AN EXAMINATION OF THE VISUAL EXPLORATORY ACTIONS OF ASSOCIATION FOOTBALL PLAYERS

This dissertation is submitted for the degree of

Doctor of Philosophy

by

Thomas Baxter McGuckian

Bachelor of Exercise & Sport Science (Hons), Bachelor of Psychological Studies, Bachelor Exercise Science & Human Movement

School of Behavioural and Health Science

Australian Catholic University

Brisbane, Queensland

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AUSTRALIAN CATHOLIC UNIVERSITY

“You’ll never find rainbows if you’re looking down”

- Sir Charles Spencer Chaplin

“Prolonged endurance tames the bold”

- Lord George G. Byron

Declaration

This thesis contains no material that has been extracted in whole or in part from a thesis that I have submitted towards the award of any other degree or diploma in any other tertiary institution. No other person's work has been used without due acknowledgment in the main text of the thesis. All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

Thomas Baxter McGuckian Date: 6 Aug. 19

Acknowledgements

I have never been one to waste words, so I will keep this characteristically brief. For a vast majority of the last few years, I felt this whole PhD fuss was going much more smoothly than people had warned it would. I had read about people's struggles, and heard stories from others, but none of them ever seemed to relate to my own experiences. That's not to say there weren't any bumps in the road, there were a few, it just says a lot about the people I have had in my life throughout this time. Firstly, a big thank you to anyone that I have not specifically mentioned below. In being sufficiently corny and obvious at once, my whole life has led me to this point, and all the people involved along the way deserve some credit for this.

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Abstract

Successful performance in association football (soccer) is determined by the interaction between the technical, tactical and physical components of match-play. While each of these factors have received extensive research attention, the actions that inform the technical, tactical and physical components of play have been relatively under-investigated. Football environments change on a moment-to-moment basis, therefore, to successfully guide their actions, players need to maintain a constant understanding of their surrounding environment. This is done with active movement of the eyes, head and body – termed visual exploratory action - which allows visual perception of affordances, that is, the possibilities for action in one's surrounding environment. Performatory actions, such as passing, moving to space and tackling, are informed by the perception of affordances that exploratory actions provide. Whether these performatory actions are afforded, however, is constrained by the relations between each individual actor (and their action capabilities), the environment (such as the weather, the ball and social expectations), and the task (such as the laws of the game and the team's strategy). Given the complexity of these interacting constraints, and the difficulty in quantifying these constraints at any given time, gaining an understanding of how an athlete visually perceives their environment (that is, their visual exploratory actions) is necessary before moving to more complex questions relating to what a player visually perceives. Taking the Ecological approach to visual perception, this thesis aimed to gain an understanding of the visual exploratory actions used by football players to perceive their environment in 360-degrees. To fulfil this aim, a series of four studies were completed.

Study 1, a systematic review of literature investigating the technology assisted quantification of visual exploratory actions, showed that eye-movements of football players have been examined extensively, but that representative designs were rarely used to investigate these actions. As a result, there is not a clear understanding of the eye-movements of players during actual football match-play. Further, the reliance on eye-movement registration technology has resulted in experimental designs that primarily present information directly in front of participants or do not require realistic responses. This is problematic given that, during match-play, players are required to perceive their environment in 360-degrees and need to respond with footballing actions. The systematic review of literature showed that there is a need to investigate the visual exploratory head movements of football players, using alternative technologies, while they perform in representative environments.

Studies 2, 3 and 4 utilised head-mounted microelectromechanical systems (MEMS) inertial measurement unit (IMU) technology to quantify the head movement of footballers while they participated in either a football passing task (Study 2) or 11v11 match-play (Study 3 and 4). Depending on the research question, IMU data were processed to obtain the number, frequency and/or excursion (i.e. size in degrees) of exploratory head movement events.

Study 2 investigated the relationship between exploratory action prior to receiving the ball and subsequent performatory action using a novel experimental design. By presenting task relevant information 360-degrees around the participants and requiring a football passing response, this study was able to investigate the relationship between exploratory head movement and passing response speed. Findings revealed that, when players were given 2-seconds or 3-seconds to explore before receiving the ball, they would explore with a lower frequency of head movements with the ball and were able to complete the passing response more quickly, compared to when they were given only 1-second to explore. Importantly, categorical linear regression revealed that when players explored with a higher frequency of head movements before receiving the ball, they were able to respond with a passing action more quickly.

Study 3 extended on Study 2 by investigating the relationships between exploratory action before receiving the ball and performance with the ball during 11v11 match-play. In addition, to understand when visual exploration is most important for performance, this study quantified the exploratory head movements of players in various time-periods before ball possession. When players explored with a higher frequency or with greater excursion than their individual average before ball possession, their performatory actions with the ball were more likely to be turns with the ball, a pass to an area that was opposite to where it was received, or a pass in an attacking direction. However, players were not more likely to play a successful pass following higher than average exploratory action. Additionally, the strength of these relationships changed according to the time-period before ball possession that was quantified. These findings showed that extensive visual exploratory action supports players' performance with the ball, such that they are better able to make use of their surrounding environment.

Study 4 represented the first study to investigate the constraining factors on players' visual exploratory actions during 11v11 match-play. Results showed that playing role, pitch position and phase of play all constrained the visual exploratory actions of players. Players explored most extensively when they had possession of the ball, and least extensively during transition phases of play. In contrast, however, there were no differences between team possession and opposition phases of play. Wide players explored more extensively during defensive phases of play (i.e. opposition ball possession), while central players explored more extensively during attacking phases of play (i.e. team ball possession). This deeper understanding of constraining factors on visual exploration can be used to inform the development of representative training designs in football.

Together, the findings supported the theoretical basis of the thesis, such that visual exploratory actions supported the discovery of afforded actions and prospective control of movement. Additionally, the findings provide some insight into the constraining factors on visual exploratory action in football. The findings have important implications for research methodology and applied practice. The novel use of wearable technology to quantify visual exploratory head movement throughout this thesis shows the value of these alternative methods for future investigations, particularly in the ability to quantify exploratory head movement in representative environments. Further, by developing the visual exploratory actions of players when they do not have the ball, coaches may see improvements in technical and tactical performance. While the novel methods used throughout this thesis have some limitations, the theoretical underpinnings, methodology and findings of this thesis provide a platform for future investigations of visual exploratory action in football and various other domains.

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List of Publications Incorporated into this Thesis

The below list outlines the published or under review studies that are incorporated into this thesis. The studies listed below are presented in full in Chapters 2, 5, 6 and 7 of this thesis. A statement of the contribution of authors is provided as Appendix 1, and evidence of publication or review is provided as Appendices 2 to 5.

i. **McGuckian, T. B.**, Cole, M. H., & Pepping, G.-J. (2018). A systematic review of the technology-based assessment of visual perception and exploration behaviour in association football. *Journal of Sports Sciences, 36*(8), 861-880. https://doi.org/10.1080/02640414.2017.1344780

ii. **McGuckian, T. B.**, Cole, M. H., Chalkley, D., Jordet, G., & Pepping, G.-J. (2019). Visual exploration when surrounded by affordances: Frequency of head movements is predictive of response speed. *Ecological Psychology, 31*(1), 30-48. https://doi.org/10.1080/10407413.2018.1495548

iii. **McGuckian, T. B.**, Cole, M. H., Jordet, G., Chalkley, D., & Pepping, G.-J. (2018). Don't turn blind! The relationship between exploration before ball possession and on-ball performance in association football. *Frontiers in Psychology, 9*(2520). https://doi.org/10.3389/fpsyg.2018.02520

iv. **McGuckian, T. B.**, Cole, M. H., Chalkley, D., Jordet, G., & Pepping, G.-J. (under review). Constraints on visual exploration of youth football players during 11v11 match-play: The influence of playing role, pitch position and phase of play. *Journal of Sports Sciences*

List of Conference Presentations

The below list outlines conference presentations at which the findings of this thesis were presented. Evidence of conference acceptance is provided as Appendices 6 to 9.

i. **McGuckian, T. B.**, Cole, M. H., Chalkley, D., Jordet, G., & Pepping, G.-J. Visual exploration in a lab-based football passing task. *Australasian Skill Acquisition Network Conference.* Brisbane, Australia, November 2017.

ii. **McGuckian, T. B.**, Chalkley, D., Shepherd, J., & Pepping, G.-J. Giving inertial sensor data context for communication in applied settings: An example of visual exploration in football. *12^{th} Conference of the International Sports Engineering Association.* Brisbane, Australia, March 2018.

iii. **McGuckian, T. B.**, Cole, M. H., Chalkley, D., Shepherd, J., Jordet, G., & Pepping, G.-J. How is scanning before ball possession related to performance with the ball? An investigation of football players' exploratory action. *23^{rd} Annual Congress of the European College of Sport Science.* Dublin, Ireland, July 2018.

iv. **McGuckian, T. B.**, Chalkley, D., & Pepping, G.-J. Positional differences in the visual exploratory actions of youth football players. *Australasian Skill Acquisition Network Conference.* Sydney, Australia, November 2018.

List of other Publications Related to this Thesis

The below list outlines other publications that were produced during the completion of this thesis, but do not form Chapters within the thesis.

i. **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.

ii. **McGuckian, T. B.**, Chalkley, D., Shepherd, J., & Pepping, G.-J. (2018). Giving inertial sensor data context for communication in applied settings: An example of visual exploration in football. *Proceedings*, *2*(6), 234-239. https://doi.org/10.3390/proceedings2060234

iii. Chalkley, D., Shepherd, J. B., **McGuckian, T. B.**, & Pepping, G. J. (2018). Development and validation of a sensor-based algorithm for detecting visual exploratory actions. *IEEE Sensors Letters*, *2*(2). https://doi.org/10.1109/LSENS.2018.2839703

iv. **McGuckian, T. B.** (2018, November 12). ISEA blog challenge winner - situation awareness wearable. Fédération Internationale de Football Association (*FIFA)*. Retrieved from https://football-technology.fifa.com/en/blog/isea-blog-challenge-winner/

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Navigation of Thesis

Visual exploratory action is pivotal for the perception of one's surrounding environment, particularly in fast-paced environments, such as football. Despite this, only a small body of literature has examined this behaviour. This thesis addresses this shortcoming with a systematic investigation of the visual exploratory action of youth football players.

Chapter 1 provides a general introduction to the thesis, including a description of the theoretical background of visual exploration, and the applicability and value of visual exploration in a football context.

Chapter 2 provides a systematic review of the extant literature which has used technology to investigate the visual exploratory action of football players. The intent of this chapter is to discover: i) what types of technology are used to investigate visual exploration in a football context, and ii) how the visual exploratory actions of footballers vary according to the task constraints, action requirements of the experimental task, and level of expertise of the athlete.

Chapter 3 provides a statement of problems and related aims of the experimental studies within this thesis.

Chapter 4 provides a description of the general methodology and design used throughout the experimental studies within this thesis, including recruitment, ethical considerations and quantification of visual exploration.

Chapter 5 examines the relationship between visual exploratory head movement and response time in a laboratory-based football passing task. In addition to investigating a performance outcome that is relevant for football (i.e. response time), this chapter forms the first use of inertial measurement units to quantify exploratory head movements of footballers in an environment that surrounds the participant with relevant environmental information.

Chapters 6 and 7 examine the exploratory head movements of youth football players in an 11v11 match setting. The intent of these chapters is to begin a systematic examination of visual exploration in 11v11 match-play, making use of inertial sensors to quantify the exploratory head movements of players. Chapter 6 investigates the relationships between visual exploratory head movement prior to ball possession and subsequent performance with the ball. Chapter 7 investigates how playing role, pitch position and phase of play constrain players' visual exploratory head movements.

Chapter 8 provides a general discussion of the thesis, including a summary of findings, an overview of the major contributions to theory, methodology and applied practice, research strengths and limitations, and an outline of future directions for this field of research.

Chapter 1: General Introduction

> *"… they aren't necessarily answers to the important questions, such as how people perceive what is going on around them so as to make good use of what the world offers"* - *(Gibson, 1997, p. 42)*

The above quote, provided by Eleanor J. Gibson, offers a simple introduction to the intent of this thesis. That is, the following thesis will explore, from an Ecological perspective, *how* football players perceive what is going on around them in order to make good use of what the game offers them. Here, *how* is used in comparison to *what* football players perceive. *What* a player perceives in the environment, for instance a teammate, is much more informative than the simple dimensions of the teammate or even the knowledge that they are a teammate. *What* a player perceives is determined by the relationship between the individual perceiver and the teammate being perceived, and it includes perception of a rich set of information. This information may include (but is certainly not limited to) the teammate's willingness to receive a pass, ability to enact a subsequent action, understanding of the team's strategy and previous performance within the game, as well as the perceiver's capability to make the pass to the teammate, position relative to the teammate, social status within the team and perception of pressure from the crowd. Clearly, *what* a player perceives is remarkably complex, and is unique for each player. *How* is used to refer to the actions used by players to give themselves the opportunity to perceive their environment, and all the environment offers, to make good use of the game's situation. Without understanding *how* players give themselves the opportunity to perceive their environment, attempts to improve a player's perceptual actions are likely to be misinformed.

The following account of the 2017 FA Cup Final serves as an applied example of the importance for players to perceive their surrounding environment. On 27th May, 2017, London-based rivals Arsenal Football Club and Chelsea Football Club competed in the 136th final of the FA Cup, the world's longest running football cup competition. In the 79th minute of the match, with the score locked at 1-1, Alexis Sánchez played a through ball to Olivier Giroud, who received the ball inside the right side of Chelsea's defensive 18-yard box. Gary Cahill closely marked Giroud, while David Luiz jogged back in support of Cahill. Giroud turned and played a first time cross, over Luiz's head, into the 6-yard box. At the same moment, Aaron Ramsey made a straight run from the top of the box, directly over the penalty spot, to meet the ball in the air, uncontested, and head the ball into the back of the Chelsea net. After seeing the ball fly into the net, Luiz flung his arms in disgrace, annoyed with himself for not being able to stop Ramsey. During the three seconds it took for the ball to travel from the foot of Sánchez, behind the Chelsea defence and onto the head of Ramsey, Luiz's body and head were solely oriented towards Giroud. Therefore, he was completely unaware that Ramsey was unmarked in the most dangerous position on the pitch. If Luiz had turned his head to perceive what was happening behind him, he may have been able to reposition himself to mark Ramsey and potentially stop the goal from being scored. In other words, he could have *made good use of what the world offered.* As it happened, Arsenal held onto their 2-1 lead for the remaining minutes of the game to be crowned FA Cup champions for the 13th time.

As will be discussed throughout this chapter, the primary means for football players to discover what is happening around them is through visual exploration. Theoretically grounded in James J. Gibson's Ecological approach to visual perception (Gibson, 1966, 1979), this thesis contends that visual exploration is vitally important for successful performance. Despite this, the visual exploratory actions of football players have been almost completely overlooked by academic literature, an oversight which this thesis aims to overcome.

Visual exploration is, however, well known about in applied football settings. More commonly known as scanning (Pulling, Kearney, Eldridge, & Dicks, 2018) or vision (Hughes et al., 2012), coaches understand that visual exploratory action is important for performance. Indeed, when considering key performance indicators of elite footballers, performance analysis experts rated vision as the most important tactical requirement for goalkeepers, central defenders, central midfielders, wide midfielders and strikers (Hughes et al., 2012). Further, organisation, anticipation, interception, passing and support play were all identified as important tactical and technical skills, all of which are strongly supported by visual exploratory action. When investigating the delivery of visual exploration training, Pulling et al. (2018) found that coaches with higher qualifications and more coaching experience were more likely to emphasise visual exploration in training by specifically focussing drills on the behaviour. This shows the importance of visual exploration from an applied perspective, and it demonstrates the need for research to support these beliefs with evidence-based findings.

Gary Neville, former England and Manchester United player, England Assistant Manager and television pundit, summed up the importance of visual exploration following a 3-3 draw between Arsenal and Liverpool on 23rd December, 2017.

"There's a quite simple rule, it's the one second rule. You cannot look at the ball or the man for more than one second… Ultimately, he just breaks that rule at the back post…. You've got to make sure you're swivelling your head back and forward… That rule, just making sure you're checking your position all the time. Simple rules, and young players do make those type of mistakes more than what an experienced player would" - (Neville, 2017)

Further evidence of the importance of visual exploration comes from two all-time Spanish greats. Winners of the 2010 FIFA World Cup, 2008 and 2012 UEFA European Championships, and multiple UEFA Champions League, La Liga and Copa del Rey trophies, Andres Iniesta and Xavi Hernández are considered to be two of the most creative footballers of the modern era. Products of the Barcelona academy, both Iniesta and Xavi can be considered integral components of the famous tiki-taka, a style of play characterised by maintenance of possession through high movement and pass-rate between players (Chassy, 2013). Speaking about receiving a pass, Andres Iniesta ensures he is aware of the options available to him.

"Before I receive the ball, I quickly look to see which players I can give it to. Always be aware of who is around you" - (Iniesta, 2018)

When speaking about the importance of finding space during a game, Xavi Hernández describes that constantly turning his head is how he finds solutions to problems.

"I spent my life searching for it, finding ways. Where is there space? How to make it happen? I was turning my head in all directions, I was nicknamed 'the girl from "The Exorcist"'. I do not turn my head to 360 degrees like her, but there are games where I have rotated mine more than 500 times… Turning my head helps me do it. And that's not only important, it's fundamental to master space-time. I think: My team-mate is man-marked, so I turn my head to look for another solution" - (Hernández, 2018)

Together, these accounts demonstrate how much players and coaches value the ability to visually perceive other players and space during a game. Common to each perspective is that movement of the head is an integral part of this visual perception process, as this allows the player to constantly be aware of their own position relative to other players, and it allows players to find available space and available teammates to pass to.

Grounded in the Ecological approach to visual perception, this thesis revolves around how footballers visually perceive their surrounding environment. Specifically, the thesis investigates the visual exploratory head movements that are used by footballers to discover opportunities to act in the 360-degree environment in which they perform. The remainder of the general introduction explains this theoretical perspective of visual perception. Following this, an explanation of visual perception in football is provided, including an overview of extant literature and the relevance of performance analysis in football.

1.1 Theoretical background: The Ecological approach to visual perception

When driving a car, the driver must prospectively (i.e. ahead of time) control their movements to change direction and accelerate or decelerate. To do so safely, the driver must be aware of their surrounding environment to avoid (or reduce the risk of) an accident. A prime example of this comes when changing lanes on a motorway. In this situation, the consequence of an accident with another vehicle could be fatal, and therefore the need to reduce the risk of an accident is paramount. Prior to changing lanes, the driver needs to perform various actions to safely complete the manoeuvre; indicate the lane change, adjust speed, and most importantly, ensure that it is safe to make the lane change. Checking the mirrors and checking the blind spots are both performed to allow the driver to discover if it is safe to perform the lane change or not. Commonly, the mirrors can be checked with only a small adjustment in eye orientation and therefore minimal head movement is required. The blind spot, however, requires head and possibly trunk movement to orient the head and eyes over the shoulder and bring the blind spot into the visual field. These movements of the eyes, head and body can be defined as visual exploratory actions, and the purpose of these movements is to allow the driver to visually perceive environmental information (Gibson, 1966, 1979; Reed, 1996).

Of note in the above example is that the driver needs to perceive their surroundings to perform the lane change action, but to perceive their environment they must act by moving their eyes, head, and/or body. Consequently, a dependent relationship is formed between perception and action; one must perceive in order to act, and one must act in order to perceive (Gibson, 1966, 1979). Further, the movement of the eyes, head and body system, and the movement required to perform the lane change, can both be described as actions; the former being exploratory actions, the latter being performatory action. Finally, whether the lane change is afforded to the driver depends on the relationships between the interacting constraints of the actor (i.e. the driver), the task (i.e. the lane change) and the environment in which the action is performed (i.e. the car on the motorway).

The above example neatly demonstrates several inter-dependent concepts which are instrumental to the Ecological approach to visual perception - perception and action, exploratory and performatory actions, affordances, the actor and environment, and constraints - each of which will be elaborated on to further explain the theoretical underpinning of this thesis. Informed by Ecological Psychology, another important aspect of understanding for this thesis is that of perception itself. Perception is the way in which an animal gains information from the environment, whether it be auditory, haptic, taste, smell or visual information (Gibson, 1966). There are two popular theories that attempt to explain how an animal perceives the environment. One theory is known as an indirect-perception view, in which the animal adds meaning to perceived stimuli internally by cognitively matching it with previously stored memories and representations (for review see Baddeley, 1999; Just & Carpenter, 1976; Neisser, 1967; Rayner, 1998). The theoretical basis of this thesis, however, is a direct-perception view, in which environmental objects and events have meaning inherently, without the need for internal processing (Gibson, 1966, 1979; Jones, 2003; Michaels & Carello, 1981). In this view, the environment is rich with information and perception actually *is* the detection of action relevant information in the environment (Michaels & Carello, 1981).

