISV (In-Situ Verbal), ISM (In-Situ Movement), ISI (In-Situ Interception), KD (Goalkeeper Dependent), KI (Goalkeeper Independent), OI (Opposite Independent), QE (Quiet Eye).

4v3 and 5v3 offensive situations (Vaeyens et al., 2007a; Vaeyens, Lenoir, Williams, & Philippaerts, 2007b). Due to the amount of variability in outcome measures between studies, further analysis of microstates between studies is impractical.

According to level of expertise

Of the 38 included studies, 22 (58%) used experimental groups that varied in the level of expertise, skill level, experience or success of performance. The most commonly used variables to distinguish between groups in these studies were the number of fixations and duration of fixations. Of the 17 studies which investigated the number of fixations (Table 3), 11 (65%) studies reported finding *no significant difference* between level of experience (N = 4), successful or unsuccessful performance (N = 4) or level of skill (N = 3). Six (35%) studies reported finding that footballers with more experience (N = 3), footballers that perform with more success (N = 1) and footballers with more skill (N = 2) used *significantly more fixations* than footballers with less experience, less successful performance or less skill. Similarly, four of the 17 studies (24%) investigating the number of fixations showed that footballers with more skill (N = 2) and expert footballers (N = 2) used *significantly fewer fixations* than footballers with less skill or expertise.

Of the 15 studies which investigated fixation duration (Table 3), nine (60%) studies reported finding *no significant difference* between level of experience (N = 2), successful or unsuccessful performance (N = 2), level of skill (N = 4) or level of expertise (N = 1). Five (33%) studies reported finding that footballers with more experience (N = 3) and more skill (N = 2) had *significantly shorter fixations* than footballers with less experience or skill. Four (27%) studies reported finding that footballers with more skill (N = 2), footballers that perform with more success (N = 1) and expert footballers (N = 1) had *significantly longer fixations* than footballers with less skill, less expertise or who performed with less success.

Many studies analysed the location of fixations used by participants; however there was little consistency in the way fixation locations were defined. Fixation locations were classified in a number of different ways between the studies, and the number of locations used ranged from 3 to 12. Some studies divided the opposition players into various locations according to body parts (e.g. head, body, kicking leg, non-kicking leg, ball, etc.), while other studies divided the playing area into locations according to potentially important areas (e.g. teammates, opposition players, the player with the ball, free space, etc.). Additionally, the locations were defined and analysed in various different ways. Taken together, the included studies varied greatly in the way fixation locations were investigated, making further analysis impractical.

Technology used to quantify visual perception and exploration behaviour

All of the included studies used some form of eye-movement registration technology to quantify the eye-movements associated with exploration behaviour. Of the 38 included studies, 10 (26%) used the Applied Science Laboratories Mobile Eye, seven (18%) used the Applied Science Laboratories 4000SU, four (11%) used the Applied Science Laboratories 5000, four (11%) used the Applied Science Laboratories 501, two (5%) used the Applied Science Laboratories 5000SU, and one (3%) study each used the Applied Science Laboratories Eye-Trac 6000, the Applied Science Laboratories Mobile Eye XG, the SR Research EyeLink 1000, the SR Research EyeLink II, the NAC-V, the NAC Eye Mark Recorder-8, the NAC Eye Mark Recorder-8B, the SensoMotoric Instruments iViewETG, and the SensoMotoric Instruments ETG 2w. The remaining two (5%) studies did not report the model of technology used.

The included studies reported using eye-movement registration technology to quantify exploration behaviour with eye-centred exploration variables (Table 1). Generally, variables were consistently defined between each of the studies, with the exception of the definition of a fixation. Studies reported defining a fixation as occurring when the eye remained stationary for periods ranging between 40ms and 140ms, or as the period between two saccades. Many different outcome variables were used to investigate the behaviours of footballers, however the most common variables used were measures of search rate, which generally include the mean number of fixations and mean fixation duration.

Discussion

The primary aim of this review was to synthesise the literature which investigated the visual perception and exploration behaviours of football players to determine differences in these behaviours according to the representativeness of the experimental setting. In addressing this aim, the results of this systematic review highlighted: i) as the action requirements became more representative of live match-play, football goalkeepers used more fixations of shorter duration to fewer locations, and also fixated the ball earlier and for longer than in less representative situations; ii) the stimulus presentation modality appeared to influence footballers' visual perception behaviours. When presented with stimuli from a first-person perspective, outfield players used less fixations of longer duration than when viewing the same stimuli from an aerial perspective; and iii) in microstates involving few players (i.e. up to 3v1 situations), outfield players had different visual perception and exploration behaviours than when making decisions in situations involving more players. Mann et al. (2007) found the research paradigm and stimulus presentation modality to be significant moderators of visual perception behaviour across various sports. This systematic review also indicates that in football, the action requirements of the task, the method of stimulus presentation, and the microstate of play may influence the visual perception behaviours of players.