1.1.1 Perception and action

When preparing to cross a road, a pedestrian does not passively perceive the visual information needed to control locomotion across the road. Rather, the pedestrian will turn their head to look to the left and the right, thereby orienting their eyes in the appropriate direction to bring in necessary visual information about the environment. In this example (as with all movement), perception of the environment is required to inform the action of crossing the road. However, to perceive the relevant information, the pedestrian needs to act by turning their head. In this way, there is a mutual relationship between perception and action, termed perception-action coupling (Michaels & Carello, 1981), whereby either perception or action cannot be understood without the other. Perception informs action just as action allows perception.

While this relationship between perception and action holds true for a range of perceptual systems (Gibson, 1966), the focus of this thesis is on the relationship between *visual* perception and action. As in the example above, the pedestrian performs actions to perceive information about the environment. This movement of the eyes, head and body is termed *visual exploration* (Gibson, 1966, 1979; Reed, 1996), an active process which orients the visual receptors in a way that allows visual information to be perceived. Important in this concept is the idea that the eyes move within the head, the head moves upon the body, and the body moves within the environment. Hence, an understanding of visual perception cannot be understood solely based on movement of the eyes, it requires an understanding of the visual exploratory system. This is an issue that is explained further in Chapter 1.2.

1.1.2 Exploratory and performatory action

Movement "is of two general types, exploratory and performatory" (Gibson, 1966, p. 57). Exploratory movements aim to provide information to the actor via the perceptual systems (Adolph, Eppler, Marin, Weise, & Wechsler Clearfield, 2000; Adolph & Kretch, 2015). An infant human will manually explore toys through touch (Soska & Adolph, 2014; Soska, Adolph, & Johnson, 2010). A toddler will explore an unknown slope through swaying movement (Adolph, 1995). An adult will explore an obstacle by fixating it (Franchak & Adolph, 2010; Patla & Vickers, 1997, 2003). While each of these examples of exploration differ with age and the perceptual systems used, they all share the common goal of discovering information about the environment. The infant aims to discover the shape and texture of the toy, the toddler aims to discover the steepness of the slope, and the adult aims discover the height of the obstacle. In essence, if a human requires information about their environment, they will engage in exploratory action to discover the necessary information for performatory action.

Performatory action is movement which engages with the physical space of the environment (Adolph & Kretch, 2015; Reed, 1996). After exploring the toy, the infant may place it in their mouth. After exploring the slope, the toddler will walk or slide down. After exploring the obstacle, the adult will step on, over or around it. These performatory actions can be separated from exploratory actions as they are goal directed. Exploratory actions allow the discovery of information that guides goal-directed activity, whereas performatory actions are the goal-directed activities that aim to achieve a purpose based on the information gained from exploratory action.

In the case of a driver on a motorway, the driver needs to perform a lane change, but needs to discover if a lane change is possible in that moment through exploratory eye, head and body movement. In this way, the performatory action is prospectively regulated by the exploratory action (Adolph et al., 2000; Gibson, 1979). By checking the mirrors and blind spot before initiating the lane change, the driver can determine if they need to alter their speed before indicating the turn. By exploring before these actions, the movements are guided prospectively, enabling the driver to complete the lane change safely. Given that the exploratory actions help guide movement prospectively, there exists a coupling between exploratory and performatory actions. This coupling need not be thought of linearly, in fact the nature of the coupled relationship indicates that both exploratory and performatory actions occur simultaneously, whereby the exploration and performance support each other in a continuous perception-action loop (Gibson, 1979; Reed, 1982).

1.1.3 Affordances

As has been described, exploratory action prospectively guides performatory movement. The way in which this occurs is through the discovery of affordances that exploratory action provides. The noun, affordance, was first used in Gibson's early work (1966), but was further refined years later (Gibson, 1979). It is used to describe the opportunities for action that exist between an organism and its environment (Gibson, 1979), in a way that no other term was previously capable of. It describes the complementary relationship between actor and environment, such that defining an affordance is a description of an opportunity for action that exists for a particular person in a particular environment (Chemero, 2003; Fajen, 2007; Gibson, 1979; Jones, 2003; Rietveld & Kiverstein, 2014; Stoffregen, 2003; Turvey, 1992; Warren, 1984). While an afforded action can be identified with ease (for example, the kick-ability of a ball), the specifics of any affordance is complex, as the afforded action describes a mutuality between the individual and their environment.

Common examples of affordances include the reach-ability of an object (Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989; Pepping & Li, 2005), the sit-ability of a chair (Mark, Balliett, Craver, Douglas, & Fox, 1990; Stoffregen, Yang, & Bardy, 2005), the walk-ability of a doorway (Warren & Whang, 1987), or the climb-ability of a stair (Warren, 1984). These examples, however, may inadvertently de-emphasise the complexity of affordances as a concept. Gibson (1979) stressed that an affordance is not an object that exists in the environment, an affordance is not a physical item. Rather, an affordance exists between the environmental properties and the animal within that environment, such that if the person is removed from the environment, the possibilities for action that existed between that environment and the person are no longer afforded. Instead, new affordances would exist between the person and their new environment. Similarly, different affordances exist between a person and environment at different points in time. The cross-ability of a busy road changes from moment to moment, just as the walk-ability of an uneven surface changes as a person develops from infancy through to old age. Further, alternative affordances exist for different people in the same environment. While two people may occupy the same environmental space, afforded actions for the two people will be enabled or restricted based on a range of factors, known as constraints.

Whether or not an action is afforded to a person is also dependent upon that person's ability to perform the action; that is, the person's action capabilities (Fajen, 2007; Mark, Jiang, King, & Paasche, 1999; Rietveld & Kiverstein, 2014; van Andel, Cole, & Pepping, 2017; Warren, 1984). For a young child, handling a drinking glass that sits on the benchtop is not likely to be afforded, merely because the child is too short to reach the glass. Alternatively, for a typical adult, the glass does afford handling because they are tall enough to reach the benchtop. The child does not have the action capability to reach the glass, whereas the adult does. As a result, the relation between the actor (the adult, with ample action capabilities) and the environment (the glass on the benchtop) afford handling the glass. The ability to accurately perceive one's action capabilities (for example, ability to grasp a glass) is influenced by their ability to explore effectively (Mark et al., 1990, 1999), indicating a mutual relationship between exploratory action and action capabilities when perceiving affordances.

The relationships between action capabilities and afforded actions have been investigated in a range of areas (Barsingerhorn, Zaal, Smith, & Pepping, 2012; van Andel et al., 2017; Wilson, Dicks, Milligan, Poolton, & Alder, 2019). Warren (1984) found that stair-climbers' perception of maximal climbable stair height was scaled to their action capabilities, as determined by the ratio between stair height and leg length. This ratio, however, differs according to the population of interest; the ratio is lower for older adults (Konczak, Meeuwsen, & Cress, 1992) and higher for individuals with greater hip flexibility (Meeuwsen, 1991). Other physical capabilities, such as a person's body mass and leg power, influence whether landing or rolling is afforded when dropping from height (Croft & Bertram, 2017).

The perception of action capabilities has been shown to be influenced by internal states, such as fatigue and emotions. For example, fatigued climbers' perceptions of maximal reach height are less than during less fatigued states (Pijpers, Oudejans, & Bakker, 2007), and states of high anxiety have been shown to influence climbers' action capabilities (Pijpers, Oudejans, Bakker, & Beek, 2006). Similarly, states of high anxiety have been shown to influence action capabilities when judging if approaching balls were reachable or not (Bootsma, Bakker, Van Snippenberg, & Tdlohreg, 1992). Finally, psychological momentum has been shown to influence one's maximum afforded putting distance, such that positive psychological momentum led to participants perceiving a longer afforded putt (Den Hartigh, Van der Sluis, & Zaal, 2018)

In addition to the perception of one's own action capabilities (and consequently affordances), people are often required to perceive others' action capabilities and afforded actions (Araújo, Silva, & Ramos, 2014; Barsingerhorn et al., 2012; Mark, 2007; Richardson, Marsh, & Schmidt, 2010; Silva, Garganta, Araújo, Davids, & Aguiar, 2013). It is through the perception of others' affordances that teams of players are able to work synergistically to achieve performance outcomes. For example, when moving into space to receive a pass from a teammate, a player is required to correctly perceive their teammate's ability to complete the pass. If this perception of a teammate's action capabilities is incorrect, the pass is unlikely to be afforded to the player with the ball. The ability to perceive others' afforded actions has been shown in various settings, such as others' optimal sitting heights (Mark, 2007; Stoffregen, Gorday, Sheng, & Flynn, 1999), gap pass-ability (Mark, 2007), visually-guided reach-ability (Mark, 2007), interpersonal grasp-ability (Richardson, Marsh, & Baron, 2007a), and maximum standing-reach and jump and reach heights (Wagman, Thomas, & McBride, 2018; Weast, Shockley, & Riley, 2011). Weast et al. (2011) also compared the perception of others' affordances between experienced and inexperienced basketball players, finding that the experienced players were better able to accurately perceive maximum jump and reach heights of others than inexperienced players. This finding shows that playing experience allows individuals to be better attuned to the information that specifies sport-relevant (i.e. jump and reach for basketball players) affordances (Araújo, Hristovski, Seifert, Carvalho, & Davids, 2017; Cañal-Bruland, van der Kamp, & Gray, 2016; Fajen, Riley, & Turvey, 2009).

1.1.4 Actor and environment

When considering human behaviour, it is important to consider that the human is always situated within an environment. The environment provides context to the human, and therefore a mutual relationship exists between the actor and the environment (Adolph & Kretch, 2015; Gibson, 1979). If the environment is changed, the relationships that exist between the actor and environment also change (Chemero, 2003), and the behaviour of the actor can no longer be understood in the context of the original environment. Rather, the behaviour of the actor would now be determined by their relationship with the new environment, which may give rise to vastly different affordances than the previous actor- environment relation.

Commonly, the concept of affordances is described with simple and singular examples, such as the kicking afforded by a ball for a football player. While this helps to describe the concept, it is important to consider that the affordances offered to an actor in a certain environment go far beyond simple physicality of the environment and actor. Indeed, affordances are also determined by the sociocultural niche in which the actor resides (Gibson, 1979; Rietveld & Kiverstein, 2014; Schmidt, 2007). As a result, the affordances offered in a social context, such as that of a football match, are likely much more complex than the mere physical presence of a teammate offering an opportunity to pass to (Pepping, Heijmerikx, & De Poel, 2011). What is afforded by the teammate is also dependent upon the social interaction between the actor, the teammate and the surrounding environment, and these affordances can likely only be truly understood by the actor themselves in that moment.

1.1.5 Constraints

As has been discussed, movement for a particular task emerges from the interaction between an actor and their specific environment (Adolph & Kretch, 2015; Gibson, 1979). Therefore, the resulting movement is *constrained* by the actor, the environment and the task in which the movement aims to achieve (Newell, 1986). Following an ecological dynamics approach to movement (Araújo et al., 2006; Araujo, Davids, Chow, Passos, & Raab, 2009; Turvey & Shaw, 1999; Vilar, Araújo, Davids, & Button, 2012), these constraints interact such that the individual will self-organise, within the boundaries determined by the constraints, to achieve the movement task (Araújo, Davids, Bennett, Button, & Chapman, 2004; Davids, Araújo, & Shuttleworth, 2005; Fajen & Warren, 2003; Glazier, 2015; Kelso & Schöner, 1988).

Individual constraints (also termed organismic constraints) refer to an actor's personal characteristics, and are further classified as either functional or structural (Newell, 1986). Functional constraints, such as fatigue, emotional state, intention, motivation, etc. change relatively faster than structural constraints, which include factors such as body composition, height, genetic make-up, etc. (Balagué, Pol, Torrents, Ric, & Hristovski, 2019; Glazier & Robins, 2015; Newell, 1986). Closely related to individual constraints is an individual's action capabilities, as it is these individual constraints that inform an individual's ability to perform a task. If an actor has limited leg strength, their structural characteristics may constrain their action capability to ascend a staircase. Similarly, for a very fatigued weight lifter, their functional characteristics may constrain their action capability to perform a heavy snatch. Although not commonly introduced as such, individual constraints are often the focus of sport science research. Whether it be from an exercise physiology, strength and conditioning, psychological, biomechanical or developmental perspective, individual constraints are commonly, either directly or indirectly, the focus of the research question.

Environmental constraints are those that are external to the individual (Balagué et al., 2019; Glazier & Robins, 2015). Newell (1986) originally made the distinction between general (e.g. weather and ambient light) and task-specific (e.g. equipment and goals) environmental constraints, but later revised the definition to include all constraints that originate outside the individual (Newell & Jordan, 2007). These environmental constraints, however, are not limited to physical components of the environment such as cones, balls, rain or pitch surface. Sociocultural constraints, such as social expectations and values, refereeing decisions or social meaning, are also considered to be environmental constraints (Balagué et al., 2019; Rietveld & Kiverstein, 2014; Schmidt, 2007). Environmental constraints also change at varied timescales, for example, equipment laws and social values change relatively more slowly than referee decisions and ambient temperature (Balagué et al., 2019).

Task constraints refer to constraints that are directly related to the task to be performed, for instance the goal of the task, rules of the task, or instructions related to the task (Newell, 1986). Manipulation of task constraints is commonly realised through practice design, and therefore has attracted some attention in the coaching literature (Passos, Araújo, Davids, & Shuttleworth, 2008). For example, Timmerman, Farrow, & Savelsbergh (2017) manipulated the number of players and density of players in field hockey game design, and found that players completed more successful actions in games with less players involved (8 vs 11 players) and had more unsuccessful dribbles when the pitch density was increased (158m^2 vs 228m^2 per player). Similarly, a reduction in the number of players and playing area density in basketball resulted in an increase in number of technical actions (Klusemann, Pyne, Foster, & Drinkwater, 2012). An increased pitch density has also been shown to result in an increased frequency of visual exploratory actions with and without the ball in football (McGuckian et al., 2017). Also in football, manipulation of the number of touches allowed (i.e. a rule manipulation) resulted in a reduction in percentage of successful passes and an increase in number of possessions when players were restricted to one-touch passing compared to free play (Dellal et al., 2011a).

1.1.6 Implications for experimental design

The coupled relations between perception-action and actor-environment dictate that, in order to understand emergent afforded actions, the many constraints on these relationships must be considered (Gibson, 1979; Newell, 1986). Aligned with this thinking is the concept of representative design, which contends that psychological phenomena should be considered at the organism-environment level (Brunswik, 1956; Dhami, Hertwig, & Hoffrage, 2004). While traditional approaches to behavioural science have often neglected the pivotal relations between actor and environment (Dunwoody, 2006), the tenants of representative design have increasing influence on the study of sport movement and practice design (Araujo & Davids, 2009; Beek, Jacobs, Daffertshofer, & Huys, 2003; Dicks, Davids, & Araújo, 2008; Fajen et al., 2009; Newcombe, Roberts, Renshaw, & Davids, 2019; Pinder, Davids, Renshaw, & Araújo, 2011; van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008). In achieving representative design, researchers should endeavour to implement experimental designs in which the environmental and task constraints align with those found in the performance environment. That is, the experimental setting should represent the performance setting to be generalised to (Araújo, Davids, & Passos, 2007; Pinder et al., 2011).

The importance of representative design is highlighted by experimental findings that show differences in perceptual actions according to the experimental protocol being used. A meta-analysis of research investigating the eye-movements, response time and response accuracy of athletes showed that, while there were expertise differences, these differences were moderated by the research paradigm and the presentation of environmental information (Mann, Williams, Ward, & Janelle, 2007). In particular, the analysis showed that the largest expertise differences were found when the experimental setting was more representative of actual performance, such as when studies used field-based settings and required realistic task responses (Mann et al., 2007). Further support for the need of representative design comes from a study that specifically investigated the differences in eye-movements according to the presentation of information and requisite responses of football goalkeepers (Dicks, Button, & Davids, 2010). This study found that when goalkeepers were required to attempt to save a penalty kick, as opposed to using a joystick or verbally indicating their response, they would attend to different visual information of the penalty taker. That is, the goalkeeper's visual exploratory actions would differ depending on the performatory actions that were required by the task (Dicks et al., 2010). When the players were required to physically act, they would perceive the environment differently to when they were only required to perceive (Milner & Goodale, 1995; van der Kamp et al., 2008; Young, 2006), indicating the need to maintain natural perception-action and actor-environment couplings when investigating motor actions (Araújo et al., 2007; Dhami et al., 2004; Dicks et al., 2008; Fajen et al., 2009; Pinder et al., 2011).

Herein lies a challenge in the investigation of visual perception in a dynamic social context such as football. While it may be possible to measure what physical environmental information may be available to a footballer (actor) at any one point in time, it is not possible to quantify that player's relationship with the environmental information. It is also not possible to quantify that player's action capabilities at a given point, or their perceived social constraints at a given point. Similarly, this relationship with the environment will differ depending on the actions the player intends to complete. Therefore, rather than attempting to understand exactly *what* visual information the player perceives, as has been a common thread in previous investigations, gaining an understanding of *how* a player visually perceives their environment appears an appropriate method to understand their footballing actions. Further, to understand how a player perceives, the investigation should be representative of the environment in which the player naturally competes. Consequently, an investigation of players' visual exploratory actions within their natural environmental niche, may give an understanding of how football players perceive their affordances, and therefore an understanding of their goal-directed football performance.

1.2 Visual perception in football

The focus of this thesis is to examine the visual exploratory actions of football players. That is, how football players visually perceive their surrounding environment when playing. Therefore, following the description of the Ecological approach to visual perception in the previous section, it is apt to give a summary of visual perception as it relates to football. First, a general description of football is given to outline the characteristics of the game which combine to warrant this thesis. Second, a summary of performance analysis research in football is given. This summary outlines the *performatory action* component of performance in football and illustrates the need to consider the *exploratory actions* that support the outcomes considered to be important performance indicators. Finally, an introduction to visual perception as it specifically relates to a football context is given. Here, the requirement for visual exploration is explained in relation to the dynamic 360-degree environment in which football players compete.

1.2.1 General description of football

Association Football is an invasion team sport played by two teams of 11 players on an ~110m by ~75m pitch (International Football Association Board, 2017). The 22 players are free to move anywhere on the pitch, which results in highly dynamic movement between players as teams attempt to create numerical superiority to create goal scoring opportunities (Hewitt, Greenham, & Norton, 2016). Due to these complex interactions, the flow of play in football is unpredictable, which requires each player to have a constant understanding of the locations, roles and abilities of their teammates in order to successfully execute the team's strategy.

Football is a very low scoring game, with an average of only 2-3 goals scored per game (Castellano, Casamichana, & Lago, 2012; Kempe & Memmert, 2018). This speaks to both the extreme difficulty in being able to score a goal, and to the value of scoring (and equally, to stopping the opposition from scoring). It is therefore unsurprising that analyses of individual and team performance that may lead to scoring more goals, or conceding less goals, is a priority for football coaches and support staff across the world. Additionally, given the vast amounts of money involved in football worldwide (Deloitte, 2017, 2018) and the relative ease in which coaches are able to lose the backing of both supporters and board members (Audas, Dobsonb, & Goddard, 2002; de Dios Tena & Forrest, 2007; Flores, Forrest,

& Tena, 2012; Frick, Barros, & Prinz, 2010), any factor that can have an impact on the outcome of a game is open to scrutiny.

1.2.2 Performance in football

Previously, performatory actions were described as movement which engages with the physical space of the environment. While this explanation still holds from a theoretical perspective, performance in an applied sense can be described as a quantifiable action of an athlete which is somehow related to scoring a goal (Carling, Williams, & Reilly, 2005; Mackenzie & Cushion, 2013). For example, a successful pass to a teammate, a shot on goal, or a sprint (Dellal et al., 2011b; Liu et al., 2015; Rein, Raabe, & Memmert, 2017). This performance results from a range of complex interactions between technical, tactical and physical aspects of play within and between players (Brink, Kuyvenhoven, Toering, Jordet, & Frencken, 2018; Hughes et al., 2012; Liu et al., 2016; Lovell, Bocking, Fransen, Kempton, & Coutts, 2018; Sarmento et al., 2018a; Yiannakos & Armatas, 2006). In attempts to improve overall team performance (i.e. winning by scoring more goals), a vast amount of research investigating the technical, tactical and physical aspects of the game has emerged (Ávila-Moreno, Chirosa-Ríos, Ureña-Espá, Lozano-Jarque, & Ulloa-Díaz, 2018; Carling, Wright, Nelson, & Bradley, 2014; Lepschy, Wäsche, & Woll, 2018; Sarmento et al., 2018a, 2014).

There is a large body of literature investigating technical performance measures during football games (Carling, 2011; Coutinho et al., 2018; Dellal et al., 2012; Folgado, Bravo, Pereira, & Sampaio, 2019; Morgans, Adams, Mullen, McLellan, & Williams, 2014; Yi, Jia, Liu, & Ángel Gómez, 2018). Various studies have investigated the differences in technical actions between playing positions, finding there are position specific technical match demands (Brito, Roriz, Silva, Duarte, & Garganta, 2017; Dellal et al., 2012; Dellal, Wong, Moalla, & Chamari, 2010; Lovell et al., 2018; Yi et al., 2018). Other studies have shown that technical measures of performance are influenced by the opposition team's formation (Carling, 2011), the number of teammates and opponents (Torrents et al., 2016), and the pitch surface (Brito et al., 2017). Comparing differences between training games and 11v11 match-play, it appears that players have a lower percentage of ball possessions and successful passes, along with more duels, when playing in small-sided games (SSGs) than during match-play (Dellal et al., 2012). Technical measures of performance that have been shown to relate to successful match outcomes include total number of shots, shots on goal, number of crosses, and amount of ball possession (Lago-Peñas, Lago-Ballesteros, Dellal, & Gómez, 2010).

Various external measures of physical performance (i.e. activity profiles, time- motion analysis) have been investigated in a football setting. These investigations have focussed on variables related to distances covered in various velocity bands during both training games and 11v11 match-play (Carling, 2011; Dellal et al., 2012; Sarmento et al., 2018b). Similar to technical match demands, differences in physical demands have been found between playing positions (Bradley et al., 2009; Brito et al., 2017; Dellal et al., 2010; Di Salvo et al., 2010, 2007; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Lovell et al., 2018; Mohr, Krustrup, & Bangsbo, 2003; Wehbe, Hartwig, & Duncan, 2014).

Physical measures have been suggested to influence team performance outcomes (Wehbe et al., 2014), however, research findings are conflicting in this area. High intensity running has been related to match outcome in some studies, sometimes showing that more successful teams engage in less high intensity running (Di Salvo et al., 2009), while others show that more successful teams engage in more high intensity running (Rampinini et al., 2009). While these physical measures do not necessarily relate to scoring goals or winning matches, analyses of positioning variables have given rise to more tactical measures of performance through the use of positioning metrics.

Player tracking technologies have been used to quantify various tactical measures of performance. These measures include such variables as length per width ratio, team centroid, team stretch index, distance between teammate dyads, spatial exploration index, and player distance from centre of team (Baptista et al., 2018; Coutinho et al., 2019, 2018; Folgado et al., 2019; Folgado, Lemmink, Frencken, & Sampaio, 2014; Gonçalves et al., 2017b; Sampaio & Macas, 2012; Serra-Olivares, García López, & Gonçalves, 2019; Torrents et al., 2016). Together, these tactical measures of performance relate to team movement, and therefore speak more to the dynamics of football match-play rather than individual player metrics which are commonly reported with physical measures of performance. Other tactical analyses have shown that counter-attacks and fast attacks can lead to more successful offensive plays than positional attacks (Sarmento et al., 2018c), indicating the value of tactical measures of football match-play.

Each of the performance measures outlined above are likely influenced by players' visual perception of the environment, as the technical actions, physical actions, and tactical actions of players are outcomes of the player's perception of their football environment. For example, the passing action a player engages in could be determined by the perception of an open teammate; the high intensity running a player engages in could be determined by the perception of a counterattacking opportunity; and the tactical positioning between teammates could be determined by the perceived need to cover defensive areas. Therefore, to gain a deeper understanding of performance outcomes in football, a consideration of players' visual exploratory actions is needed. Thus far, very little attention has been given to football player's visual exploratory actions, a shortcoming that this thesis aims to address.

1.2.3 The enveloping football environment

Due to the dynamic and chaotic nature of football, it is typical that each player will be completely surrounded by task relevant information. Most obviously, this information could be in the form of teammates, opponents, the ball, (un)occupied space or the goals (Tedesqui & Orlick, 2014). As an example of the combined need for eye, head and body movement to adequately explore, Figure 1.1 depicts a typical football situation. Suppose Player A is about to receive a pass from Player B. It is likely that, with primarily eye movement, Player A can visually explore and perceive affordances offered by Player B, the ball (C) and possibly Player D. For Player A to effectively perceive what is afforded by Player E and Player F, however, they would need to explore with both eye and head movement, as without this movement the relevant information (Players E and F, and the space and opposition players surrounding them) would be outside the player's visual field. Further, it would be beneficial for Player A to gain information about the amount of pressure from the opposition Player G, as this may determine whether a pass to the free space (H) would be afforded or not. Again, exploratory head movement would be required in this situation, and it is also likely that trunk movement would support the larger head movement needed to bring Player G and the free space (H) into the visual field. With the above example in mind, it is clear that there is a need to understand the exploratory head movements that support performatory action in the enveloping football environment.

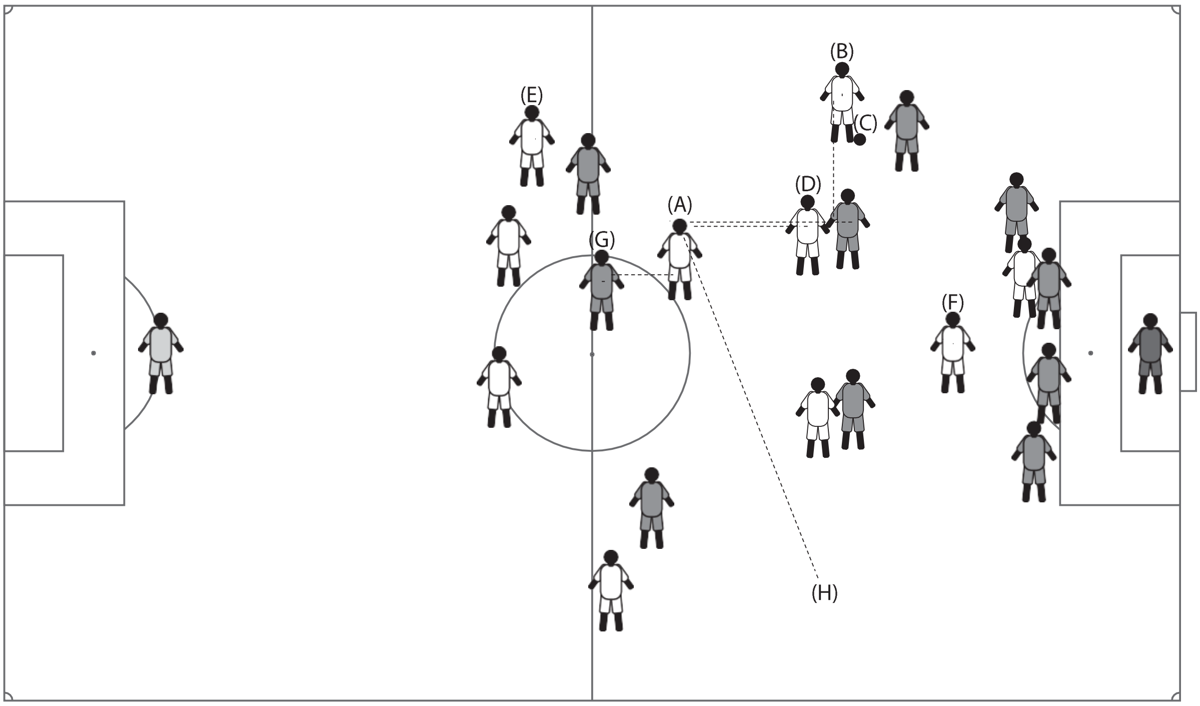

Figure 1.1 Schematic illustrating the requirement of exploratory eye, head and body movement to perceive potential affordances in 360-degrees. White team attacking from left to right.

The above example explains the need for visual exploration for a player about to receive possession of the ball. In this situation, exploratory head movement allows the perception of the entire 360-degree environment, which is used to prospectively control the player's actions with the ball. In one of the few investigations of visual exploratory head movement in football, Jordet, Bloomfield, and Heijmerikx (2013) found strong relationships between high frequency exploratory head movement before receiving a pass and subsequent performance with the ball. By reviewing match footage from 64 English Premier League games, the authors manually counted the exploratory actions of 118 players for a total of 1,279 possessions. Exploratory actions were quantified for the 10-seconds before players received a pass, and situations were only included for analysis when the player of interest was in a more advanced position than the teammate they received the pass from. Across all situations, players were more likely to complete a successful pass when they had a high exploratory frequency before receiving the ball (72.6% pass success) compared to when they had a low exploratory frequency (52.7% pass success), OR = 2.29, $p < .001$. This same relationship remained when players were located in either their defensive half or attacking half, and held true for both midfield players and strikers (Jordet et al., 2013).

In a separate study, Eldridge, Pulling, and Robins (2013) investigated the relationship between visual exploratory activity and performance among three youth football players. Data relating to the occurrence of exploratory action before possessions and performance with the ball were manually counted during 9v9 training games, resulting in a total of 247 individual possessions. When the players visually explored before receiving the ball, they were more likely to play a successful pass forward, play a pass into the attacking half, and turn with the ball compared to when they had not visually explored. Further, players also experienced less defensive pressure from opponents when they had visually explored before receiving the ball. The players in this study were very often able to maintain possession of the ball, regardless of preceding exploratory action, however it is important to find that players were more likely to make more attacking plays when they had visually explored prior to receiving the ball. Additionally, for players to have less defensive pressure when they receive the ball in situations when they had visually explored indicates further value in this behaviour, as it suggests that the exploratory action is not only useful for actions with the ball, but also for positioning on the pitch. In all likelihood, the visual exploration supports the player's prospective regulation of movement around the pitch, informing their movements into space in preparation for receiving a pass (Adolph et al., 2000; Gibson, 1979). While actions with the ball are important, this finding shows that exploratory actions are necessary throughout the entire game, as successful performance requires players to position themselves relative to other players to find time on the ball, make leading runs for teammates, apply defensive pressure, fill passing lanes, etc.

In addition to the above, there have been a number of unpublished Master's theses that have investigated the visual exploratory action of youth and senior footballers (Fagereng, 2010; Nyland, 2010; Pedersen, 2016; Spearritt, 2013). These studies have investigated both youth (Fagereng, 2010; Spearritt, 2013) and adult players (Nyland, 2010; Pedersen, 2016), and they generally find similar outcomes; extensive visual exploratory actions prior to ball possession support the prospective control of subsequent actions with the ball. This was evidenced by a higher likelihood of successful passes, forward passes and less defensive pressure when players explored more extensively prior to ball possessions. Novel findings showed that players explored more often immediately after teammates touch the ball, indicating that players explored when the movement of the ball was more predictable (Pedersen, 2016). Further, Nyland (2010) investigated defensive players' visual exploratory actions, and found that elite players explored more frequently than sub-elite players when defending a cross.

Based on the theoretical underpinnings and previous experimental findings, in environments that envelope an individual (such as football), one must utilise visual exploratory action to visually perceive the environment in 360-degrees. Doing so allows the individual to perceive a wider range of afforded actions, which enables prospective regulation of a wider range of action possibilities. In football, this translates to a player being able to use their surroundings more effectively, by achieving more successful passes, more forward passes, more turns with the ball and having more time with the ball (Eldridge et al., 2013; Jordet et al., 2013; Pedersen, 2016; Spearritt, 2013). Despite the value of these actions, to date there has been few in-depth investigations of the exploratory head movements of football players. There have been some research endeavours that have quantified the eye and head movements of baseball (Bahill & Laritz, 1984; Fogt & Zimmerman, 2014; Higuchi, Nagami, Nakata, & Kanosue, 2018) and cricket (Mann, Spratford, & Abernethy, 2013) batters leading up to a hit, however, this research has not translated across to sports which completely surround the athlete. Primarily, this is likely due to a limited capacity to quantify the exploratory head movement of football players in the fast-paced football environment. Therefore, there is a need to develop this area of research by employing novel data collection and analysis techniques that will allow a deeper understanding of the visual exploratory actions used by footballers during representative match-play. To best inform the experimental studies of this thesis, a systematic review of technologies that have been used to quantify the visual exploratory eye, head and body movements of footballers is presented next.

Chapter 2: A Systematic Review of the Technology-Based Assessment of Visual Perception and Exploration Behaviour in Association Football

Given the dynamic nature of football, various technologies may be useful to reliably and efficiently quantify the high-speed exploratory movements used by players throughout 11v11 match-play. To date, no research has systematically reviewed literature specifically relating to the use of technology to quantify visual exploratory actions of football players. Therefore, a review of literature is needed to inform future research in this area.

This study has been accepted for publication following peer review. The content has been reformatted for the purposes of this thesis. Author contributions are given in Appendix 1. Full reference details for this study are:

> McGuckian, T. B., Cole, M. H., & Pepping, G.-J. (2018). A systematic review of the technology-based assessment of visual perception and exploration behaviour in association football. *Journal of Sports Sciences, 36*(8), 861-880. https://doi.org/10.1080/02640414.2017.1344780

2.1 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.

2.2 Introduction

It is well accepted that effective visual perception is required for prospective control of movement and appropriate goal-directed actions (Gibson, 1979; Mann et al., 2007; van der Kamp et al., 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

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[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.

superior response accuracy and response times on perceptual-cognitive tasks (Abernethy, 1990a; Helsen & Starkes, 1999; Mann et al., 2007; Wright, Gomez-Meza, & Pleasants, 1990). Additionally, this research has shown that expert performers generally utilise different perceptual behaviours than their less skilled counterparts; expert performers will 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). 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, 2018), 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 et al., 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 et al., 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, & Philippaerts (2007), 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 et al., 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 (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 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, 2018). 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.

2.3 Methods

2.3.1 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 the supplementary material.

2.3.2 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 2.1.

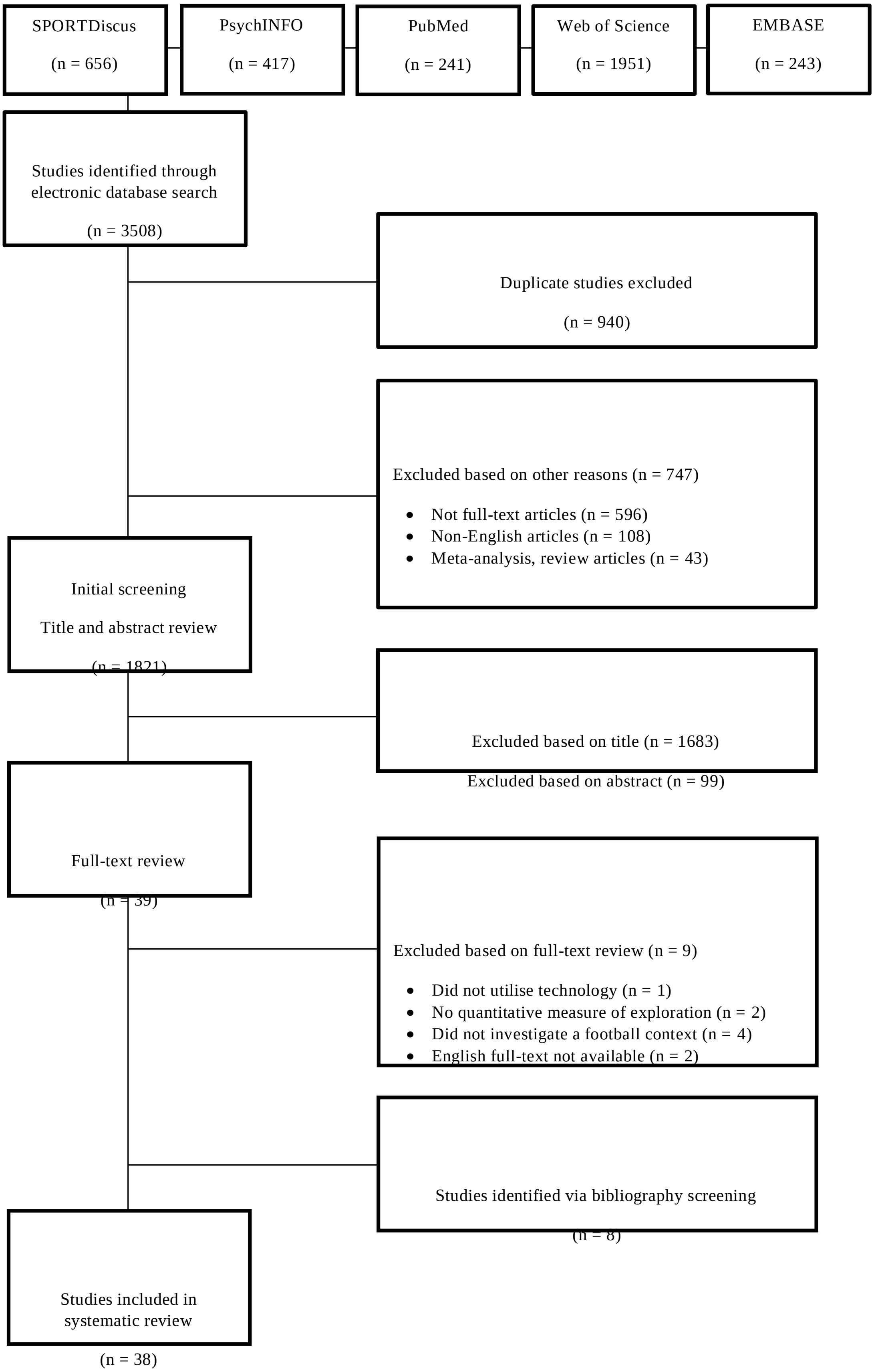

Figure 2.1 PRISMA flow diagram outlining the implementation of the systematic search strategy and review process.

2.3.3 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 the supplementary material.

2.3.4 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 2.1 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 of the task, 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.