There were 11 studies which utilised a controlled in-situ setting, which was the most representative setting among the included studies. All of these studies investigated microstates of play with a very limited number of players, namely 1v1 situations. Eight of these studies involved a penalty kick situation, which is only ever a 1v1 situation. It is striking that there was no studies which investigated the visual exploration behaviours of footballers in the open and dynamic situations which are more commonly experienced by outfield players during a game. Footballers are rarely competing in a 1v1 situation, so it is important that future research investigates the behaviour of

Table 3. Summary of the research reporting the number and duration of fixations in football according to level of expertise.

	Kick	1v1	3v3	4v4	2v2 to 5v3	10–17 players	11v11
Number of Fixations							
More fixations for experienced, experts, more skilled or successful performance		Bertrand and Thullier (2009)* Williams and Davids (1998)*			Vaeyens et al. (2007a)^		Williams et al. (1994)* Roca et al. (2011)# Roca et al. (2013)#
No difference according to experience, expertise, skill level or performance	Nagano et al. (2006)^	Savelsbergh et al. (2002)^ Savelsbergh et al. (2005)^ Krzepota et al. (2016)*	Williams and Davids (1997)* Williams and Davids (1998)*	Savelsbergh et al. (2006)^	Vaeyens et al. (2007b)#	Canal-Bruland et al. (2011)#[a]	Williams and Davids (1997)* North et al. (2009)#
Fewer fixations for experienced, experts, more skilled or successful performance		Savelsbergh et al. (2002)+ Woolley et al. (2015)#[bc]				Canal-Bruland et al. (2011)#[b]	Helsen and Starkes (1999)+
Fixation Duration							
Shorter fixation duration for experienced, experts, more skilled or successful performance		Bertrand and Thullier (2009)* Williams and Davids (1998)*					Williams et al. (1994)* Roca et al. (2011)# Roca et al. (2013)#
No difference according to experience, expertise, skill level or performance		Savelsbergh et al. (2005)^ Woolley et al. (2015)#[c] Krzepota et al. (2016)*	Williams and Davids (1998)*		Vaeyens et al. (2007b)# Vaeyens et al. (2007a)^	Canal-Bruland et al. (2011) #[a]	Helsen and Starkes (1999)+ North et al. (2009)#
Longer fixation duration for experienced, experts, more skilled or successful performance		Savelsbergh et al. (2002)+ Woolley et al. (2015)#[b]		Savelsbergh et al. (2006)^		Canal-Bruland et al. (2011) #[b]	

*Experience
^Performance
#Skill
+Expertise
[a]Compared to less skilled
[b]Compared to controls
[c]Compared to field players

footballers in the situations in which they are asked to perform (Brunswik, 1956; Dhami et al., 2004; Gibson, 1979). It is important to note that visual exploration research in an open in-situ setting does exist. Eldridge, Pulling, and Robins (2013) and Jordet, Bloomfield, and Heijmerikx (2013) investigated the head movements that support exploration behaviour of footballers while they played in competitive matches. In both of these instances, head movements were manually counted by viewing video footage of the games, a process which can be time consuming, labour intensive and potentially prone to errors. Both studies found evidence that exploratory head movements prior to receiving a pass were associated with more successful performance with the ball (Eldridge et al., 2013; Jordet et al., 2013), suggesting the exploration behaviours of footballers while playing in representative games are important to investigate.

Regarding the second aim of this review, there appeared to be conflicting findings regarding the visual perception behaviours of footballers according to their level of expertise. The included studies varied in the experimental groups used to compare findings, with participants being grouped based on skill level, amount of experience, level of expertise, or performance outcomes. Of the studies which used the most common eye-movement variables (i.e. number and duration of fixations), a majority of studies (65% and 60%, respectively) found no difference between the more expert footballers and the footballers with less expertise. Additionally, roughly the same amount of studies found that the expert footballers would either use more (35%) or less (24%) fixations, and fixations of either longer (27%) or shorter (33%) duration than the footballers with less expertise. Taken together, there does not seem to be any clear differences in visual perception and exploration behaviour between players with different levels of expertise in football. This finding is contrary to those found by Mann et al. (2007), who found that experts used fewer fixations of longer duration. It is possible, however, that this null finding is due to the various research paradigms and outcome variables used in the studies included in this review. Given the apparent lack of differences between highly skilled and less skilled players, with respect to the number and duration of fixations used, there is a need for well-controlled and large-scaled research and/or a meta-analysis of the existing data to confirm this finding.