Table 2.1 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., 2009a; 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 & Thullier, 2009; Binsch et al., 2010a; Binsch et al., 2010b; Horn et al., 2002; Kim & Lee, 2006; Nagano et al., 2006; Noel & van der Kamp, 2012; Piras & Vickers, 2011; Poulter et al., 2005; Vater et al., 2016)
	When the eye remains in a stationary position for a period equal to or greater than 116.67ms	(Vaeyens et al., 2007a; Vaeyens et al., 2007b)
	When the eye remains in a stationary position for a period equal to or greater than 120ms	(Bakker et al., 2006a; Button et al., 2011; Dicks et al., 2010; Mann et al., 2009; North et al., 2009; Roca et al., 2011, 2013; Savelsbergh et al., 2006a; Savelsbergh et al., 2005; Savelsbergh et al., 2002; Timmis et al., 2014; Williams & Davids, 1997a, 1998; Williams et al., 1994; Wood & Wilson, 2010; Wood & Wilson, 2011)
	When the eye remains in a stationary position for a period equal to or greater than 140ms	(Helsen & Starkes, 1999)
	The period between the end of one saccade and the onset of the next saccade	(Krzepota, Stepinski, & Zwierko, 2016b)
Mean number of fixations	The average number of fixations for each condition	(Bertrand & Thullier, 2009; Button et al., 2011; Canal-Bruland et al., 2011; Dicks et al., 2010; Helsen & Starkes, 1999; Horn et al., 2002; Krzepota et al., 2016b; Roca et al., 2011, 2013; Savelsbergh et al., 2006a; Savelsbergh et al., 2005; Savelsbergh et al., 2002; Vaeyens et al., 2007a; Vaeyens et al., 2007b; Vater et al., 2016; Williams & Davids, 1997a, 1998; Williams et al., 1994; Wood & 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., 2009a)
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., 2010a; 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 & Thullier, 2009; Bishop et al., 2014; Button et al., 2011; Canal-Bruland et al., 2011; Dicks et al., 2010; Helsen & Starkes, 1999; Horn et al., 2002; Kim & Lee, 2006; Krzepota et al., 2016b; Mann et al., 2009; North et al., 2009; Roca et

		al., 2011, 2013; Savelsbergh et al., 2006a; Savelsbergh et al., 2005; Savelsbergh et al., 2002; Vaeyens et al., 2007a; Vaeyens et al., 2007b; Vater et al., 2016; Williams & Davids, 1998; Williams et al., 1994; Woolley et al., 2015)
Fixation time rate	The rate of total fixation time relative to total performance time	(Kim & Lee, 2006)
Mean fixation duration per location	The average duration (ms) of fixations according to each categorised area of the display	(Bertrand & Thullier, 2009; Nagano et al., 2006; Piras & Vickers, 2011)
Relative fixation duration per location	Not defined	(Piras & 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., 2010a; Wilson et al., 2009a)
First fixation mean duration	The average duration of the first ocular fixation on each categorised areas of the display	(Bertrand & Thullier, 2009)
Initial fixation duration	The duration of the initial fixation on a categorised area of the display	(Binsch et al., 2010b)
Final fixation duration	The average duration of the final fixation on a categorised area of the display	(Binsch et al., 2010b; Wood & 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., 2016b; North et al., 2009; Roca et al., 2011, 2013; Savelsbergh et al., 2005; Savelsbergh et al., 2002; Vater et al., 2016)
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 & Starkes, 1999; Kim & Lee, 2006; Mann et al., 2009)
First fixation location	The location of the first ocular fixation on the display	(Bakker et al., 2006a; Bertrand & Thullier, 2009)
Final fixation location	The location of the final fixation, represented as the mean distance (cm) from the centre of the goal	(Wood & Wilson, 2010)
Final fixation location	The location of the final fixation according to the categorised areas of the display	(Woolley et al., 2015)
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., 2016b; Noel & van der Kamp, 2012; North et al., 2009; Roca et al., 2011, 2013; Savelsbergh et al., 2010; Savelsbergh et al., 2006a; Savelsbergh et al., 2005; Savelsbergh et al., 2002; Timmis et al., 2014; Vaeyens et al., 2007a; Vaeyens et al., 2007b; van der Kamp, 2011; Vater et al., 2016; Williams & Davids, 1997a, 1998; Williams et al., 1994; 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., 2010b)
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., 2010b)
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., 2007a; Vaeyens et al., 2007b; Williams & Davids, 1997a, 1998; Williams et al., 1994)
Fixation transition	The ocular displacement between two fixations	(Bertrand & 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 & 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 & 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., 2009a)
Interfixation distance	The distance between subsequent fixations, calculated in degrees of visual angle	(Vaeyens et al., 2007a; Vaeyens et al., 2007b)
Interfixation duration	The time between the end of one fixation and the start of the next fixation	(Vaeyens et al., 2007a; Vaeyens et al., 2007b)
Interfixation rate	Represents the tempo of successive fixations. Calculated by dividing the interfixation distance by the interfixation duration.	(Vaeyens et al., 2007a; Vaeyens et al., 2007b)
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 & Vickers, 2011)
Mean quiet eye duration	The average duration of the quiet eye period	(Nagano et al., 2006; Piras & Vickers, 2011)
Quiet eye duration - prior to run-up	**Quiet eye location – prior to run-up**	The duration of the last fixation prior to the initiation of the penalty kick run-up
Quiet eye duration – final ball fixation		The duration of the last fixation

on the ball during the execution phase of the kick	(Wood & Wilson, 2011) (Wood & Wilson, 2011) (Wood & Wilson, 2011)	
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		
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)

*Note. 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)

2.4 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 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.

2.4.1 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.

2.4.2 Research paradigm

2.4.2.1 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 2.2). 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.

2.4.2.2 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 2.2).

Table 2.2 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.

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
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.
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	Mean no. fixations, mean fixation	Controlled lab Controlled in-situ	VSV (verbally identify direction	1v1 penalty defence	Performance in ISM and ISI better than in VSV, VSM and

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
		Mobile-Eye)	duration, mean no. fixation locations, % viewing time at fixation locations (10 areas)		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)		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	Eye-Movement Registration (SensoMotoric	Mean no. fixations, mean fixation duration, mean no.	Controlled lab	No response required	1v1 defensive situations	No difference in number of fixations or fixation duration between three groups.

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
	(23.5 ± 4.1) Non-Players = 8/8 (23.2 ± 4.0)	Instruments ETG 2w)	fixation locations (7 areas), % fixation duration per location				Experienced group fixated fewer areas and fixated more towards the ball/foot area than non-player group.
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	Controlled lab	Place marker on schematic board to anticipate destination of ball. Press button to indicate if clip is	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

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
			duration per location (5 areas), fixation transitions (3 categories)		recognised or not.		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.
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	19/19 (22.2 ± 3.0)	Eye-Movement	Mean no. fixations,	Open lab	Physically move to	4v4 offensive	High score group had longer

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Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
al. (2006)		Registration (ASL 4000SU)	mean fixation duration, % viewing time per location (8 areas)		the expected destination of the pass	situation	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	% no. fixations and % viewing time per	Controlled in-situ	Physically kick soccer ball to goal	1v1 penalty kick	Players fixated the GK more often when executing a power

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
		(SensoMotoric Instruments iViewETG)	location (4 areas)		according to condition		kick and the edges of the goal more often when executing a placement kick. Ball fixated for the longest for both types of kick.
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.

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
Vater et al. (2016)	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.
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),	Open lab	Experiment 1A: Physically move left, right, forward, or backward to simulate intercepting pass	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

Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
			fixation order Experiment 1B: Mean no. fixations, mean fixation duration, % viewing time per location (3 areas), fixation order		Experiment 1B: Physically move left or right to anticipate tackling the opponent		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	Eye-Movement Registration (ASL	Mean no. fixations, mean fixation	Open lab	Physically move arm to indicate	1v1 penalty defence	GKs had fewer fixations of longer duration, longer QE

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Article	Experimental Groups n/N* (Mean Age ± SD)	Technology Used (Model)	Outcome Measures	Experimental Setting	Action Requirements	Microstate of Play	Findings
	(21.2 ± 2.1) Control = 20/20 (20.5 ± 2.1)	Mobile Eye XG)	duration, no. changes in fixation location, QE duration, QE location, % viewing time per location (9 areas)		anticipated direction of kick		duration and fewer changes in fixation location than controls. GKs QE location predominantly on stance foot of kicker and the ball.

*Note. 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).

2.4.3 Visual perception and exploration behaviours in football

2.4.3.1 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).

2.4.3.2 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, 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.

2.4.3.3 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 2.3), 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 2.3), 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.

Table 2.3 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 & Thullier, 2009)[*] (Williams & 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 & Davids, 1997)[*] (Williams & Davids, 1998)[*]	(Savelsbergh et al., 2006)[^]	(Vaeyens et al., 2007b)[#]	(Canal-Bruland et al., 2011)[#a]	(Williams & 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 & Starkes, 1999)[+]
Fixation Duration							
Shorter fixation duration for experienced, experts, more skilled or successful performance		(Bertrand & Thullier, 2009)[*] (Williams & 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 & Davids, 1998)[*]		(Vaeyens et al., 2007a)[^] (Vaeyens et al., 2007b)[#]	(Canal-Bruland et al., 2011)[#a]	(Helsen & 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[+], Compared to less skilled[a], Compared to controls[b], Compared to field players[c]

Many studies analysed the location of fixations used by participants; however, there was little consistency in the way fixation locations were created between studies. 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.

2.4.4 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 2.1). 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.

2.5 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 (no studies utilised an open in-situ setting). All of these studies investigated microstates of play with a very limited number of players, namely 1v1 situations. While 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 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, & Robins (2013) and Jordet, Bloomfield, & 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 an apparent 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 2.1). 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 2.2). 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), 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 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.

2.6 Supplementary material

Supp. 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 and 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, Sheppard and Campbell (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, 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: 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

Supp. 2 CCAT scores for individual categories, overall score and quality rating of each paper included in the systematic review.

Article	Preliminaries	Introduction	Design	Sampling	Data collection	Ethical matters	Results	Discussion	Total	Total (%)	Reporting Quality
Abellan et al. (2016)	1	2	0	2	2	2	1	1	11	27.5	Low
Bakker et al. (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 et al. (2010a)	4	4	5	1	4	3	3	5	29	72.5	High
Binsch et al. (2010b)	4	4	3	1	4	3	4	3	26	65	High
Bishop et al. (2014)	4	5	3	2	5	2	4	4	29	72.5	High
Button et al. (2011)	4	5	4	2	4	2	4	3	28	70	High
Canal-Bruland et al. (2011)	1	3	2	1	1	2	2	2	14	35	Low
Dicks et al. (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 et al. (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 et al. (2016)	3	3	2	2	3	5	2	2	22	55	Moderate
Mann et al. (2009)	4	4	4	1	4	1	3	4	25	62.5	High
Nagano et al. (2004)	2	1	1	1	2	0	2	1	10	25	Low
Nagano et al. (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 et al. (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 et al. (2005)	3	4	3	1	2	3	2	3	21	52.5	Moderate
Roca et al. (2011)	5	5	4	2	4	4	4	4	32	80	Very high
Roca et al. (2013)	5	4	4	2	4	4	4	3	30	75	High

Article	Preliminaries	Introduction	Design	Sampling	Data collection	Ethical matters	Results	Discussion	Total	Total (%)	Reporting Quality
Savelsbergh et al. (2010)	3	3	3	1	4	3	2	2	21	52.5	Moderate
Savelsbergh et al. (2006)	4	4	4	1	4	3	3	2	25	62.5	High
Savelsbergh et al. (2005)	3	4	3	1	3	2	2	4	22	55	Moderate
Savelsbergh et al. (2002)	4	5	4	1	3	2	3	4	26	65	High
Timmis et al. (2014)	5	5	3	1	4	4	4	5	31	77.5	High
Vaeyens et al. (2007a)	4	5	4	2	4	4	4	4	31	77.5	High
Vaeyens et al. (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 et al. (2016)	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 et al. (1994)	3	4	3	1	3	2	3	4	23	57.5	Moderate
Wilson et al. (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 et al. (2015)	4	5	4	4	4	3	4	4	32	80	Very high

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Chapter 3: Statement of Problems and Research Aims

While there has been some research interest in the exploratory eye or head movements of footballers, the current body of literature is confined to a small number of studies which consider the representativeness of the research setting. To advance this field of research, a systematic approach to the development and implementation of methods that can capture exploratory actions in representative environments is needed. The statement of problems and research aims outlined below are pertinent to this development of visual exploratory action research in football.

3.1.1 Exploratory action when surrounded by affordances

The systematic review of literature presented in Chapter 2 identified that no research has utilised technology to quantify exploratory head movement of football players. Further, the review identified that research typically presents information in front of participants, removing the need for exploratory head movements that naturally occur during match-play, and often does not require a representative performatory response. Therefore, research overcoming these design restrictions is warranted to better understand the exploratory head movement of football players.

Aim 1: To understand how teammate location and time constraints influence visual exploratory head movement and the speed of a football specific performatory response.

Aim 2: To understand the relationship between visual exploratory head movement and the speed of a football specific performatory response.

3.1.2 Exploratory action and performance in 11v11 football match-play

While a small amount of research has investigated the relationships between exploratory head movement and performance in football match-play (Eldridge et al., 2013; Jordet et al., 2013), this research is based on manual quantification of head movements, which is time-consuming and prone to subjective error. Further, exploration has been quantified in relatively large time-periods before ball possession, however, in a dynamic football environment it is likely that exploratory head movement closer to ball possession would be more closely related to the performatory actions used. Therefore, an understanding of the relationships between exploration in various time-periods before possession and performance with the ball is needed.

Aim 1: To understand the relationships between visual exploratory head movement and performatory actions with the ball during 11v11 football match-play.

Aim 2: To understand how the relationships between visual exploratory head movement and performatory actions change according to the time- period before possession that is investigated.

3.1.3 Exploratory action and constraints in 11v11 football match-play

Each playing role requires different performatory actions to maximise performance. Similarly, it is likely that some playing roles require different exploratory activity to others, however, any differences between playing roles are currently unknown. Additionally, as players move around the pitch during a game, the availability of information changes. As a result, it is likely that some areas of the pitch require different exploratory actions to perceive afforded actions, however, any differences between pitch positions are currently unknown. Finally, task constraints as a result of phases of play (i.e. individual possession, team possession, opposition possession, transition) are likely to influence visual exploration, however any relationships are currently are unknown.

Aim 1: To understand how playing role constrains visual exploratory head movements in 11v11 football match-play.

Aim 2: To understand how pitch position constrains visual exploratory head movements in 11v11 football match-play.

Aim 3: To understand how phase of play constrains visual exploratory head movements in 11v11 football match-play.

Chapter 4: General Methodology and Design

Chapters 5, 6 and 7 contain the methods of each study in their published form, as per the guidelines provided by their respective journals. As per University guidelines, general methods and design of the studies within this thesis are described below. Including the systematic review of literature presented in Chapter 2, this thesis is comprised of four independent but related studies. General methodology relating to recruitment and ethical considerations for the three experimental studies are described first. Each study builds on the preceding study with respect to the complexity of the question, design, methods and analyses, so as to develop a rigorous schedule of research. Given the need for the use of technology to quantify visual exploratory movement, an overview of current technology is given. This overview outlines eye-movement registration technologies and the limitations of this technology, and then proposes the use of alternative methods to quantify visual exploratory actions of players in-situ. New analysis methods and visual exploratory action variables were progressively developed with each study, with some variables used in multiple studies. Justification for the use of these analysis methods and variables are described in full within this chapter.

4.1 Recruitment

Recruitment for Chapters 5, 6 and 7 began with discussions with coaches and technical directors from local National Premier League Queensland football clubs. These discussions confirmed the need for research to understand the visual exploratory actions of football players, and coaches expressed their own ideas about the relevance of the actions of interest. Potential benefits of being involved with the research were discussed with the clubs and requirements for both parties were agreed upon.

Team meetings were held with potential participants, during which an outline of the research was discussed. Potential participants were given the opportunity to ask questions about the research. For Chapter 5, participants were contacted via email to schedule a date to complete testing at the Australian Catholic University, Brisbane campus. For Chapters 6 and 7, data were collected during regular training times for each club.

4.2 Ethical considerations

All research conducted within this thesis was granted ethical approval by the Australian Catholic University's Human Ethics Review Board. The three studies involving human participants were conducted according to the ethical approval granted under ethics register numbers 2016-230E (Appendix 10) and 2017-154H (Appendix 11). The ethics approval granted under ethics register number 2016-230E was subsequently modified and approved to include a wider age range of participants and to carry-out testing procedures on an outdoor football pitch (Appendix 12).

The participation requirements and potential benefits of the research were verbally presented to potential participants, and participants were given the opportunity to ask any questions relating to the research and data collection procedures. Potential participants were presented with an information letter (Appendix 13, 14 and 15) according to their age. The information letter described the background, risks and procedures involved with the research, and detailed contact information of the Ethics Manager in case of any complaints or concerns. Potential participants were informed verbally and in writing that participation in the research was completely voluntary, that they would not receive negative consequences of any kind for not participating, and that they could withdraw their participation at any time. Potential participants who wished to take part in the studies signed a consent form, while any participant under the age of 18 signed an assent form and had a parent/guardian sign a consent form (Appendices 16 to 19).

4.3 Quantification of visual exploration

Due to the complexity of visual exploratory action, it is necessary to take advantage of technology to 1) streamline the process of collecting such data, and 2) ensure the consistency and accuracy of any data being collected. Given the propensity of eye-movement registration technology, a technical outline of the technology is needed. This technology, however, has several theoretical and applied limitations which influence the methodological decisions made within this thesis. Given these limitations, microelectromechanical systems (MEMS) inertial measurement units (IMUs) are outlined as an alternative method of quantifying the visual exploratory actions of football players. This section justifies the use of inertial measurement units to quantify visual exploratory action throughout the studies within this thesis.

4.3.1 Outline of eye-movement registration technology

Eye movement registration technology has been used in lab-based sport-related research since 1976, with a rise in the number of studies utilising this technology in field- based situations occurring in the mid-1980s (Kredel, Vater, Klostermann, & Hossner, 2017). Apart from football, the technology has been used across a wide range of sports, including but not limited to basketball (Bard & Fleury, 1976; Gorman, Abernethy, & Farrow, 2015; van Maarseveen, Savelsbergh, & Oudejans, 2018), boxing (Ripoll, Kerlirzin, Stein, & Reine, 1995), fencing (Hagemann, Schorer, Cañal-Bruland, Lotz, & Strauss, 2010), golf (Vickers, 1992), horse riding (Hall, Varley, Kay, & Crundall, 2014), karate (Milazzo, Farrow, Ruffault, & Fournier, 2016; Williams & Elliott, 1999), sailing (Manzanares et al., 2015), squash (Abernethy, 1990b), tennis (Goulet, Bard, & Fleury, 1989; Murray & Hunfalvay, 2017), and volleyball (Afonso, Garganta, McRobert, Williams, & Mesquita, 2014).

There are three types of eye-movement registration devices that have been used in sport research; desk-mounted eye-trackers, remote eye-trackers and head-mounted eye- trackers (Discombe & Cotterill, 2015; Holmqvist et al., 2011). A desk-mounted eye-tracker is mounted on a table in a laboratory, and the participant is restrained to limit any movement of the head. This method leads to the most accurate eye-movement data, however, at the cost of putting the participant in an unnatural position without the ability to move the rest of the visual exploratory system. A remote eye-tracker is also desk-mounted, however, these devices do not require head restraint and therefore allow participants to sit in a more natural position. Head-mounted eye-trackers allow more free movement by the participant, as the entire device is mounted to a helmet or housed within a set of glasses. Given their portability and ability to present information in more varied ways, head-mounted eye-trackers are preferred in sport research domains.

Head-mounted eye-movement registration technology tracks the movement of the wearer's pupils and combines this information with video footage taken from the perspective of the wearer via an integrated head-mounted video camera (Discombe & Cotterill, 2015; Holmqvist et al., 2011). More recent versions of this technology allow the pupil and video information to be processed semi-automatically, allowing extraction of variables related to the movement of the eyes and the direction of gaze of the wearer. Despite the automation of gaze detection, mobile head-mounted devices still require calibration to determine the point of gaze relative to the head-mounted video footage. This calibration involves mapping eye- movements to known areas of the video display (Kredel et al., 2017). To ensure accuracy, the calibration procedure commonly needs to be repeated several times throughout a data collection session, as increased movement of the participant results in greater artefacts in the data.

4.3.2 Limitations of eye-movement registration technology

Eye-movement registration systems have given researchers the tools to investigate the role of the eye in visual perception, which has provided a wealth of knowledge to the area. However, the nature of this technology significantly limits the practicality of its use in certain settings, particularly representative sport settings. Consequently, research utilising eye-movement registration has primarily relied on laboratory-based experimental designs, which limit both the generalisability to applied settings and the scope of the experimental investigation (Brunswik, 1956; Dhami et al., 2004; Dicks et al., 2009; Kredel et al., 2017).

Despite advances in eye-movement registration systems, which no longer require participants to keep their head completely still (as with desk-mounted systems), the representativeness of research designs in certain settings is still limited due to eye-movement registration systems. Mobile systems are limited in their ability to reliably track eye-movements in situations with high amount of natural light (Discombe & Cotterill, 2015; Kredel et al., 2017). With high amounts of natural light, the wearer's pupils will contract significantly, making the target of the eye-tracking much smaller and difficult to track for the system. Further, bright light may interfere with the quality of video footage capture by mobile eye-trackers, which also leads to a loss of data. As a consequence, research has typically investigated the eye-movements of footballers indoors, in situations that do not put the participant or equipment at risk of damage (Discombe & Cotterill, 2015; Kredel et al., 2017). Generally, this results in the use of either frontal projection, in which participants are required to respond to video projections presented directly ahead (Savelsbergh, Haans, Kooijman, & van Kampen, 2010; Savelsbergh et al., 2006; Vater, Roca, & Williams, 2016; Williams & Davids, 1998), or penalty kick situations, in which the task (Binsch, Oudejans, Bakker, Hoozemans, & Savelsbergh, 2010a; Binsch, Oudejans, Bakker, & Savelsbergh, 2010b) or environment (Bakker, Oudejans, Binsch, & van der Kamp, 2006; van der Kamp, 2011; Wood & Wilson, 2011) are modified such that findings may no longer be generalisable to outdoor football situations (Brunswik, 1956; Dicks et al., 2009).

From a practical perspective, mobile eye-trackers may not be safe to use in some applied settings (Discombe & Cotterill, 2015). For example, having players wear mobile eye-trackers while playing in sports such as football (any code), basketball, netball or combat sports presents a major safety concern. In addition to any safety concerns, the financial cost of eye-trackers further limits their applicability in many applied settings, due to the risk of damaging the hardware. Finally, practitioners wishing to implement eye-tracking technology in applied settings must be willing to commit many hours of time for the collection, analysis and interpretation of eye-movement data. While modern systems can automate some aspects of the analysis process, ensuring accurate data output requires some visual inspection by the practitioner themselves. Together, the injury risk, financial cost and time commitment required for analysis make eye-movement registration in applied settings impractical.

Of greater concern than the above limitations of eye-movement registration systems are the interpretation of eye-movement data and potential implications of these interpretations. Many eye-movement studies focus on variables such as duration of fixations and fixation location (Mann et al., 2007; McGuckian, Cole, & Pepping, 2018c). These variables are derived based on the area of the display which the pupil is focussed upon, and therefore are a measure of central vision (Discombe & Cotterill, 2015; Holmqvist et al., 2011; Ryu, Abernethy, Mann, Poolton, & Gorman, 2013; Vater, Kredel, & Hossner, 2017). Interpretations based on these variables assume that the information contained in central vision is also the focus of the participant’s attention (Moran, Campbell, & Ranieri, 2018; Williams & Ericsson, 2005). This assumption, however, ignores the value of information contained within peripheral vision, which is used to guide performance in various situations and across various skills (Alfano & Michel, 1990; Ando, Kida, & Oda, 2001; Bardy & Laurent, 1989; Eves’, Corban, & Challis, 2000; Lemmink, Dijkstra, & Visscher, 2005; Pesce, Cereatti, Casella, Baldari, & Capranica, 2007a; Pesce, Tessitore, Casella, Pirritano, &

Capranica, 2007b; Ryu et al., 2013; Vater, Klostermann, Kredel, & Hossner, 2019a; Vater, Williams, & Hossner, 2019b; Williams & Davids, 1998). Given that peripheral vision is particularly important for movement (Alfano & Michel, 1990) and postural control (Bardy, Warren, & Kay, 1999), it is unsurprising that information within peripheral vision would be useful to athletes competing in environments requiring constant movement. By solely investigating central vision of athletes, researchers are assuming that information perceived by non-central vision does not inform the athlete in a functional manner, an assumption that does not stand up to theoretical or experimental scrutiny (Vater et al., 2019a, 2017).

Further, by assuming that only central vision is important for athletes' perceptual-cognitive skill, eye-movement research may have inadvertently led people to believe that it is *only* the areas in which central vision is fixated that are important for sport performance (Abernethy & Russell, 1987). Given that expert athletes make use of peripheral vision to guide their actions (Pesce et al., 2007a, 2007b), solely focussing on central vision risks ignoring important perceptual information. The assumption that areas fixated by central vision are the only important areas for performance is at the core of eye-movement research, as this is what eye-movement registration systems quantify, and therefore the interpretation of this data may be misleading.

Given that afforded actions depend upon the environment and the individual's own action capabilities, the above assumption could also be debilitating for performance if athletes are trained to focus their attention on areas deemed to be important based on eye-movement registration research. For example, different expert athletes may use different perceptual information to achieve the same task to the same standard. When the fixation data of these athletes (which may not be the only relevant information) is averaged and used to train less skilled athletes to focus their attention, the trained athlete may begin to centrally fixate information in ways that no expert performer would, potentially restricting any performance improvements. In fact, this may be why research which has attempted to train visual search patterns based on expert performer's eye-movement data has not resulted in improved decision-making on sport-specific tasks (Bishop et al., 2014).

Together, the limitations of eye-movement registration technology, and the associated assumptions that accompany research utilising eye-movement registration technology, indicate that alternative methods are required to properly understand the visual exploratory actions of athletes in-situ.

4.3.3 Microelectromechanical systems inertial measurement units

Microelectromechanical systems (MEMS) inertial measurement unit (IMU) technology has advanced such that devices embedding the technology can be used for new data collection and analysis methods in exercise and sporting applications. IMUs typically integrate tri-axial accelerometers, gyroscopes and magnetometers, resulting in a 9-degrees-of- freedom (9-DOF) device that is capable of onboard data logging. These sensors are capable of providing a measure of the device's orientation relative to gravity and the Earth's magnetic field, known as an attitude and heading reference system (AHRS)(Madgwick, Harrison, & Vaidyanathan, 2011). When attached to the body or equipment, the data obtained from IMUs can be used to quantify movement in a similar fashion to optical 3D motion capture systems. However, as IMUs are self-contained, they are able to capture this data without the restrictions of portability, scale of capture and cost associated with typical video-based motion capture systems (Sabatini, 2011).

Consequently, wearable IMU devices have been utilised in a range of research settings that require unrestricted movement in spaces that are larger than can be practically captured with optical systems (Ahmad, Ghazilla, Khairi, & Kasi, 2013; Camomilla, Bergamini, Fantozzi, & Vannozzi, 2018; O'Reilly, Caulfield, Ward, Johnston, & Doherty, 2018). As a few examples, IMUs have been used in the detection and measurement of various lower body movements (for review see O'Reilly et al., 2018), jump power and height (Rantalainen, Gastin, Spangler, & Wundersitz, 2018), kicking biomechanics (Blair, Duthie, Robertson, Hopkins, & Ball, 2018), gait analysis (Benson, Clermont, Bošnjak, & Ferber, 2018; Hubble, Naughton, Silburn, & Cole, 2015), and quantification of activity demands in multi-directional sports (McLaren et al., 2018; Taylor, Wright, Dischiavi, Townsend, & Marmon, 2017). Further, IMUs have been implemented in a wide range of sports, including but not limited to; athletics-based throwing (Brice, Hurley, & Phillips, 2018) and running (Setuain et al., 2017) events, baseball (Murray et al., 2017), basketball (Nguyen et al., 2015), climbing (Boulanger, Seifert, Herault, & Coeurjolly, 2016), cricket (Senington, Lee, & Williams, 2018), golf (Jensen et al., 2015; King, Yoon, Perkins, & Najafi, 2008), netball (Shepherd, Giblin, Pepping, Thiel, & Rowlands, 2017), rugby (Chambers, Gabbett, & Cole, 2019), swimming (Fantozzi et al., 2016), and wheelchair sports (Shepherd, Wada, Rowlands, & James, 2016).

Together, the wide use of IMUs in sport settings shows the value of such devices to quantify movement in sporting environments (Camomilla et al., 2018). Given that this thesis is interested in the head movement of football players in representative environments, IMUs present as a logical technology to implement for data collection needs. The devices can be worn by players during regular play without restricting the natural movements that players would display during competition. Further, as the devices are self-contained, data collection is not restricted by small spaces, and the relatively low cost allows data collection of multiple athletes concurrently. Finally, as novel analysis methods can be used to automatically process data and detect movement events (Chambers et al., 2019; Murray et al., 2017), IMU devices are capable of greatly reducing the time investment required by notational analysis methods that are currently used to quantify visual exploratory actions in football settings (Eldridge et al., 2013; Jordet, 2005; Jordet et al., 2013).

Recently, analysis methods have been validated to quantify visual exploratory head movement from data obtained from head-mounted IMUs (Chalkley, Shepherd, McGuckian, & Pepping, 2018). This analysis method uses a 9-DOF orientation filter (Madgwick et al., 2011) to obtain the sensor's orientation relative to gravity and Earth's magnetic field. The resulting yaw orientation data (i.e. representing rotation about the long axis of the head and, hence, head turn) was processed through a 10-frame moving window to produce a measure of head velocity in the yaw direction. Head movements were then detected in two ways: 1) when the yaw velocity exceeded 125 degrees/second then slowed below this threshold, 2) when a peak in the yaw velocity was detected without the velocity dropping below the 125 degrees/second threshold. A head movement was detected with the second detection method when a movement of the head slowed before continuing to move in the same direction, such as occurs with a sequential exploratory head movement (Jordet, 2005). This analysis method was shown to be valid for the detection of exploratory head movements and to be more reliable than manual counting of exploratory head movements (Chalkley et al., 2018). Therefore, this method was used to quantify exploratory head movements in the studies included in this thesis.

4.3.4 Variables obtained from inertial measurement units

The use of IMUs to quantify the head movements of athletes during match-play allows for a wider range of exploratory movements to be detected compared to the notational analysis methods used previously (Eldridge et al., 2013; Jordet, 2005; Jordet et al., 2013). In particular, the fidelity of IMUs allows for variables to be created which can be used to better understand the movements being utilised by players to visually perceive their environment.

Several visual exploratory head movement variables were developed and utilised in the studies within this thesis. The use of these different variables assisted in answering the specific questions for each individual study. Therefore, some variables were used in multiple studies, while others were only used in one study. Each variable is based on the detection of a head movement as defined by Chalkley et al. (2018). A definition of each variable is given in Table 4.1.

Table 4.1 Description of visual exploration variables

Variable	Definition of Variable	Studies/Chapters variable used in
Head turn number	The total number of head turns that occur during a specified time period	Study 2/Chapter 5
Head turn frequency	The total number of head turns that occur during a specified time period divided by the time period, expressed in turns per second	Study 2/Chapter 5, Study 3/Chapter 6
Head turn excursion	The total angular distance of all head turns that occur during a specified time period divided by the time period, expressed in degrees per second	Study 3/Chapter 6
Continuous head turn frequency	The total number of head turns that occur during the preceding 1-second, calculated at every data point available using the preceding 1-second of data	Study 4/Chapter 7
Continuous head turn excursion	The total angular distance of all head turns that occur during the preceding 1-second, calculated at every data point available using the preceding 1-second of data	Study 4/Chapter 7

Variables were chosen according to the aim of each study to best answer the a-priori research questions. Head turn number, head turn frequency and head turn excursion were used in Chapters 5 and 6 as they relate to discrete events in time (i.e. before ball possession, during ball possession). This allowed an investigation of the relationships between discrete events, for example visual exploration before ball possession and actions with the ball. Chapter 7, however, was interested in exploration as players' position changed over time, and therefore required that the visual exploratory variables were expressed on a continuous timescale. Consequently, the frequency and excursion of head turns were calculated at every data point obtained from the IMUs using the preceding 1-second of data. The resulting output contained a timeseries of exploratory head movement data across entire periods of football match-play.

Chapter 5: Visual Exploration when Surrounded by Affordances: Frequency of Head Movements is Predictive of Response Speed

Study 1 revealed that investigations of visual exploratory action have almost exclusively been interested in the eye movement of footballers. Additionally, no research has used technology to assist in the quantification of exploratory head movements, which has limited the breadth of research that has been conducted in this area. Consequently, Study 2 implemented inertial sensor technology and validated algorithms (Chalkley et al., 2018) to quantify exploratory head movement in a football situation for the first time. As this was the first investigation of its kind, Study 2 utilised a lab-based task, which allowed for a controlled setting to further progress the utilisation of the technology.

This study has been accepted for publication following peer review. The content has been reformatted for the purposes of this thesis. Author contributions are given in Appendix 1. Full reference details for this study are:

> McGuckian, T. B., Cole, M. H., Chalkley, D., Jordet, G., & Pepping, G.-J. (2019). Visual exploration when surrounded by affordances: Frequency of head movements is predictive of response speed. *Ecological Psychology, 31*(1), 30-48. https://doi.org/10.1080/10407413.2018.1495548

5.1 Abstract

Little is known about the actions supporting exploration and their relation to subsequent actions in situations when participants are surrounded by opportunities for action. Here, the movements that support visual exploration were related to performance in an enveloping football (soccer) passing task. Head movements of experienced football players were quantified with inertial measurement units. In a simulated football scenario, participants completed a receiving-passing task that required them to indicate pass direction to one of four surrounding targets, as quickly as they could after they gained simulated ball-possession. The frequency of head movements before and after gaining ball-possession, and pass response times were recorded. We controlled exploration time - the time before gaining simulated ball-possession - to be one, two, or three seconds. Exploration time significantly influenced the frequency of head movements, and a higher frequency of head turns before gaining ball-possession resulted in faster pass responses. Exploratory action influenced subsequent performatory action. That is, higher frequencies of head movements resulted in faster decisions. Implications for research and practice are discussed.

5.2 Introduction

In chaotic and fast-paced environments, such as in team sport, navigation, driving or combat, the speed with which individuals are able to make decisions is vital for successful performance. Having *prospective* knowledge of the action relevant information (about space, obstacles, other individuals, etc.) enables people to make appropriate decisions in a timely manner. Relations between an individual's action capabilities and the environment provide action relevant information about opportunities for action; i.e. affordances (Gibson, 1979). The ability to make decisions quickly is reliant on an individual's ability to discover the multiple affordances in the environment. Early knowledge of available affordances may allow faster responses in situations where fast responses are essential. Although laboratory studies have typically made action relevant information easily available to participants (by means of frontal visual projection), in real-world scenarios individuals are generally completely surrounded by affordances. That is, individuals need to discover affordances through *exploratory action*, in which the movement of the eyes, head and body enable perception of the full, 360 degrees, surrounding environment (Reed, 1996). The more action relevant information that an individual has about the surrounding affordances, the better they are able to make decisions and guide their subsequent actions. In terms of performance in time constrained situations, individuals explore to gain prospective knowledge about opportunities for action and hence, what to do *before* they need to act. For instance, in the case of football, which will be the focus of the current paper, by having prospective knowledge (through exploration) about the opportunities for action, players have knowledge about what to do with the ball before they take possession of it. To date, there is no research that has experimentally investigated the link between exploratory head movement and subsequent behaviour in football (Jordet et al., 2013; McGuckian et al., 2018c).

The eye-movements involved with visual perception have been studied extensively in the sport expertise domain. (Mann et al., 2007) found differences between novice and expert performers' eye-movements on perceptual tasks. However, these differences were modified by the sport, experimental setting and method of presenting stimuli, indicating that the specific context is important to consider for any application of findings (Dicks et al., 2009; Jordet & Pepping, 2018). Specifically, in football, eye-movements that support visual exploration have been the focus of visual perception research. A recent systematic review revealed no clear differences in eye-movements according to level of expertise (McGuckian et al., 2018c), but added support to previous research suggesting that the representativeness of the experimental task influences the visual perception behaviours of footballers (Dicks et al., 2009). Importantly, McGuckian et al. (2018) found that the research utilising technology to investigate visual exploratory action of footballers employed eye-movement registration technology. This reliance on eye-movement registration technology has primarily led to controlled laboratory studies in which action-relevant information is presented in front of participants, which has prevented researchers from developing an understanding of the head and body movements that support visual exploratory action. Considering that, in the sport domain and other situations that require whole body-environment interaction, the head and body are required for visual perception of affordances (Fajen et al., 2009; Gibson, 1979; Reed, 1996), there is a need to investigate how these aspects of exploratory action relate to performance. Further, given that investigations of eye-head coordination in 360-degree environments show that visual perception is improved when the eyes and head are oriented in the same direction (Nakashima & Shioiri, 2014), and that the eyes and head are often oriented in the same direction (Fang, Nakashima, Matsumiya, Kuriki, & Shioiri, 2015), the orientation of the head appears to be a valid proxy for visual attention in environments which surround an individual.

5.2.1 Exploratory versus performatory action

"Movement ... is of two general types, exploratory and performatory" (Gibson, 1966, p. 57).

Thus far, head movements have been described as exploratory in that their purpose is to facilitate exploration of one's surroundings to perceive the environment. That is, the function of exploratory head movements (along with eye and body movements) has been described to be instrumental for the perception of the enveloping environment and to facilitate prospective regulation of action (Adolph et al., 2000; Reed, 1996). Gibson (1966) argued that exploratory movements are of a different nature and have a different function compared to movement aimed at directly interacting with, or altering, the environment. According to Reed (1996), and following Gibson (1979), these latter movements are performatory, and are defined as movements in which one must compete for resources by using force to interact with the environment. For instance, a golfer may move their eyes, head and body to perceive the different surface properties of a putting green (exploratory action) before completing a putt (performatory action) (Button & Pepping, 2002). Examples of potentially useful environmental resources in football that constitute future opportunities for action may be teammates and opposition players, the ball, free space, the goals, etc., and often the players within a game must compete for these resources in order to win. However, simply perceiving these features does not *use up* the features (Reed, 1996). That is, all the players can explore the environment and perceive these features at the same time, and the features will remain in the same state. Conversely, in the case of performatory actions, the players cannot all interact with these resources together without changing the state of the resources. Players will engage in exploratory actions to perceive available space, and then engage in performatory actions, such as running, to move into that space and create a passing opportunity.

It should be noted that exploratory and performatory actions do not occur independently, or as sequentially, as has been described. In fact, as exploratory action does not interfere with the environment (Reed, 1996), it is likely that both exploratory and performatory actions occur simultaneously. Regardless, exploration allows the discovery of opportunities to act, which are utilised when engaging in performatory actions. To date, no experimental research has investigated the relationship between a player's exploratory actions and performatory actions in a football setting.

5.2.2 Exploratory action in support of performatory action

With an understanding that exploratory and performatory actions occur simultaneously, we can also say that exploratory behaviour provides the link between perception and action (Gibson, 1969; Gibson, 1979). The information gained from exploratory action guides movement prospectively (Adolph et al., 2000; von Hofsten, 1993). Research has shown that humans display various exploratory actions, such as manual-, oral- and visual exploratory actions, as early in life as infancy (Soska & Adolph, 2014). The relationship between visual exploratory action and performatory actions is already apparent in infant locomotion, where toddlers engage in exploratory action at a distance before moving toward a slope (Adolph, 1995; Adolph et al., 2000; Kretch & Adolph, 2017). In adult life, exploratory action is also used to prospectively regulate performatory action (Barton, Matthis, & Fajen, 2017). In walking, it has been shown that adults will often fixate action relevant information two or three steps *before* they initiate a step over an obstacle (Franchak & Adolph, 2010; Patla & Vickers, 1997) or on a target (Patla & Vickers, 2003). Taken together, these studies provide further support for the role of exploratory action in the prospective regulation of performatory action.

Initial investigations into the role of exploratory head movements in football have been based on observational research employing notational analysis. Findings suggest that these behaviours are important for prospective regulation and coordination (i.e. performance) in elite adult (Jordet et al., 2013) and youth (Eldridge et al., 2013) players (see also Jordet & Pepping, 2018). When players visually explored their surroundings more frequently before receiving possession of the ball (as quantified through manually counting head movements), they successfully completed performatory actions (i.e. a subsequent pass or turn with the ball) more often (Eldridge et al., 2013; Jordet et al., 2013). Using a similar methodology, McGuckian et al. (2017) found that youth football players explored more frequently when they were not in ball possession, and when they were playing on a pitch with less space compared to a full-size pitch.

5.2.3 Current study

The current study expands on this previous observational research by experimentally investigating the exploratory and performatory actions of footballers. The first aim of this study was to gain a better understanding of the exploratory actions used by footballers in a perception-action football receiving-passing task, that is, a task in which the participant is surrounded by task-relevant affordances. In doing so, the current study investigated how football-relevant task constraints, such as i) the location of a teammate to pass the ball to, and ii) the amount of available time before ball possession, changed the frequency of head movements, and the time taken to respond. Secondly, using the same perception-action football task, this study aimed to empirically test the relationship between head movements, as a proxy for visual exploratory action, and performatory action. Accordingly, the relationship between the frequency of head movements and the time taken to initiate passes was examined. Specifically, it was predicted that more visual exploration (i.e. more frequent head movements) before gaining possession of the ball would be related to shorter response times for performatory actions.

5.3 Methods

5.3.1 Participants

Participants were 12[3] male football players aged 16 to 18 years (*M* = 17.25, *SD* = 0.75) with 9 to 14 years playing experience (*M* = 12.42, *SD* = 1.44). These 12 players included two wide defenders, four defensive/central midfielders, three wide midfielders and three attacking midfielders/strikers, ensuring that the sample was representative of all football positions except for the goalkeeper. All participants played for the same semi-professional club, which participated in the Australian National Premier League competition. Participants were conveniently recruited and represented the playing ability and standard of competitive- elite youth players in Australia (Swann, Moran, & Piggott, 2015). To be included in the study, participants needed to volunteer their time, be playing in the Under-18 or Under-20 team, and be considered free from injury by club medical staff. Participants (and their parent/guardians where appropriate) gave informed consent/assent prior to taking part in the experiment. The research was approved by the lead institution's Human Research Ethics Committee (Application ID: 2016-230E) and participants were free to withdraw at any stage.

5.3.2 Experimental setup

Visual stimuli were presented via a custom-made PsychoPy (Peirce, 2007) script running on a 15-inch laptop (Apple Inc., Cupertino, USA) connected to four 22-inch computer monitors (Dell 2209WA, Round Rock, USA) with a screen resolution of 1680 x 1050 pixels. The surrounding screens were set to a portrait position and placed atop 75cm tall tables, three meters away from the participant, at 100 degrees and 150 degrees to the left and right of the participant's forward-facing position (see Figure 5.1). The participant's forward- facing position was toward the control computer (screen 0), which was positioned one meter away on another 75cm tall table. Four 22cm tall sports cones were aligned with each surrounding screen and placed one meter from the participant. From three meters away, the

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[3] Data was originally collected from 16 participants. Due to an error in data collection, head movement data from four participants could not be used and these four participants were excluded from analysis.

vertical size (47cm) of each surrounding screen equated to a visual angle of 8.96 degrees, the same visual angle produced by a 180cm tall player standing 11.49m away on a football pitch.