The final aim of this systematic review was to gain an understanding of the types of technology that have been used to quantify the exploration behaviours of football players. With respect to this aim, all of the included studies utilised eye-movement registration technology to quantify the visual perception and exploration behaviours of footballers. While there is some evidence to suggest other technologies may be useful to examine the exploration behaviours of athletes (McGuckian & Pepping, 2016), the findings of the current review indicate that the available research is saturated by the use of eye-movement registration technology. This type of technology uses a video-based pupil and corneal reflection system to monitor the point of gaze of the wearer (Discombe & Cotterill, 2015; Holmqvist et al., 2011). To do this, the head-mounted system uses one camera to record the movement of the pupils and corneal reflection, and a second camera to capture the real-world in front of the wearer. The position of the pupils and corneal reflection is then mapped onto the real-world image, highlighting the point of gaze of the wearer. From this data, a number of different variables related to the spatial and temporal aspects of eye-movements are extracted (Table 1). Inferences are then made from these variables about the perceptual and information processing demands and attentional focus of the wearer (Vickers, 2009). While some variables were used more commonly between studies, there was a wide variety of variables created from the eye-movement registration technology, which resulted in a lack of consistency between studies and difficulty in synthesising the outcomes to find a consensus. Interestingly, one of the earliest studies included in this review suggested that variables obtained from eye-movement registration technology may not always be an appropriate measure of visual attention (Williams & Davids, 1997), advice which researchers seem to have taken lightly according to the amount of research that followed.

It should be noted that exploration behaviour involves the movement of the eyes, which are in the head, which is on the body (Reed, 1996), and therefore the entire eye/head/body system should be considered when investigating exploration behaviour. Eye-movement registration can certainly help with this endeavour, however to date a majority of the implementation of this technology in a football setting has resulted in experimental designs which have not been interested in, or in some cases intentionally excluded (Bishop, Kuhn, & Maton, 2014; Kim & Lee, 2006), the head and body movements of the participants. One reason for this may be due to limitations of the technology itself. Without the correct environmental conditions data collection may be unreliable, leading to data being excluded, which occurred in a number of the included studies in this review (Table 2). To ensure reliable data, researchers have depended upon more controllable environments, such as projecting stimuli on a screen in a laboratory, which removes the possibility of stimuli being anywhere but in front of the participant, and therefore the head and body movements associated with exploration behaviour are ignored. One solution to this problem may come from virtual reality (VR) technology. The development of VR has led to environments that are perceptually representative of real environments (Correia, Araújo, Watson, & Craig, 2014), making the use of VR technology popular for research (Tirp, Steingröver, Wattie, Baker, & Schorer, 2015; Vignais, Kulpa, Brault, Presse, & Bideau, 2015). For visual perception research, VR may provide controllable environments which completely surround the participant, allowing investigation of the eye/head/body system used by participants to explore their surroundings.

According to the methodological quality assessment, a majority of papers (66%) were rated as having a high or very high reporting quality, while 34% of papers scored either a low or moderate rating of reporting quality. A common downfall for the included studies was the reporting of sampling. The included studies generally neglected to report sufficient detail regarding their sampling methods, the appropriateness of their chosen sample sizes, and/or the inclusion/exclusion criteria applied during the recruitment of participants. Therefore, it is recommended that future studies focus on ensuring further detail is included regarding the sampling of participants to improve the overall reporting quality of research in this area. Additionally, it was somewhat common for studies to report the outcome variables used in analysis without clearly defining each of the variables. If researchers wish to clearly communicate their findings and allow a comparison of results between studies, it is important to clearly define outcome variables obtained from the particular technology used.

This systematic review has some limitations which should be considered when evaluating the findings. First, due to the broad range of research and various inconsistencies between the included studies, a meta-analysis of the data was not possible. It is possible that some papers were missed during the systematic database search, however, by identifying other potentially relevant papers in the reference lists of those papers considered eligible for inclusion, we are confident that the review represents the bulk of research conducted in this area. Second, the critical appraisal tool used to assess the reporting quality of the papers only allowed each category to be scored with a whole number. While measures were taken to ensure fair assessment of the reporting quality of each paper, a small variation in scoring of categories could lead to relatively large change in the overall percentage score for that paper (i.e. each point corresponded with a 2.5% increase in score). It is also important to consider that the appraisal of a manuscript's reporting quality can only be based on what information has been included by the authors. As such, it is possible that papers published in journals that have much stricter word limits may score more poorly due to a reduced capacity to describe all aspects of their methodologies. Finally, it is possible the aims of this review restricted the number of papers that have been included. The aim of this review was to understand which technologies are used to quantify visual perception and exploration behaviour in football, therefore, any research using methods that did not produce outcome measures from technology were excluded. As a result, research investigating visual exploration behaviours through other methods (i.e. observation or verbal report) was not included in this review.