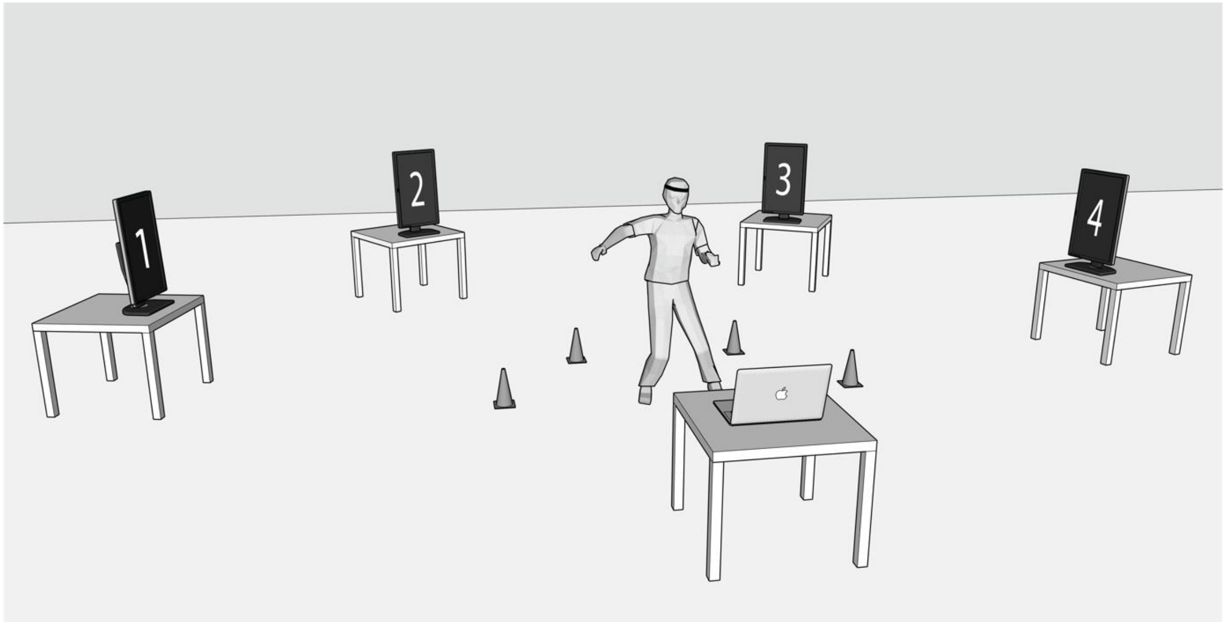

Figure 5.1 A schematic illustrating the experimental design used throughout data collection. Numbers indicate the screen numbers referred to in the analyses.

A 9-DOF Inertial Measurement Unit (IMU; SABELSense, Nathan, Australia), as described by (James et al., 2011), was used to collect head movement data. Data were captured at 250Hz and stored locally on each IMU's memory card, and downloaded at the end of each testing session. Each IMU was controlled remotely with a master device connected to a laptop (Dell, Round Rock, USA).

The experiment investigated the head movements of football players by simulating a common game situation in a laboratory setting. To ensure the findings would be generalizable to real-world environments, effort was made to make the experimental design as representative as possible by using dynamic stimulus presentation and requisite responses that reflected those used in-situ (Travassos et al., 2013). The task simulated a situation in a game where a player receives a pass and then needs to pass the ball to a free teammate that is located somewhere in the surrounding environment. In the experiment, the players were presented with four dynamic options, and one of these options was a free teammate. As soon as the participant received possession of the ball, their task was to indicate pass direction of the ball to the free teammate as quickly as possible by kicking the corresponding cone.

5.3.3 Procedure

After arriving at the testing facility, the procedure was explained to the participants and an IMU (SABELSense, Nathan, Australia) was secured at the external occipital protuberance with an elastic headband. Participants completed a series of five practice trials to familiarise themselves with the experimental task. Following this, participants completed the first of four testing blocks of 24 trials, with each block separated by a five-minute break.

It was explained to participants that the experiment was designed to replicate a passing situation in a game, whereby they would receive a pass from a teammate and needed to pass to another free teammate. While standing at the starting position and facing screen 0, participants were instructed to press the spacebar on the keyboard of the control computer when they were ready for each trial to begin. Upon pressing the spacebar, an audible beep sounded to act as a primer for the trial to begin. After a randomly programmed delay between one and four seconds, each of the four surrounding screens and screen 0 simultaneously began playing different videos (TS, Figure 5.2). Each surrounding screen presented one of the four video situations (open space, free teammate, opponent, and marked teammate). Screen 0 presented one of six passing videos (left or right foot pass, with a delay of one, two or three seconds). As soon as the videos began playing, the participant was allowed to begin exploring their surroundings. The participants were given no specific instructions regarding how to explore the environment and were not restricted with respect to how they were allowed to move. The participants were told that once the ball was no longer visible in the passing video (BP, Figure 5.2), they then had possession of the ball and needed to respond by passing the ball to the simulated free teammate. To complete the pass, the participants needed to kick the sports cone which corresponded to the surrounding screen displaying the free teammate. Participants were told to complete the simulated pass as quickly as they could after they had possession of the ball. Each trial was complete after the participant had kicked a cone (PP, Figure 5.2). The response was noted and the participant was asked to press the spacebar when they were ready for the next trial to begin. The entire testing procedure was completed in approximately 50 minutes, and was video recorded with a digital video camera (Sony RX100 IV, Tokyo, Japan) at 50Hz.

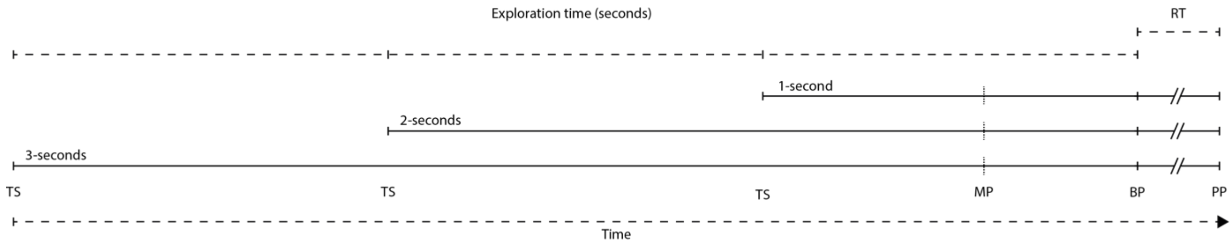

Figure 5.2 A schematic illustrating the timing of events in trials with one, two and three seconds exploration time. RT = response time, TS = trial start, MP = model pass, BP = ball possession, PP = participant pass. Time between MP and BP = 410ms.

5.3.4 Visual information

A series of ball-passing videos were created to be presented on screen 0. These videos involved a model receiving a pass, and then passing the ball towards the video camera. The original video (right-foot pass) was duplicated and flipped vertically to create a video in which the same model used his left foot to complete the pass. Both videos were then edited such that the pass toward the camera would exit the shot after one, two or three seconds from the beginning of the video, resulting in a total of six passing videos to be used in the trials. The amount of time between the model making contact with the ball and the ball exiting the videos was 410ms. The design of these videos enabled the participants either one, two or three seconds to freely explore their environment before 'receiving' the ball (Figure 5.2).

Four different target videos were produced to be presented to participants during the experiment; *open space, free teammate, opponent,* and *marked teammate*. The *open space* video included an open football pitch without any players in the scene. The *free teammate* video included open space with a model wearing a blue football shirt, who was moving on the spot as if to be ready to receive a pass. The *opponent* video included open space with a model wearing a red football shirt, who was moving on the spot as if to defend the viewer. The *marked teammate* video included open space with an opponent model closely defending a teammate model.

In football, the positions of teammate and opponent players constantly change as the game progresses. Therefore, to ensure the study design remained as representative as possible, the target videos were developed to ensure that they also dynamically changed. To achieve this, additional target videos were used in which the models moved in and out of the shot at certain times. For example, a video may start as a *free teammate* video, and after two seconds an opponent player enters the shot to make it a *marked teammate* video. This method was used to create videos that changed from *open space to opponent, free teammate to marked teammate, and free teammate to open space.* The inclusion of both types of video created a dynamically changing and unpredictable environment, and aimed to ensure that participants would need to continuously explore their surroundings in order to successfully complete the task.

The models were all of similar age to the participants and had experience playing football. All visual stimuli were recorded on a natural football pitch with a high definition video camera (Sony RX100 IV, Tokyo, Japan), from an elevated position of 1.75m from the ground. All videos were edited to a total length of six seconds.

5.3.5 Independent (IV) and dependent (DV) variables

Following synchronisation between the IMU and video data, the following variables were calculated for statistical analysis.

5.3.5.1 IV: Correct screen

The location of the free teammate was recorded for each trial. Screens two and three were located at 150 degrees from the participants' forward-facing position (towards screen 0), and screens one and four were located at 100 degrees from the participants' forward-facing position (Figure 5.1).

5.3.5.2 IV: Exploration time

Exploration time was defined as the amount of time between the trial beginning (i.e. videos start playing) and the ball exiting the pass video (i.e. the participant has possession of the ball). The duration of this period was controlled for in the study design and was either one, two or three seconds (Figure 5.2).

5.3.5.3 IV: Possession

Before ball possession and *in ball possession* were used to indicate whether the participant had possession of the ball or not. *Before ball possession* was defined as the period between the trial beginning and the ball exiting the pass video. The participant was considered to be *in ball possession* once the ball exited the pass video (Figure 5.2).

5.3.5.4 DV: Number and frequency of head turns

A head turn[4] was defined as a distinct movement of the head about the longitudinal axis that resulted in an angular velocity that exceeded 125deg/s. The time at which each head turn occurred was extracted from the head-mounted IMU data using a custom-made algorithm (Chalkley et al., 2018). The number of head turns before ball possession and number of head turns in ball possession were collected. The frequency of head turns before ball possession and the frequency of head turns in ball possession were calculated by dividing the number of head turns by the elapsed time.

5.3.5.5 DV: Response time

The response time (in seconds) was calculated as the amount of time that elapsed between the participant gaining possession of the ball - defined as the time that the ball was no longer visible in the pass video - and the participant completing their pass - defined as the moment in time that the participant made first contact with the cone (Figure 5.2). Frame by frame video inspection was used to identify when foot-to-cone contact was made.

5.3.6 Statistical analysis

On the basis of a predicted medium effect size, it was determined using G*Power v.3.19 (Faul, Erdfelder, Lang, & Buchner, 2007) that a minimum of 9 participants was required (Effect Size = 0.31, Power = 0.80, p = 0.05). As such, the recruited sample of 12 participants was considered appropriate to not only ensure adequate statistical power for the statistical comparisons, but also to allow for the recruitment of a sample that was representative of a complete team of association footballers. All statistical analysis was completed using IBM SPSS version 22 (IBM Corp., Chicago, IL, USA). Alpha was set at $p < 0.05$ for all analyses.

A Shapiro-Wilk test was used to test for normality of the dependent variables. The test results for number of head turns, frequency of head turns and response times were all non-significant, indicating the data were normally distributed. To test for any learning or fatigue

[4] Note that this definition of head turn describes a movement of the head relative to space. Therefore, a head movement may (or may not) include rotation of the body relative to space.

effects, one-way repeated-measures ANOVAs were conducted to compare the effect of block number (four levels; block 1, 2, 3, 4) on the number and frequency of head turns before ball possession and in ball possession, and on response time.

5.3.6.1 Aim 1: Impact of task constraints on head movements and response time

A (4x3x2) factorial repeated-measures ANOVA was conducted on the frequency of head turns, with repeated measures on correct screen (four levels), exploration time (three levels; 1sec, 2sec, 3sec) and possession (two levels; before ball possession, in ball possession). A (4x3) factorial repeated-measures ANOVA was conducted for response time, with repeated measures on correct screen (four levels) and exploration time (three levels; 1sec, 2sec, 3sec). When Mauchly's test indicated the assumption of sphericity had been violated, the Greenhouse-Geisser correction was used to adjust the degrees of freedom. Post- hoc comparisons were completed for each ANOVA using Bonferroni tests. Effect sizes, *r*, were calculated and defined as follows: ≤0.10 = trivial, 0.10 – 0.30 = small to medium, 0.30 – 0.50 = medium to large, ≥0.50 = large to very large (Cohen, 1992).

5.3.6.2 Aim 2: Relationship between head movements before and after gaining ball possession and response time

Pearson's correlation tests were conducted on response time and the frequency of head turns before ball possession; on response time and the number of head turns when in ball possession[5]; and on the frequency of head turns before ball possession and the number of head turns when in ball possession. To test the relationship between the frequency of head turns before ball possession and response time, categorical linear regression analysis was used with frequency of head turns before ball possession as the independent variable. All trials were grouped based on the frequency of head turns before possession of the ball, which created four groups; very low head turn frequency (zero to one head turn per second), low head turn frequency (more than one to two head turns per second), high head turn frequency (more than two to three head turns per second), and very high head turn frequency (more than three head

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[5] Since the frequency of head turns when in ball possession was calculated as a function of response time, to prevent biased or specious results due to violation of independence, we performed correlation analysis on response time and the number of head turns when in ball possession.

turns per second). It was predicted that more frequent head movements (i.e. more frequent visual exploration) would result in shorter response times.

5.4 Results

A total of 1,152 trials were collected from the 12 participants. Six trials (0.52%) were removed because of faults in the data collection procedure, and 22 trials (1.91%) were removed because the participant responded before they had received the ball, resulting in a total of 1,124 trials included for analysis. Summary statistics for the average number of head turns according to the exploration time and possession of the ball are presented in Table 5.1.

Table 5.1 Mean (SD) number of head turns according to exploration time and possession.

Exploration time (sec)	Before ball possession	In ball possession
1	1.96 (0.81)	2.80 (1.47)
2	4.31 (1.23)	1.91 (1.27)
3	6.31 (1.79)	1.77 (1.36)

5.4.1 Learning and fatigue effects

There was a significant effect of block number on the number ($F(2.113, 23.248) = 17.50$, $p < .001$, $r = .66$) and frequency ($F(3, 33) = 2.94$, $p = .047$, $r = .29$) of head turns before ball possession. There was no significant effect of block number on the number ($F(3, 33) = 1.23$, $p = .316$, $r = .19$), or frequency ($F(3, 33) = 0.39$, $p = .758$, $r = .11$) of head turns in ball possession, or on response time ($F(3, 33) = 2.63$, $p = .067$, $r = .27$). Pairwise comparisons revealed a higher number of head turns before ball possession in block two (*Mean* = 4.80) than in block three (*Mean* = 3.83) and block four (*Mean* = 3.70), but no difference in the frequency of head turns before ball possession between any of the blocks. Block three and four, however, had a much higher proportion of trials with only one second of exploration time (11/24 trials and 12/24 trials, respectively) than block two (3/24 trials). Given that players completed less head turns before ball possession when they only had one second of exploration time (Table 5.1), the above differences in total number of head turns between block numbers were expected. Considering there were no significant differences in the frequency of head turns before ball possession between blocks, it can be concluded that there were no significant learning or fatigue effects present throughout the trials. Therefore, block number was excluded from the remaining analyses.

5.4.2 Aim 1: Impact of constraints on head movements and response time

5.4.2.1 Frequency of head turns

There were no significant main effects of correct screen, exploration time or possession on the frequency of head turns, however, a significant exploration time by possession interaction was identified ($F(2, 22) = 12.02$, $p < .001$, $r = .59$). Pairwise comparisons indicated no difference in frequency of head turns between exploration times before players were in possession of the ball (Figure 5.3a). When players were in possession of the ball, they had a significantly higher frequency of head turns when there was one second before receiving the ball than when there were two or three seconds before receiving the ball (Figure 5.3a). Finally, when there was one second of exploration time, players had a significantly higher frequency of head turns when they were in possession of the ball than before they were in possession of the ball. This difference was not found when there was two or three seconds of exploration time before receiving the ball (Figure 5.3a).

5.4.2.2 Response time

There were significant main effects of correct screen ($F(3, 33) = 10.27$, $p < .001$, $r = .49$) and exploration time ($F(1.140, 12.544) = 27.96$, $p < .001$, $r = .83$) on response time, but no significant interaction between these two factors. Pairwise comparisons for the main effect of correct screen indicated that players responded significantly faster when screens one or four were correct compared to when screens two or three were correct (Figure 5.3b). Pairwise comparisons for the main effect of exploration time indicated that when there were two or three seconds before being in possession of the ball, players responded significantly faster than when there was one second before being in possession of the ball (Figure 5.3c).

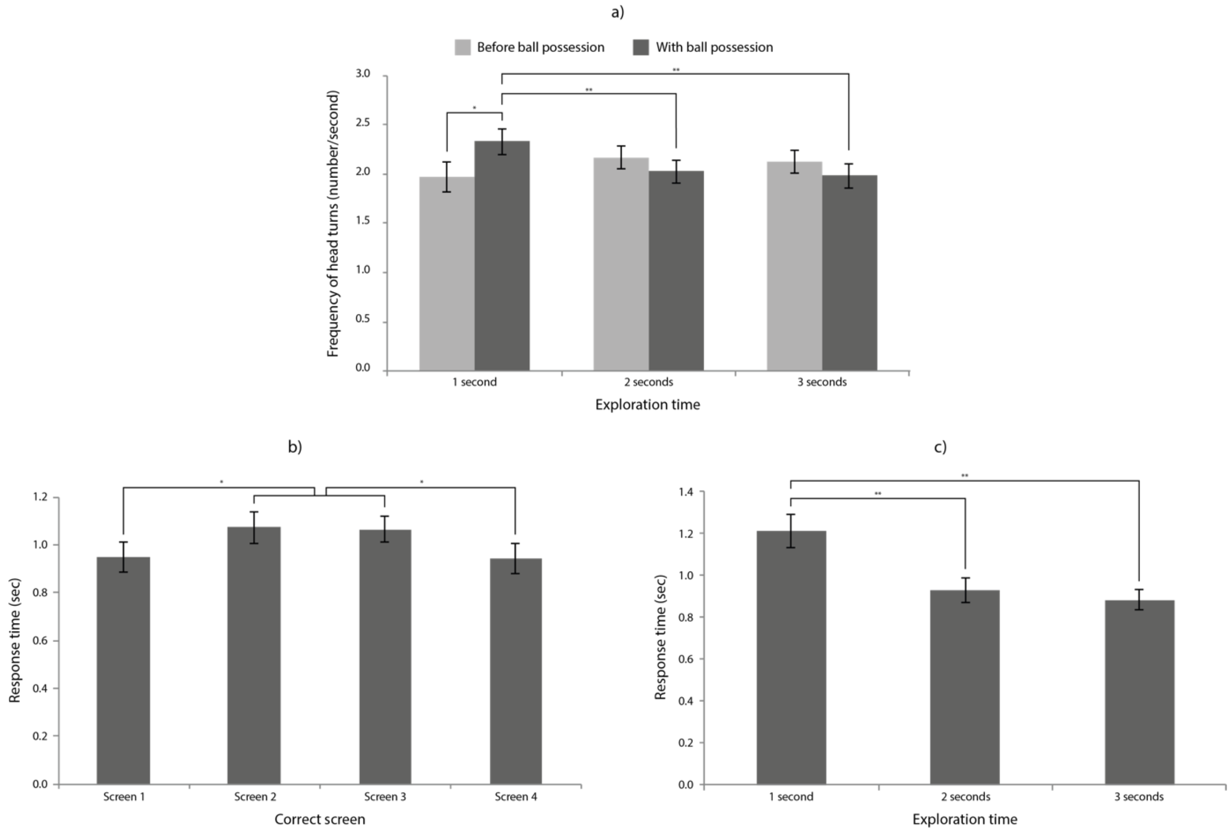


Figure 5.3 The mean (SE); a) frequency of head turns according to exploration time before ball possession and in ball possession; b) response time according to correct screen; c) response time according to exploration time. * indicates $p < 0.05$. ** indicates $p < 0.01$.

5.4.3 Aim 2: Relationship between head movements and response time

Response time was significantly negatively correlated with the frequency of head turns before ball possession ($r = -.255$, 95% BCa CI [-.310, -.197], $p < .001$). These correlations show that when the players had a higher frequency of head turns before receiving the ball, they responded with a pass more quickly. Response time was positively correlated with the number of head turns when in possession of the ball ($r = .724$, 95% BCa CI [.680, .762], $p < .001$). Higher response times were associated with more head movements when in ball possession. Finally, the frequency of head turns before receiving the ball was negatively associated with the number of head turns when in possession of the ball ($r = -.188$, 95% BCa CI [-.248, -.122], $p < .001$). A higher head turn frequency before gaining ball possession was associated with fewer head turns when in ball possession.