In conclusion, the results of this systematic review indicate that the examination of visual perception and exploratory behaviours of footballers has primarily relied upon eye-tracking technology. Given the inherent shortcomings of this approach and recent developments in the use of alternate technologies (e.g. IMUs, VR), future research may seek to utilise technologies that are capable of providing insight into the role of other body segments in the exploration process. These technologies may provide more accurate and efficient data collection methods than have previously been used (Eldridge et al., 2013; Jordet et al., 2013), giving researchers and applied practitioners a better understanding of exploration behaviour in sport. Additionally, a shift in research focus from laboratory to field-based settings is recommended to better understand visual exploratory behaviour of footballers in representative situations (Dicks, Davids, & Button, 2009), that is, while in their natural environment of a football pitch. By adopting this approach, applied practitioners may be more informed of the actual behaviours used by athletes, enabling more targeted training and rehabilitation methods.

Until research provides a better understanding of the ways in which athletes use the eye/head/body system to explore their surroundings in representative situations, it is advised that applied practitioners judiciously consider the research currently available. A small amount of research has found that the exploratory head movements of footballers are important for on ball performance during live games (Eldridge et al., 2013; Jordet et al., 2013). It is therefore recommended that coaches encourage the development of this behaviour with their players through the design of training drills which require exploratory behaviour in order to perform successfully. For example, changing the constraints of games to encourage more exploratory behaviour (McGuckian et al., 2017) or designing passing drills which require a decision to be made (and therefore exploration behaviour to prospectively control actions) instead of passing drills in which the destination of a pass is dictated by the design of the drill.

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ORCID

Thomas B. McGuckian http://orcid.org/0000-0002-5490-0042
Michael H. Cole http://orcid.org/0000-0003-1817-7528
Gert-Jan Pepping http://orcid.org/0000-0002-5926-2000

References

Abellan, J., Savelsbergh, G. J. P., Jordan, O. R. C., & Vila-Maldonado, S. (2016). Interception of a corner kick in football: A task analysis. *Revista Internacional De Medicina Y Ciencias De La Actividad Fisica Y Del Deporte*, *16*(61), 111–126. doi:10.15366/rimcafd2016.61.009

Abernethy, B. (1990). Anticipation in squash: Differences in advance cue utilization between expert and novice players. *Journal of Sports Sciences*, *8*(1), 17–34. doi:10.1080/02640419008732128

Bakker, F. C., Oudejans, R. R., Binsch, O., & Van der Kamp, J. (2006). Penalty shooting and gaze behavior: Unwanted effects of the wish not to miss. *International Journal of Sport Psychology*, *37*(2/3), 265–280.

Bertrand, C., & Thullier, F. (2009). Effects of player position and task complexity in visual exploration behavior in soccer. *International Journal of Sport Psychology*, *40*(2), 306–323.

Binsch, O., Oudejans, R. R., Bakker, F. C., Hoozemans, M. J., & Savelsbergh, G. J. P. (2010a). Ironic effects in a simulated penalty shooting task: Is the negative wording in the instruction essential? *International Journal of Sport Psychology*, *41*(2), 118–133.

Binsch, O., Oudejans, R. R., Bakker, F. C., & Savelsbergh, G. J. P. (2010b). Ironic effects and final target fixation in a penalty shooting task. *Human Movement Science*, *29*(2), 277–288. doi:10.1016/j.humov.2009.12.002

Bishop, D., Kuhn, G., & Maton, C. (2014). Telling people where to look in a soccer-based decision task: A nomothetic approach. *Journal of Eye Movement Research*, *7*(2), 1–13.

Brunswik, E. (1956). *Perception and the representative design of psychological experiments* (2nd ed.). Berkeley: University of California Press.

Button, C., Dicks, M., Haines, R., Barker, R., & Davids, K. (2011). Statistical modelling of gaze behaviour as categorical time series: What you should watch to save soccer penalties. *Cognitive Processing*, *12*(3), 235–244. doi:10.1007/s10339-010-0384-6

Canal-Bruland, R., Lotz, S., Hagemann, N., Schorer, J., & Strauss, B. (2011). Visual span and change detection in soccer: An expertise study. *Journal of Cognitive Psychology*, *23*(3), 302–310. doi:10.1080/20445911.2011.496723

Correia, V., Araújo, D., Watson, G., & Craig, C. (2014). Using virtual environments to study interactions in sport performance. In K. Davids, R. Hristovski, D. Araújo, N. Balagué Serre, C. Button, & P. Passos (Eds.), *Complex systems in sport* (pp. 175–189). New York, NY: Taylor & Francis.

Crowe, M., Sheppard, L., & Campbell, A. (2012). Reliability analysis for a proposed critical appraisal tool demonstrated value for diverse research designs. *Journal of Clinical Epidemiology*, *65*(4), 375–383. doi:10.1016/j.jclinepi.2011.08.006

Dhami, M. K., Hertwig, R., & Hoffrage, U. (2004). The role of representative design in an ecological approach to cognition. *Psychological Bulletin*, *130*(6), 959–988. doi:10.1037/0033-2909.130.6.959

Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, & Psychophysics*, *72*(3), 706–720. doi:10.3758/APP.72.3.706

Dicks, M., Davids, K., & Button, C. (2009). Representative task designs for the study of perception and action in sport. *International Journal of Sport Psychology*, *40*(4), 506–524.

Discombe, R. M., & Cotterill, S. T. (2015). Eye tracking in sport: A guide for new and aspiring researchers. *Sport & Exercise Psychology Review*, *11*(2), 49–58.

Eldridge, D., Pulling, C., & Robins, M. T. (2013). Visual exploratory activity and resultant behavioural analysis of youth midfield soccer players. *Journal of Human Sport and Exercise*, *8*(3), 560–577. doi:10.4100/jhse.2013.8.Proc3.02

Fajen, B. R., Riley, M. A., & Turvey, M. T. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology*, *40*(1), 79.

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston, MA: Houghton- Mifflin.

Gibson, J. J. (1979). *An ecological approach to visual perception*. Boston, MA: Houghton-Mifflin.

Helsen, W. F., & Starkes, J. L. (1999). A multidimensional approach to skilled perception and performance in sport. *Applied Cognitive Psychology*, *13*(1), 1–27. doi:10.1002/(ISSN)1099-0720

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., & Van De Weijer, J. (2011). *Eye tracking: A comprehensive guide to methods and measures*. New York: Oxford University Press.

Horn, R. R., Williams, A. M., & Scott, M. A. (2002). Learning from demonstrations: The role of visual search during observational learning from video and point-light models. *Journal of Sports Sciences*, *20*(3), 253–269. doi:10.1080/026404102317284808

Jordet, G., Bloomfield, J., & Heijmerikx, J. (2013). *The hidden foundation of field vision in english premier league (EPL) soccer players*. MIT Sloan Sports Analytics Conference, Boston, MA.

Jordet, G., & Pepping, G.-J. (in press). Flipping sport psychology theory into practice. A context- and behavior centered approach. In M. L.