Categorical linear regression analysis was used to compare the response times of the low, high and very high head turn frequency groups to the very low head turn frequency group. Results of this analysis are presented in Table 5.2 and Figure 5.4. Results show that each group had a significantly shorter response time than the very low head turn frequency group. This relationship became more pronounced as the frequency of head turns increased, with the very high frequency group having an average response time more than half a second shorter than the very low frequency group.

Table 5.2 Mean (SD) response time, number of trials, number of participants, and categorical linear regression output for the head turn frequency of each group.

Head turn frequency (turns/sec)	Mean (SD) response time	Number of trials in group	Number of participants represented in group	t	p	B	95% CI for B
Very low, 0 – 1	1.27 (0.43)	142	11/12	-	-	-	-
Low, > 1 - 2	1.05 (0.45)	573	12/12	-5.447	.000	-.219	LB: -.298 UB: -.140
High, > 2 - 3	0.88 (0.39)	377	12/12	-9.206	.000	-.390	LB: -.473 UB: -.307
Very high, > 3	0.75 (0.46)	32	8/12	-6.184	.000	-.520	LB: -.685 UB: -.355

Note. Low, high and very high head turn frequency groups are compared to very low head turn frequency group.

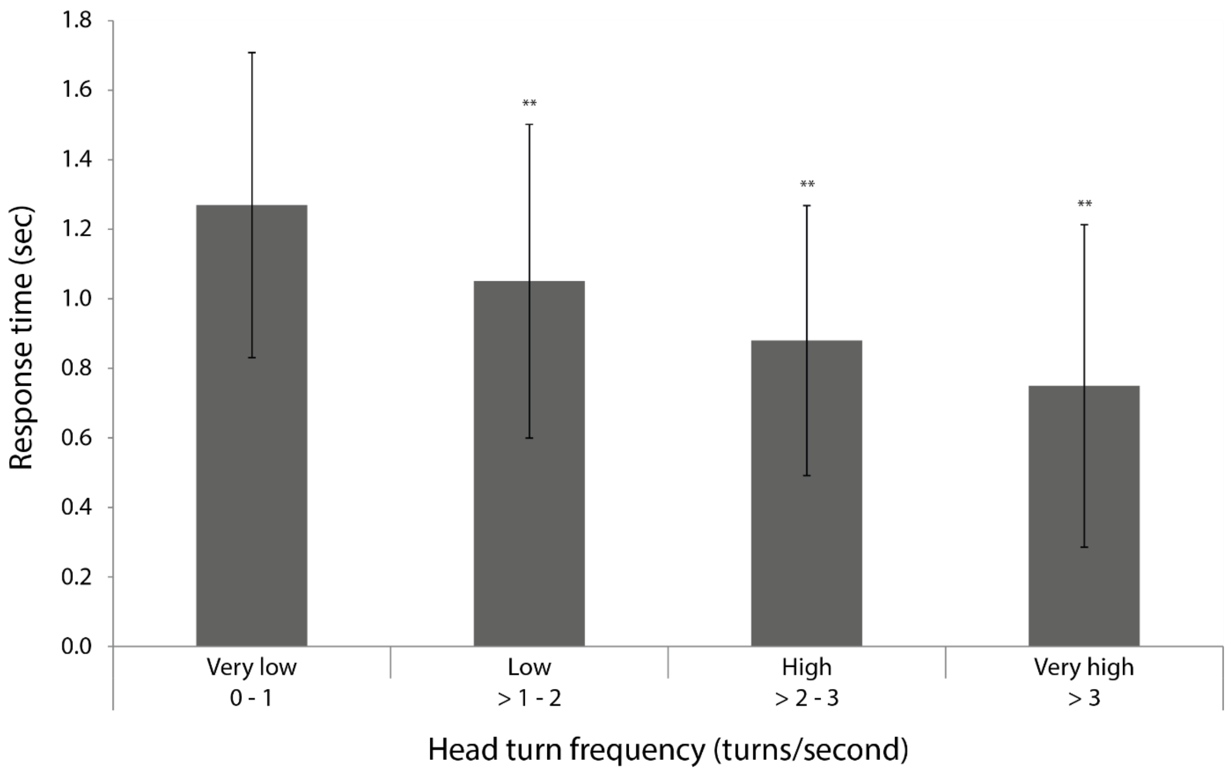


Figure 5.4 Mean (SD) response time according to head turn frequency. ** indicates $p < 0.01$ difference compared to *very low* group.

5.5 Discussion

The current study aimed to gain a better understanding of the importance of exploratory action for performatory action in situations where participants are enveloped by affordances, as well as to empirically test the link between exploratory action and performatory action. In doing so, we measured the head movements of footballers before they received a simulated pass and while they completed a simulated pass to a free teammate. There are two major findings from the current study. First, it appeared that the time constraints of the task influenced the head movements and performatory actions of footballers in the passing task. Second, the relationship between head movements and the speed of a passing response gives further evidence for the importance of exploratory action in service of the prospective regulation of movement. These findings have clear implications for practitioners, as well as implications for future research designs interested in the perceptual- motor abilities of athletes.

The findings of the current study clearly demonstrate the idea that prospectively regulating movements requires players to visually explore their environment to discover the future opportunities for action – i.e. affordances - in the environment (Adolph et al., 2000; Gibson, 1979; Reed, 1996). These findings suggest that when players have time to discover the affordances available to them before they initiate a task, they are able to complete the required task more effectively. This was evidenced by two findings; i) the occurrence of head movements while the players had possession of the ball, and ii) the time taken to complete the requisite pass. There was no difference in the frequency of head turns during the one, two and three seconds before the players were in possession of the ball. Once they had received the ball, however, players' subsequent head turn frequency was higher in the condition in which they had one second to explore prior to receiving the ball, compared to the conditions in which they were able to explore two or three seconds prior to receiving the ball. This suggests that when the constraints of the task resulted in players only having a very short opportunity to explore their environment before receiving the ball, they were unable to adequately establish the available opportunities for future action and therefore, once they did have the ball, made more rapid head turns to locate the free teammate to pass to. This increased head movement frequency in the condition in which players only had one second to explore prior to receiving the ball was accompanied by an increase in time to complete the pass, compared to the conditions in which the players had more time to explore (two and three seconds). This further illustrates and supports the importance of exploratory action (i.e. exploratory head turns prior to receiving the ball) for prospective regulation of performatory actions (i.e. fast and adequate decision making when in possession of the ball).

Across all trials, there was a significant negative correlation between the frequency of exploratory head movements prior to having possession of the ball, and the response time to complete a pass once in possession of the ball. Furthermore, the findings from the grouped regression analysis showed that a higher frequency of exploratory head movement resulted in a shorter response time. Given the available time to explore without the ball, more visual exploration supported the players' perception of the available opportunities for action. This resulted in a faster response once they did have the ball. What's more, when players had a higher frequency of head movements before gaining ball passion there were fewer head movements when in ball possession. These findings give clear evidence for the value of exploratory action in fast-paced environments, such as team-sports, and has clear implications for practitioners wanting to improve performance in these domains. For example, for a team wishing to adopt a fast-paced, high pass-rate style of play, the ability to quickly move the ball between players is vital (Chassy, 2013). The current findings showed that players' exploratory action before receiving a pass will assist in the fast completion of subsequent passes. Additionally, Jordet et al. (2013) showed that a higher exploration frequency resulted in a higher likelihood of a successful pass. Together with those of Jordet et al. (2013), the current findings suggest that frequent exploration before receiving a pass improves the speed and accuracy of passing in football, implying this should be an endeavour for future player development. While more research is needed to understand the best ways of developing the exploratory actions of athletes, manipulating environmental and task constraints, such as the pitch size or number of players, may encourage these perceptual-motor behaviours in training (McGuckian et al., 2017; Oppici, Panchuk, Serpiello, & Farrow, 2017). Further, imagery interventions showed improved visual exploratory actions in both elite youth (Pocock, Dicks, Thelwell, Chapman, & Barker, 2019) and professional adult football players (Jordet, 2005).

Efforts were made in the current study to make the perception-action football task similar to a common match situation; receiving a pass from a teammate and completing a subsequent pass to a free teammate in a fully surrounded task environment. In the experimental design used here, visual information was presented dynamically and participants were required to produce a physical response similar to a real game, therefore maintaining the natural perception-action couplings as much as possible in a laboratory-based setting. Nevertheless, the study was still completed in a laboratory environment, and some aspects of the design may not translate to the more dynamic performance environment experienced by players in a real game (Dhami et al., 2004; Dicks et al., 2009). For example, visual information was presented relatively proximally in the current study, whereas during a match, potentially useful information is available both proximally and more distally (i.e. at the other end of the pitch). Additionally, even though the participant was able to move freely and the videos presented dynamic movement of players, the screen locations were static in the experimental environment and a real ball was not used for the passing response. Finally, during a match, a player may want to disguise their intentions by restricting their head movements at certain times. However, considering there would be no advantage to disguising head turns in the present task, this is unlikely to have influenced the reported outcomes. Importantly, however, the current study introduced a novel methodology for the study of perception and action in sport by investigating an often neglected (McGuckian et al., 2018c), but vitally important behaviour; the head movements that support visual perception.

Future research should take the above limitation into account when investigating exploratory action in sport. In order to best understand the exploratory actions of footballers, researchers need to ensure their task designs are representative of the actual environment in which the behaviour occurs (Dhami et al., 2004; Dicks et al., 2009). This endeavour has been limited by the difficulty in accurately measuring exploratory actions in situ, however technological advances now provide an accurate alternative to the notational analysis methods currently used (Jordet et al., 2013; McGuckian & Pepping, 2016). By completely surrounding participants with potentially relevant information, the current study showed that moving the head is necessary for the successful completion of a common perception-action task in football, demonstrating the need for researchers to consider this behaviour, and to develop methodologies capable of investigating this behaviour, in future perceptual research endeavours.

There is a vast amount of research that has investigated the performatory actions (i.e. technical skills) of athletes in football (Hughes et al., 2012; Liu et al., 2016; Mackenzie & Cushion, 2013; Rein et al., 2017). However, investigations of exploratory head movements reveal that the actions which precede performance with the ball can influence the effectiveness of such performatory actions. Therefore, coaches should aim to improve the visual exploratory actions of footballers in order to enhance the technical ability of players. While this specific topic requires further investigation, we believe coaches would do well to encourage the development of exploratory head movement by implementing representative learning designs in practice (Araújo et al., 2006; Dicks et al., 2009; Krause, Farrow, Reid, Buszard, & Pinder, 2018; Pinder et al., 2011). That is, coaches should endeavour to create training situations where athletes are surrounded by relevant information in 360-degrees rather than only frontally located information. Further, players should be required to make decisions in response to realistic situations while under time constraints. As an example, traditional practices may aim to develop technical passing ability by having two players repeatably pass a ball to one another. As an alternative, coaches may consider designing passing drills which surround the passer with passing solutions, require a decision to be made about the passing solution, and require the execution of a pass under pressure. This may be done by introducing defensive players to apply time pressure, introducing additional teammates to provide alternative pass options and force decision-making, and introducing dynamic movement of players to ensure passing options are available in a 360-degree environment. These modifications would likely better simulate the decision-making and time constraints experienced in match-play (Araújo et al., 2006; Carling, 2011; Torrents et al., 2016).

5.6 Conclusion

With an aim to increase our understanding of the role of exploratory action in fast-paced environments in which individuals are fully surrounded by opportunities for action, the current study showed that utilising frequent exploratory head movements before a decision was required (i.e. before gaining ball-possession) assisted in the successful completion of the subsequent action (i.e. the pass to a free teammate). The findings from the study should be used as a platform for future investigations into the role of exploratory action in representative team sport environments, as well as for broader applications, such as emergency services, navigation, driving, and defence forces. Additionally, the findings should highlight to practitioners the potential value of designing training drills that encourage frequent visual exploratory action in order to promote successful performance.

Previously, Jordet et al. (2013) showed that frequent exploratory head movement before receiving a pass resulted in a higher likelihood of a subsequent successful pass. Here, we have added to this finding by showing that frequent exploratory head movement before receiving the ball allows a player to identify an available teammate more quickly. Together, these findings show that visual exploratory action before receiving the ball is vital for both the speed and accuracy of prospective movement with the ball in football, and therefore, this behaviour should be given more attention by researchers and applied practitioners. Particularly, the development of exploratory actions in youth players should be a priority, as it is likely that this would develop more creative players that are able to make use of their teammates more effectively through quick and accurate ball movement.

Chapter 6: Don’t Turn Blind! The Relationship Between Exploration Before Ball Possession and On-Ball Performance in Association Football

Following Study 2, there was a need to implement more ecologically-valid and representative experimental settings to further expand our understanding of the visual exploratory actions of players in their natural environment. In doing so, Study 3 quantified players’ exploratory head movements during 11v11 match-play. Given that relatively little was known about exploratory head movement, Study 3 aimed to show the applied value of visual exploration by investigating the relationship between exploratory head movement and performance with the ball. Study 3 was the first study to utilise inertial sensors to quantify exploratory head movement during open 11v11 match-play, and it presented a substantial advancement in the ability to quantify these behaviours over previous investigations.

This study has been accepted for publication following peer review. The content has been reformatted for the purposes of this thesis. Author contributions are given in Appendix 1. Full reference details for this study are:

> McGuckian, T. B., Cole, M. H., Jordet, G., Chalkley, D., & Pepping, G.-J. (2018). Don’t turn blind! The relationship between exploration before ball possession and on-ball performance in association football. *Frontiers in Psychology, 9*(2520), 1-13. https://doi.org/10.3389/fpsyg.2018.02520

6.1 Abstract

Visual exploratory action - scanning movements expressed through left and right rotation of the head - allows perception of a surrounding environment and supports prospective actions. In the dynamically changing football environment, the extent to which exploratory action benefits a player's subsequent performance with the ball is likely influenced by how and when the exploratory action occurs. Although few studies have examined the relationship between visual exploration and on-pitch football performance, it has been reported that a higher frequency of exploratory head movement up to 10-seconds before receiving the ball increases the likelihood of successful performance with the ball. This study investigated the relationship between head turn frequency and head turn excursion, and how and when exploratory head movement - within 10-seconds before ball possession - is related to performance with the ball in 11v11 match-play. Thirty-two semi-elite football players competed in 11v11 match-play. Head turn frequency and head turn excursion before ball possession were quantified with wearable inertial measurement units, and actions with the ball were coded via notational analysis. Odds ratio calculations were conducted to determine the associations between exploration variables and on-ball performance outcomes. A total of 783 actions with the ball were analysed. Results revealed a strong relationship between head turn frequency and head turn excursion. Further, a higher than average head turn frequency and head turn excursion before receiving the ball resulted in a higher likelihood of turning with the ball, playing a pass in the attacking direction and playing a pass to an area that is opposite to which it was received from. The strength of these outcomes varied for different time periods before receiving the ball. When players explored their environment with higher than average head turn frequency and excursion, they used more complex action opportunities afforded by the surrounding environment. Considerations for future research and practical implications are discussed.

6.2 Introduction

"Don't turn blind" or "check your shoulder" is often exclaimed by coaches when a player unwittingly turns into an opponent, usually resulting in the loss of possession. Given the dynamic nature of football match-play (Memmert, Lemmink, & Sampaio, 2017), performance is determined by a complex interaction between various physical, psychological, technical and tactical components (Brink et al., 2018; Hughes et al., 2012; Lovell et al., 2018; Sarmento et al., 2018a). Therefore, understanding specific determinants of performatory actions with the ball can be difficult, as the events that lead to a successful pass, for example, will be a complex combination of the physical, psychological, technical and tactical components of the game for that specific pass. Performance analysis in football has typically focussed on player actions with the ball (Carling et al., 2005; Sarmento et al., 2014), as variables such as possession (Castellano et al., 2012; Liu et al., 2015), pass accuracy (Liu et al., 2016; Rampinini et al., 2009; Redwood-Brown, 2008), shots on goal (Castellano et al., 2012; Liu et al., 2016; Rampinini et al., 2009), and pass effectiveness (Rein et al., 2017) have been related to overall performance. Given that actions with the ball are so valuable for overall match success, it is important to also understand the factors that lead up to them. Whilst coaches and players know intuitively that it is important to visually scan their surroundings in order to aid performance (Pulling et al., 2018), to date, little research has been devoted to understanding how players visually perceive their surroundings, and how this relates to on-pitch football performance.

In order for a player to perform a successful action with the ball in football, they must prospectively guide their actions (Adolph et al., 2000; Fajen, 2007; Fajen et al., 2009; Reed, 1996). To do this, players engage in visual exploratory actions, in which they move their body, head and eyes to visually perceive the game around them (Gibson, 1966, 1979; Reed, 1996). In doing so, the player is able to perceive the availability of space and other players, which provides information about the opportunities to act (known as affordances; Fajen et al., 2009; Gibson, 1979), such as an open pass, space to run into, or time to shoot. Critically, players can engage in this exploratory action *before* they receive the ball, which allows the guidance of their performatory actions with the ball once they have gained possession (McGuckian, Cole, Chalkley, Jordet, & Pepping, 2019). This visual exploratory action, therefore, is an important consideration when analysing performatory actions with the ball in football.

Previous investigations have shown that an increase in a player's exploratory action prior to receiving the ball, expressed as a higher frequency of head movements, resulted in improved performance with the ball. These improvements in performatory actions include faster subsequent passes (McGuckian et al., 2019), more turns with the ball and more forward passes (Eldridge et al., 2013), and a higher likelihood of playing a successful pass (Jordet et al., 2013). Taken together, this research shows the importance of visually scanning one's surroundings *prior* to receiving the ball. Despite these encouraging findings, the exploratory head movements of football players have been scarcely investigated during live match-play (McGuckian et al., 2018c), indicating a need to strengthen the evidence base with investigations that comprehensively capture the exploratory actions used by players in competitive settings.

In football, the constant movement of two teams of 11 players results in a dynamic and complex environment in which players compete (Memmert et al., 2017). As a consequence, a pass to a teammate that is afforded in one instance may not be afforded to the player in the next instance (Fajen, 2007; Fajen et al., 2009). Given their constantly changing environment, it is important to understand when, in the time that players spend before ball possession, visual exploration is most important for performance with the ball. Jordet et al. (2013) investigated the visual exploratory head movements that occurred in the 10-seconds before ball possession and found that a higher frequency of head movements increased the chance of a successful pass to a teammate (i.e. successful performatory action). However, affordances for a footballer can change drastically in 10-seconds, and it may be that exploratory action in a shorter time period before ball possession could be more important for subsequent successful performance with the ball. McGuckian et al. (2018a) investigated exploratory actions one, two and three seconds before ball possession, and showed that players were able to respond with a pass more quickly when they had longer (two or three seconds) to explore before gaining ball possession; that is, a lack of time to explore (i.e. one second of exploration) did not allow enough time for the players to adequately determine future opportunities for action. With a better understanding of the optimal time-periods to explore before a player gains possession of the ball, practitioners can better focus their assessment and development of exploratory head movement in applied settings.

To allow an extended understanding of the behaviour in the information rich environment that players compete, previous definitions of visual exploratory action in football require further elaboration. Previously, visual exploration in a football context has been operationally defined as movements of the "body and/or head prior to receiving the ball, engaged in to perceive information away from the ball and to act appropriately when the ball arrives" (Jordet, 2005, p. 141). While logical, this definition is somewhat subjective and may inadvertently miss important qualitative information about the exploratory head movements used by footballers. For example, a player who looks away from the ball to their right, then further to their right before looking back towards the ball, may be picking up different environmental information (and therefore affordances) than when that same player only looks away from the ball to their right and straight back to the ball. The first situation could be described as a *sequential exploration* (Jordet, 2005), and it is functionally and kinematically distinct to the second situation. Consequently, there is a need to supplement the operational definition used previously by defining exploratory action by the movement itself. McGuckian et al. (2018a) defined visual exploratory action as "a distinct movement of the head about the longitudinal axis" (p. 8). Similarly, Chalkley et al. (2018) validated the measurement of exploration as head movement that occurs around the longitudinal (yaw) axis. Definition of visual exploration for information in situations where individuals are surrounded by information in this manner provides a relevant and complete representation of the exploratory head movements used by players (in the yaw orientation), and it covers both sequential and non-sequential head movements. Therefore, the definition given by McGuckian et al. (2018a) and validated by Chalkley et al. (2018) has been adopted here.