Cappuccio (Ed.), *Handbook of embodied cognition and sport psychology*. Cambridge, MA: The MIT Press.
Kim, S., & Lee, S. (2006). Gaze behavior of elite soccer goalkeeper in successful penalty kick defense. *Korean Journal of Sport Science*, *16*(4), 117–127.
Krzepota, J., Stepinski, M., & Zwierko, T. (2016). Gaze control in one versus one defensive situations in soccer players with various levels of expertise. *Perceptual and Motor Skills*, *123*(3), 769–783. doi:10.1177/0031512516664903
Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., … Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *Plos Med*, *6*(7), e1000100. doi:10.1371/journal.pmed.1000100
Mann, D. L., Farrow, D., Shuttleworth, R., & Hopwood, M. (2009). The influence of viewing perspective on decision-making and visual search behaviour in an invasive sport. *International Journal of Sport Psychology*, *40*(4), 546–564.
Mann, D. L., Williams, M., Ward, P., & Janelle, C. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology*, *29*, 457–478. doi:10.1123/jsep.29.4.457
McGuckian, T. B., Askew, G., Greenwood, D., Chalkley, D., Cole, M., & Pepping, G.-J. (2017). The impact of constraints on visual exploratory behaviour in football. In J. A. Weast-Knapp & G.-J. Pepping (Eds.), *Studies in perception and action XIV*. New York: Taylor & Francis.
McGuckian, T. B., & Pepping, G.-J. (2016). A wearable inertial sensor for improved measurement of exploration behaviour in sport compared to notational analysis. *Journal of Fitness Research*, *5*, 40–42.
Nagano, T., Kato, T., & Fukuda, T. (2004). Visual search strategies of soccer players in one-on-one defensive situations on the field. *Perceptual and Motor Skills*, *99*(3), 968–974. doi:10.2466/pms.99.3.968-974
Nagano, T., Kato, T., & Fukuda, T. (2006). Visual behaviors of soccer players while kicking with the inside of the foot. *Perceptual and Motor Skills*, *102*(1), 147–156. doi:10.2466/PMS.102.1.147-156
Noel, B., & Van der Kamp, J. (2012). Gaze behaviour during the soccer penalty kick: An investigation of the effects of strategy and anxiety. *International Journal of Sport Psychology*, *43*(4), 326.
North, J. S., Williams, A. M., Hodges, N., Ward, P., & Ericsson, K. A. (2009). Perceiving patterns in dynamic action sequences: Investigating the processes underpinning stimulus recognition and anticipation skill. *Applied Cognitive Psychology*, *23*(6), 878–894. doi:10.1002/acp.v23:6
Piras, A., & Vickers, J. N. (2011). The effect of fixation transitions on quiet eye duration and performance in the soccer penalty kick: Instep versus inside kicks. *Cognitive Processing*, *12*(3), 245–255. doi:10.1007/s10339-011-0406-z
Poulter, D. R., Jackson, R. C., Wann, J. P., & Berry, D. C. (2005). The effect of learning condition on perceptual anticipation, awareness, and visual search. *Human Movement Science*, *24*(3), 345–361. doi:10.1016/j.humov.2005.06.005
Reed, E. S. (1996). *Encountering the world: Toward an ecological psychology*. New York, NY: Oxford University Press.
Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2011). Identifying the processes underpinning anticipation and decision-making in a dynamic time-constrained task. *Cognitive Processing*, *12*(3), 301–310. doi:10.1007/s10339-011-0392-1
Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of Sport & Exercise Psychology*, *35*(2), 144–155. doi:10.1123/jsep.35.2.144
Savelsbergh, G. J. P., Haans, S. H. A., Kooijman, M. K., & Van Kampen, P. M. (2010). A method to identify talent: Visual search and locomotion behavior in young football players. *Human Movement Science*, *29*(5), 764–776. doi:10.1016/j.humov.2010.05.003
Savelsbergh, G. J. P., Onrust, M., Rouwenhorst, A., & Van der Kamp, J. (2006). Visual search and locomotion behaviour in a four-to-four football tactical position game. *International Journal of Sport Psychology*, *37*(2/3), 248–264.
Savelsbergh, G. J. P., Van Der Kamp, J., Williams, A. M., & Ward, P. (2005). Anticipation and visual search behaviour in expert soccer goalkeepers. *Ergonomics*, *48*(11–14), 1686–1697. doi:10.1080/00140130500101346
Savelsbergh, G. J. P., Williams, A. M., Van der Kamp, J., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sports Sciences*, *20*(3), 279–287. doi:10.1080/026404102317284826
Shim, J., Carlton, L. G., Chow, J. W., & Chae, W. S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *Journal of Motor Behavior*, *37*(2), 164–175. doi:10.3200/jmbr.37.2.164-175
Timmis, M. A., Turner, K., & Van Paridon, K. N. (2014). Visual search strategies of soccer players executing a power vs. placement penalty kick. *Plos One*, *9*(12), e115179. doi:10.1371/journal.pone.0115179
Tirp, J., Steingröver, C., Wattie, N., Baker, J., & Schorer, J. (2015). Virtual realities as optimal learning environments in sport - A transfer study of virtual and real dart throwing. *Psychological Test and Assessment Modeling*, *57*(1), 57–69.
Vaeyens, R., Lenoir, M., Williams, A. M., Mazyn, L., & Philippaerts, R. M. (2007a). The effects of task constraints on visual search behavior and decision-making skill in youth soccer players. *Journal of Sport & Exercise Psychology*, *29*(2), 147–169. doi:10.1123/jsep.29.2.147
Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2007b). Mechanisms underpinning successful decision making in skilled youth soccer players: An analysis of visual search Behaviors. *Journal of Motor Behavior*, *39*(5), 395–408. doi:10.3200/jmbr.39.5.395-408
Van der Kamp, J. (2011). Exploring the merits of perceptual anticipation in the soccer penalty kick. *Motor Control*, *15*(3), 342–358. doi:10.1123/mcj.15.3.342
Van der Kamp, J., Rivas, F., Van Doorn, H., & Savelsbergh, G. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. *International Journal of Sport Psychology*, *39*(2), 100.
Vater, C., Roca, A., & Williams, A. M. (2015). Effects of anxiety on anticipation and visual search in dynamic, time-constrained situations. *Sport, Exercise, and Performance Psychology*. doi:10.1037/spy0000056
Vickers, J. N. (2007). *Perception, cognition, and decision training: The quiet eye in action*. Champaign, IL: Human Kinetics.
Vickers, J. N. (2009). Advances in coupling perception and action: The quiet eye as a bidirectional link between gaze, attention, and action. *Progress in Brain Research*, *174*, 279–288. doi:10.1016/S0079-6123(09)01322-3
Vignais, N., Kulpa, R., Brault, S., Presse, D., & Bideau, B. (2015). Which technology to investigate visual perception in sport: Video vs. virtual reality. *Human Movement Science*, *39*, 12–26. doi:10.1016/j.humov.2014.10.006
Williams, A. M., & Davids, K. (1997). Assessing cue usage in performance contexts: A comparison between eye-movement and concurrent verbal report methods. *Behavior Research Methods, Instruments, & Computers*, *29*(3), 364–375. doi:10.3758/bf03200589
Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport*, *69*(2), 111–128. doi:10.1080/02701367.1998.10607677
Williams, A. M., Davids, K., Burwitz, L., & Williams, J. G. (1994). Visual search strategies in experienced and inexperienced soccer players. *Research Quarterly for Exercise and Sport*, *65*(2), 127–135. doi:10.1080/02701367.1994.10607607
Williams, A. M., Davids, K., & Williams, J. G. P. (1999). *Visual perception and action in sport*. London: E & FN Spon.
Wilson, M. R., Wood, G., & Vine, S. J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport & Exercise Psychology*, *31*(6), 761–775. doi:10.1123/jsep.31.6.761
Wood, G., & Wilson, M. R. (2010). Gaze behaviour and shooting strategies in football penalty kicks: Implications of a keeper-dependent approach. *International Journal of Sport Psychology*, *41*(3), 293–312.
Wood, G., & Wilson, M. R. (2011). Quiet-eye training for soccer penalty kicks. *Cognitive Processing*, *12*(3), 257–266. doi:10.1007/s10339-011-0393-0
Woolley, T. L., Crowther, R. G., Doma, K., & Connor, J. D. (2015). The use of spatial manipulation to examine goalkeepers' anticipation. *Journal of Sports Sciences*, *33*(17), 1766–1774. doi:10.1080/02640414.2015.1014830
Wright, D. L., Pleasants, F., & Gomez-Meza, M. (1990). Use of advanced visual cue sources in volleyball. *Journal of Sport & Exercise Psychology*, *12*(4), 406–414. doi:10.1123/jsep.12.4.406

Appendices

Appendix 1

Systematic search strategy and procedures

Research Question: What evidence is there for the use of technology to measure visual perception and exploration behaviour in association football?

Research Protocol

Methods for Literature Search

A targeted search will be conducted of relevant databases for articles that report the measurement of exploration behaviour in football. Specifically, the databases searched will be:

SPORTDiscus
PsychINFO
PubMed
Web of Science
EMBASE

Additionally, the bibliographies of the studies that meet the inclusion criteria for this review will be screened for relevant articles that may have been missed during the initial database searches. As potential papers are identified, they will be added to an Endnote database to eliminate duplicate entries of research studies. The following outlines the complete combination of search terms to be used to search the titles and abstracts of potential papers for each of the five databases:

Team sport OR field sport OR sport OR football OR soccer

AND

Exploration OR decision making OR decision-making OR gaze OR vision OR perception action OR perception-action OR fixation OR visual search OR head check OR percept* OR affordance OR calibrat*

AND

Eye track* OR acceler* OR gyroscope OR sensor OR wearable OR observation OR technology OR video OR eye movement OR eye-movement

Strict Inclusion/Exclusion Criteria

To be eligible for inclusion in the systematic review, papers are required to meet the following inclusion and exclusion criteria:

Inclusion Criteria: For inclusion, papers are required to; i) investigate an association football setting; ii) utilise technology to measure exploration; iii) present at least one quantitative outcome measure for exploration behaviour; iv) be written in English; v) be a full-text article (i.e. not a conference abstract, book, systematic review or meta-analysis).

Exclusion Criteria: Papers will be excluded if they; i) use technology, but not for the purpose of quantifying exploration behaviour; ii) do not have a full-text article available.

Paper Review Process

A minimum of 3 reviewers discussed the search terms and inclusion/exclusion criteria until consensus was reached. One reviewer will perform the initial screening of articles based on the title and abstract of the papers identified in the initial search. When the suitability of a paper cannot be determined based on its title or abstract, it will progress to full-text review. The full-text of those papers that are considered potentially relevant following title and abstract screening will be reviewed by 1 of the reviewers and papers that are eligible will be subjected to quality assessment and data extraction. Where there are uncertainties about the relevance of a paper following full-text review, a second reviewer will independently evaluate the study and the inclusion status of the paper discussed until a final consensus is reached.

Quality Assessment

The methodological quality of each included paper will be assessed using the Crowe Critical Appraisal Tool (CCAT) as described by Crowe et al. (2012). This quality assessment checklist uses 22 items divided into eight categories to assist readers in assessing the reporting quality of the research. Each category on the checklist receives a score on a 6 point scale, where all scores are required to be whole numbers. The lowest score a category can achieve is 0, and the highest score is 5. The sum of the scores for each category will be divided by the maximum possible score (40) and multiplied by 100 to yield a percentage that provides an assessment of the manuscript's methodological and reporting quality. Manuscripts will be classified as having either very low (<20%), low (≥20% but <40%), moderate (≥40% but <60%), high (≥60% but <80%), or very high (≥80%) reporting quality.

Crowe et al. (2012). Reliability analysis for a proposed critical appraisal tool demonstrated value for diverse research designs. *Journal of Clinical Epidemiology, 65*(4), 375–383. doi: http://dx.doi.org/10.1016/j.jclinepi.2011.08.006

Methods for Data Extraction and Analysis

The initial step for this process involves a simple descriptive evaluation of each of the studies included in the review. Furthermore, the table will include a number of important pieces of information to be extracted from these studies and will include:

Demographics – Number and age of experimental groups
Technology Details – Type and model
Outcome Measures – Variables and definitions
Research Paradigm – Experimental setting and action requirements of participants
Findings – Results of the study
Quality Assessment Scores – Details regarding the methodological quality of the study

Appendix 2

CCAT scores for individual categories, overall score and quality rating of each paper included in the systematic review.

Paper	Preliminaries	Introduction	Design	Sampling	Data collection	Ethical matters	Results	Discussion	Total	Total (%)	Reporting Quality
Abellan, Savelsbergh, Jordan, and Vila-Maldonado (2016)	1	2	0	2	2	2	1	1	11	27.5	Low
Bakker, Oudejans, Binsch, and Van der Kamp (2006)	4	5	3	1	3	1	2	5	24	60	High
Bertrand and Thullier (2009)	2	4	3	1	1	0	4	2	17	42.5	Moderate
Binsch, Oudejans, Bakker, Hoozemans, and Savelsbergh (2010a)	4	4	5	1	4	3	3	5	29	72.5	High
Binsch, Oudejans, Bakker, and Savelsbergh (2010b)	4	4	3	1	4	3	4	3	26	65	High
Bishop, Kuhn, and Maton (2014)	4	5	3	2	5	2	4	4	29	72.5	High
Button, Dicks, Haines, Barker, and Davids (2011)	4	5	4	2	4	2	4	3	28	70	High
Canal-Bruland, Lotz, Hagemann, Schorer, and Strauss (2011)	1	3	2	1	1	2	2	2	14	35	Low
Dicks, Button, and Davids (2010)	5	4	5	1	4	2	4	4	29	72.5	High
Helsen and Starkes (1999)	1	3	3	1	3	2	2	2	17	42.5	Moderate
Horn, Williams, & Scott (2002)	2	4	3	1	2	1	4	3	20	50	Moderate
Kim and Lee (2006)	0	2	1	0	3	1	1	1	9	22.5	Low
Krzepota, Stepinski, and Zwierko (2016)	3	3	2	2	3	5	2	2	22	55	Moderate
Mann, Farrow, Shuttleworth, and Hopwood (2009)	4	4	4	1	4	1	3	4	25	62.5	High
Nagano, Kato, and Fukuda (2004)	2	1	1	1	2	0	2	1	10	25	Low
Nagano, Kato, and Fukuda (2006)	2	3	3	1	2	1	2	1	15	37.5	Low
Noel and Van Der Kamp (2012)	5	5	4	1	5	3	5	4	32	80	Very high
North, Williams, Hodges, Ward, and Ericsson (2009)	4	4	4	1	5	3	4	4	29	72.5	High
Piras and Vickers (2011)	4	4	3	1	4	4	3	3	26	65	High
Poulter, Jackson, Wann, and Berry (2005)	3	4	3	1	2	3	2	3	21	52.5	Moderate
Roca, Ford, McRobert, and Williams (2011)	5	5	4	2	4	4	4	4	32	80	Very high
Roca, Ford, McRobert, and Williams (2013)	5	4	4	2	4	4	4	3	30	75	High
Savelsbergh, Haans, Kooijman, and Van Kampen (2010)	3	3	3	1	4	3	2	2	21	52.5	Moderate
Savelsbergh, Onrust, Rouwenhorst, and Van der Kamp (2006)	4	4	4	1	4	3	3	2	25	62.5	High
Savelsbergh, Van Der Kamp, Williams, and Ward (2005)	3	4	3	1	3	2	2	4	22	55	Moderate
Savelsbergh, Williams, Van der Kamp, and Ward (2002)	4	5	4	1	3	2	3	4	26	65	High
Timmis, Turner, and Van Paridon (2014)	5	5	3	1	4	4	4	5	31	77.5	High
Vaeyens, Lenoir, Williams, Mazyn, and Philippaerts (2007a)	4	5	4	2	4	4	4	4	31	77.5	High
Vaeyens, Lenoir, Williams, and Philippaerts (2007b)	4	4	5	2	4	3	4	4	30	75	High
Van Der Kamp (2011)	4	5	3	2	4	2	3	4	27	67.5	High
Vater, Roca, and Williams (2015)	5	5	4	2	4	3	5	4	32	80	Very high
Williams and Davids (1997)	5	5	5	1	4	1	4	5	30	75	High
Williams and Davids (1998)	5	5	5	1	4	2	4	4	30	75	High
Williams, Davids, Burwitz, and Williams (1994)	3	4	3	1	3	2	3	4	23	57.5	Moderate
Wilson, Wood, and Vine (2009)	4	5	4	1	3	3	4	5	29	72.5	High
Wood and Wilson (2010)	5	5	4	2	4	3	3	5	31	77.5	High
Wood and Wilson (2011)	5	5	5	3	5	3	4	5	35	87.5	Very high
Woolley, Crowther, Doma, and Connor (2015)	4	5	4	4	4	3	4	4	32	80	Very high