Another important aspect of visual exploration in football, related to *how much* of the environment a player has explored, is the total radial distance of a head turn, here termed *excursion*. Despite giving an understanding of the magnitude of a head turn, and being recognized to be an important aspect of exploration (Jordet & Pepping, 2018; McGuckian, Chalkley, Shepherd, & Pepping, 2018a; McGuckian et al., 2019), previous quantification of exploration through manually counting head movements is unable to accurately quantify excursion. For this reason, exploration excursion has thus far not received any attention in the scientific literature.

Building upon previous research, inertial measurement units (IMUs) have recently been validated to quantify exploratory head movements (Chalkley et al., 2018), and have been used in representative laboratory environments (McGuckian et al., 2018a, 2019). Housed in an elastic headband and worn at the back of the player's head, these devices allow time- efficient data collection and analysis on whole teams of players and provide sensitive and objective data collection that is able to detect the rapid head movements used by footballers in live match-play. Together, the variables obtained from head-mounted IMUs reported in this study give an indication of *how often* a player explores their environment (i.e. the rate of exploration - frequency) and *how much* of the environment a player explores (excursion) before gaining possession of the ball (McGuckian et al., 2018a).

Despite the recent interest in exploratory head movement of footballers, it is unclear how and when - in such a fast-paced and constantly changing environment - exploratory head movements before ball possession are related to performance with the ball in 11v11 match-play. To prepare for elaborate research questions that include football specific individual differences and contexts, a general understanding of the relationships between exploration and on-ball performance is required. To that end, the primary aim of this study was to further our understanding of how exploratory head movements relate to performance with the ball, and how this relationship changes with exploration in various time-periods before gaining possession of the ball. In doing so, the frequency and excursion of football players' head movements before ball possession were quantified, in 10 increasing time-periods, up to 10-seconds before ball possession (i.e. 0-1 second before ball possession; 0-2 seconds before ball possession, etc. up to 0-10 seconds before ball possession; see also Figure 6.1). Following previous research (Eldridge et al., 2013; Jordet et al., 2013; Pocock et al., 2019), exploratory head movements were then related to common important measures of on-ball performance. It was expected that increased head turn frequency and head turn excursion before gaining possession of the ball would result in a higher likelihood of successful actions with the ball. It was further expected that exploratory head movement performed closer to the time of ball reception would be more closely associated with on-ball performance than temporally distant exploration.

This study is the first of its kind to consider the frequency and excursion of exploratory head movements. Hence, the relationship between the frequency and excursion of head movements have not previously been examined. Therefore, a secondary aim of this study was to investigate the relationships between these two exploratory variables in the defined time-periods before ball possession. It was expected that head turn frequency and head turn excursion would be closely related across all time-periods before ball possession. That is, it was hypothesised that as the frequency of head turns increases the total excursion of head turns also increases.

6.3 Methods

6.3.1 Participants

Participants were 32 male football players aged 16 to 30 years (19.03 ± 2.88 years). The sample represented all regular outfield playing positions. Goalkeepers were not included in the study due to the specificity of their role. Participants were conveniently recruited from clubs playing in the Australian National Premier League, therefore representing a group with homogeneous playing ability. The participants were assessed to be at the standard of semi- elite players in Australia (Swann et al., 2015). To be included in the study, participants needed to be considered free from injury by club medical staff. In accordance with the Declaration of Helsinki, written informed consent was obtained from all adult participants and the parents/legal guardians of all non-adult participants. The protocol was approved by the Australian Catholic University Human Research Ethics Committee (Application ID: 2017-154H) and participants were free to withdraw at any stage.

6.3.2 Procedure

Participants competed in 11v11 match-play according to official rules (International Football Association Board, 2017), with some minor adaptations. Given that players wore an IMU on their head, matches could not be officially sanctioned by the governing body. Instead of collecting data in competitive matches, participants played in pre-season games in which final team selection was not yet decided. Additionally, as a pre-season load management precaution, matches were not all played as two halves of 45-minutes each. Instead, play was divided into two or three playing periods that ranged from 20-45 minutes each, resulting in total match times of between 60 and 80 minutes. Despite the above adaptations, the games were deemed to be acceptably competitive and representative of competitive match-play.

Outfield players wore a 9-degrees-of-freedom IMU (SABELSense, Nathan, Australia), housed within an elastic headband, over their occipital protuberance while playing. Data were captured at 250 Hz and stored locally on each IMU's memory card. Following the completion of games, data were downloaded and processed using a custom-made algorithm developed in MATLAB (MathWorks, Natick, USA). This previously validated algorithm determines the time at which a distinct head turn occurs, defined as a movement of the head about the longitudinal axis that exceeds 125deg/s (Chalkley et al., 2018; McGuckian et al., 2019). Further, the algorithm determines the total excursion (i.e. angular distance) of each head turn by finding the absolute difference in orientation of the IMU between the beginning and end of each head turn. Together, the outputs from the head-mounted IMU gave an indication of how often a player explored the field and how much of the field the player explored.

Matches were video recorded with two high-definition video cameras (Sony FDR-AX100E, Tokyo, Japan) at 50 Hz from an elevated position along the side of the playing area. One video camera was zoomed close to the ball, while the other was zoomed out to give a wide angle of the playing field. The combination of the two camera angles ensured quality footage to assist with notational analysis of performance with the ball.

6.3.3 Variables

The two video sources were synchronised with each player's IMU data to allow manual coding of actions with the ball and the calculation of variables used for statistical analysis.

6.3.3.1 Exploratory action

Head turn frequency (HTF): The total number of head turns - as obtained from the IMU data – were divided by the number of seconds in that time-period, giving the frequency of head turns before ball possession for each time-period before ball possession (see Figure 6.1).

Head turn excursion (HTE): The excursion of each head turn - as obtained from the IMU data – was summed to give a total excursion for each time-period before ball possession. In order to time-normalise excursion and therefore compare different time-periods, the total HTE was then divided by the number of seconds in the time-period, therefore expressing HTE in total degrees per second of play (see Figure 6.1).

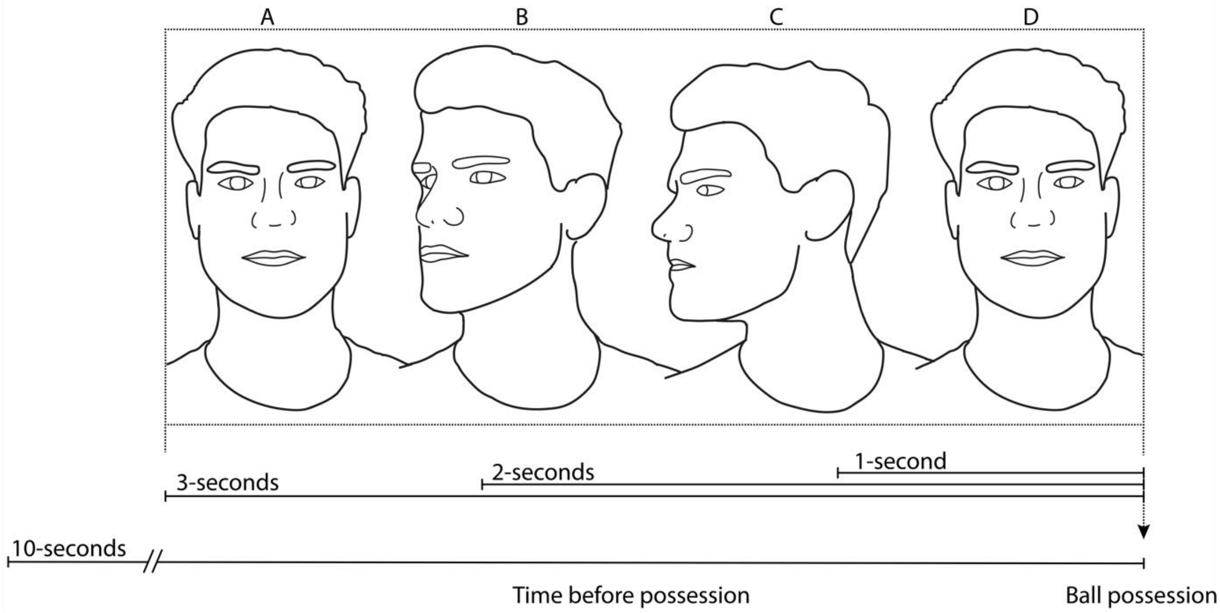


Figure 6.1 An example of three head turns during a 3-second period of time before possession: One head turn from A to B (approx. 45 degrees), one head turn from B to C (approx. 45 degrees), and one head turn from C to D (approx. 90 degrees). For this 3-second period, the head turn frequency is equal to 1.0 (three turns/three seconds) and the head turn excursion is equal to 60-degrees per second (180-degrees/three seconds).

6.3.3.2 Performance with the ball

Each players' possessions – as coded in SportsCode v.11.2.15 (Hudl, Lincoln, USA) – were tagged with technical on-ball performance indicators commonly used in performance analysis research (Dellal et al., 2011b; Hughes & Franks, 2005; Liu et al., 2016; Morgans et al., 2014; Russell, Rees, & Kingsley, 2013). An operational definition, including the total number of occurrences across all participants, of each of the performance variables are given in Table 6.1. Together, these tagged variables described the players' actions with the ball and were treated as outcome variables in the statistical analysis.

6.3.3.3 Time before possession

The exploratory actions of each player were collected for the time prior to each individual ball possession for ten time-periods, spanning from 1-second before ball possession to 10-seconds before ball possession (see Figure 6.1). The players were deemed to be in possession of the ball once their foot (or other legal body part) first made contact with the ball. For a one-touch pass, the time at which foot-to-ball contact was made was also used to signify the moment of ball possession.

Table 6.1 Operational definition of each performance outcome.

Performance Outcome	**Coded Action**	**Definition**	**Total number of occurrences**
Pass Direction - Field-centric (PD-FC)	Pass Forward	The direction of a pass is in the team's attacking direction.	265
	Pass Backwards	The direction of a pass is in the team's defensive direction.	106
Pass Direction - Player-centric (PD-PC)	Pass Behind	The direction of a pass is behind the player relative to the area it was received. For example, when a player receives a pass from one side of the field and plays a pass to the other side of the field.	172
	Pass Return	The direction of a pass is returned back towards the area to which it was received. For example, when a player receives a pass from one side of the field and plays a pass back to the same side of the field.	141
Turn with the Ball	Turn with the Ball	After receiving the ball, the player turns with the ball in order to move in a different direction.	261
	No Turn with the Ball	After receiving the ball, the player completes a subsequent action without turning with the ball.	522
One-Touch Pass	One-Touch Pass	A pass in which the player requires no more than one touch (i.e. the pass itself) to deliver the ball to a teammate. Only possessions in which a pass was attempted were included.	168
	Not One-Touch Pass	A pass in which the player takes at least one touch to control the ball and another to pass the ball (i.e. at least two touches). Only possessions in which a pass was attempted were included.	467
Pass Success	Successful Pass	An intentionally played ball which successfully reaches a teammate and possession is retained.	549
	Unsuccessful Pass	An intentionally played ball which goes out of bounds or is intercepted by the opposition and results in losing possession.	71

Note. Pass Direction – Player-centric can include passes in all field-centric directions (i.e. a *pass behind* and a *pass return* can also be a *pass forward* or a *pass backwards*).

6.3.4 Statistical analysis

6.3.4.1 Inter-rater reliability

To ensure accurate coding of performance with the ball, 159 of the 783 possessions (20%) were coded by a second coder. Inter-rater reliability (IRR) analysis was performed to determine the degree of consistency between the two coders' assessments of performance. Kappa values (Cohen, 1960) were calculated for each performance measure presented in the results. For pass direction – player centric (PD-PC) and pass direction – field centric (PD-FC), kappa values were calculated for each pass direction and averaged to provide a single IRR value (Landis & Koch, 1977). Kappa values indicated substantial agreement between coders for PD-PC (k = .724, 95% CI [.598, .850]) and turns with the ball (k = .641, 95% CI [.522,

.760]), and almost perfect agreement for pass success (k = .835, 95% CI [.758, .912]), PD-FC (k = .854, 95% CI [.767, .940]) and one-touch pass (k = .817, 95% CI [.720, .914]).

6.3.4.2 Descriptive analysis

One-way repeated measures analyses of variance (ANOVA) were conducted to compare the effect of time before possession (ten levels) on the average HTF and HTE. When Mauchly's test indicated the assumption of sphericity had been violated, the Greenhouse-Geisser correction was used to adjust the degrees of freedom. Post-hoc comparisons were completed on adjacent levels using Bonferroni tests. To investigate the relationship between HTF and HTE, exploratory Pearson's correlation tests were run on the HTF and HTE for each time-period before possession. Alpha was set at $p < 0.05$.

6.3.4.3 Relationship between exploration and performance with the ball

Research has demonstrated that individual players show differences in the frequency of head turns before ball possession (McGuckian et al., 2019). Therefore, we normalised data to input into odds ratio (OR) calculations by comparing each player's HTF and HTE before each ball possession to their individual average HTF and average HTE across all of their own possessions. As a result, the HTF and HTE for each possession for each player was categorised as being either higher or lower than their individual average HTF and average HTE.

For each time period before ball possession, ORs were calculated to determine the association between exploration (higher or lower HTF and HTE) and each performance outcome as described in Table 6.1. The first listed action (i.e. *pass forward, pass behind, turn with the ball, one-touch pass, and successful pass*) for each outcome was treated as the outcome of interest. For each OR, a value above 1 indicated that the outcome of interest was more likely to occur when the players' HTF or HTE before ball possession was higher than their individual average. In contrast, an OR below 1 indicated that the outcome of interest was more likely to occur when the players' HTF or HTE before ball possession was less than their individual average (Schmidt & Kohlmann, 2008; Szumilas, 2010).

6.4 Results

The mean, standard deviation and range of HTF and HTE for each time-period before ball possession, as well as the correlation between HTF and HTE, are shown in Table 6.2. As participants came closer to receiving the ball (i.e. time before possession approached 1-second), the mean HTF and HTE became significantly higher. There was a strong correlation between HTF and HTE for all time-periods before possession, with the strongest relationship occurring 10-seconds before ball possession.

Table 6.2 Mean, standard deviation and range of head turn frequency (HTF) and head turn excursion (HTE), and correlation between HTF and HTE for each time-period before possession.

Time-period before possession	Mean (SD) HTF (turns/ second)	HTF range	Mean (SD) HTE (degrees/ second)	HTE range	Correlation between HTF and HTE (Pearson's *r*)
1-second	1.44 (0.53) #	0.50 – 2.96	56.11 (27.27) #	12.47 – 106.75	.666*
2-seconds	1.32 (0.40) #	0.70 – 2.48	50.60 (20.19) #	15.70 – 88.20	.658*
3-seconds	1.20 (0.34) #	0.67 – 2.04	45.64 (15.63) #	20.83 – 80.43	.639*
4-seconds	1.15 (0.32) #	0.65 – 1.86	43.69 (14.32) #	20.47 – 71.54	.658*
5-seconds	1.09 (0.28) #	0.59 – 1.71	41.43 (13.12) #	18.18 – 66.64	.670*
6-seconds	1.05 (0.27) #	0.52 – 1.67	39.90 (12.09) #	16.83 – 63.47	.678*
7-seconds	1.02 (0.25) #	0.51 – 1.53	38.63 (11.46) #	17.33 – 61.03	.707*
8-seconds	0.99 (0.23) #	0.53 – 1.43	37.27 (10.85) #	19.09 – 58.59	.718*
9-seconds	0.96 (0.22) #	0.50 – 1.36	35.96 (10.55) #	18.29 – 58.05	.728*
10-seconds	0.95 (0.21) #	0.49 – 1.29	35.29 (10.30) #	18.03 – 57.76	.744*

Note. # indicates difference to adjacent time-periods at $p < 0.05$, * indicates correlation at $p < 0.001$.

Odds ratios (±95% CI) for each performance outcome across each time period before ball possession are presented in Figures 6.2 to 6.6.

Pass forward: When players had a higher HTF 2-seconds to 9-seconds before ball possession they were more likely to play a forward pass. A higher or lower HTE was not associated with a higher likelihood of playing a forward pass for any time-period before gaining possession of the ball (Figure 6.2).

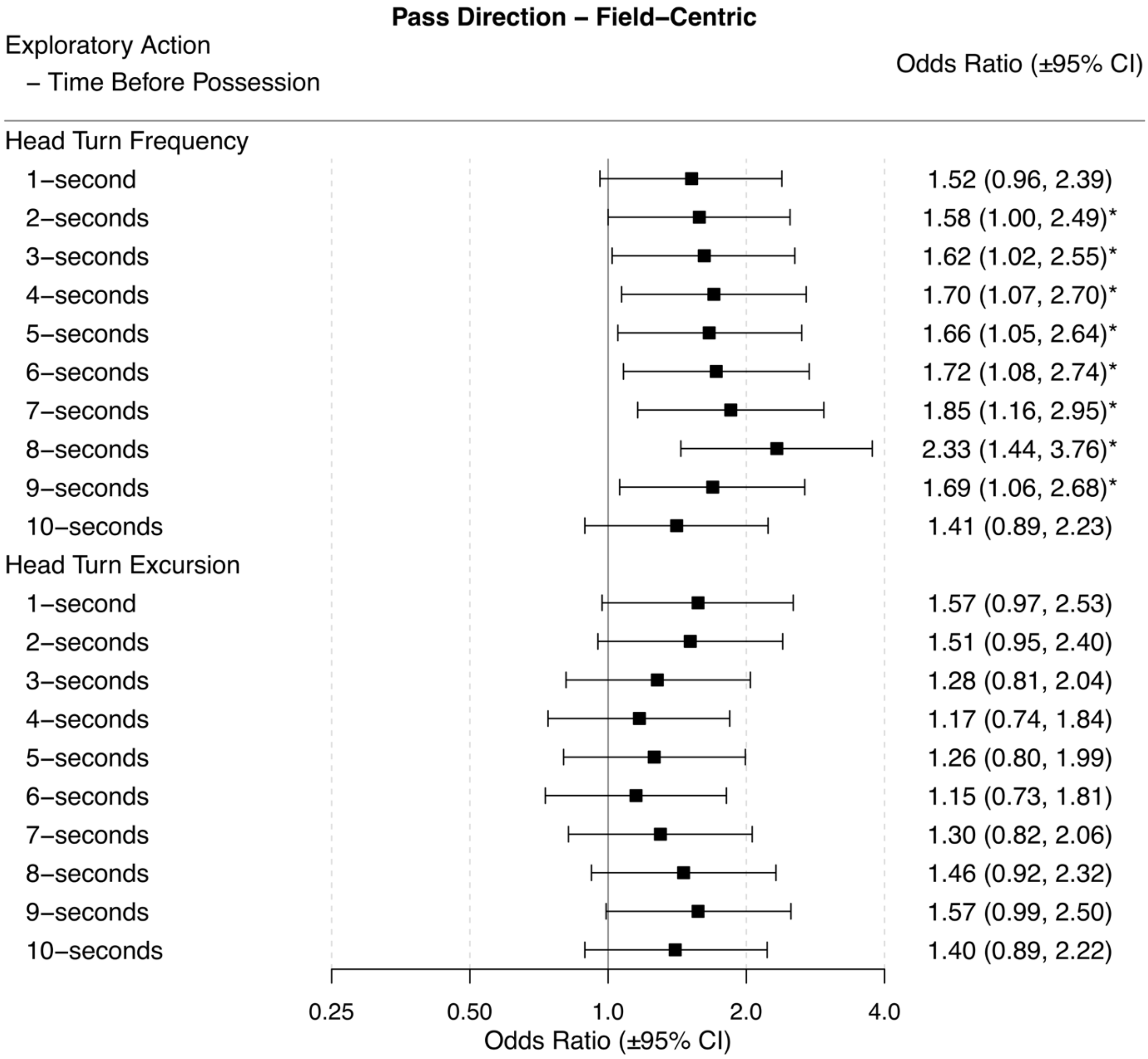


Figure 6.2 Odds ratios (±95% CI) for each time period before ball possession, describing the associations between HTF and HTE, and pass direction – field centric. * indicates statistical significance, as the 95% CIs do not cross 1.

Pass behind: A higher HTF 1-second, 2-seconds and 10-seconds before gaining ball possession was associated with a higher likelihood of playing a pass to an area opposite to where it was received from (Figure 6.3). When players had a higher HTE before ball possession they were more likely to play a pass to an area that was opposite to where it was received from for all time-periods except for 9-seconds before gaining possession of the ball. Odds ratios indicated that with a higher HTE during the 1-second to 6-seconds before gaining ball possession, players were two to three times more likely to play a pass to an area that was opposite to where it was received from (Figure 6.3).

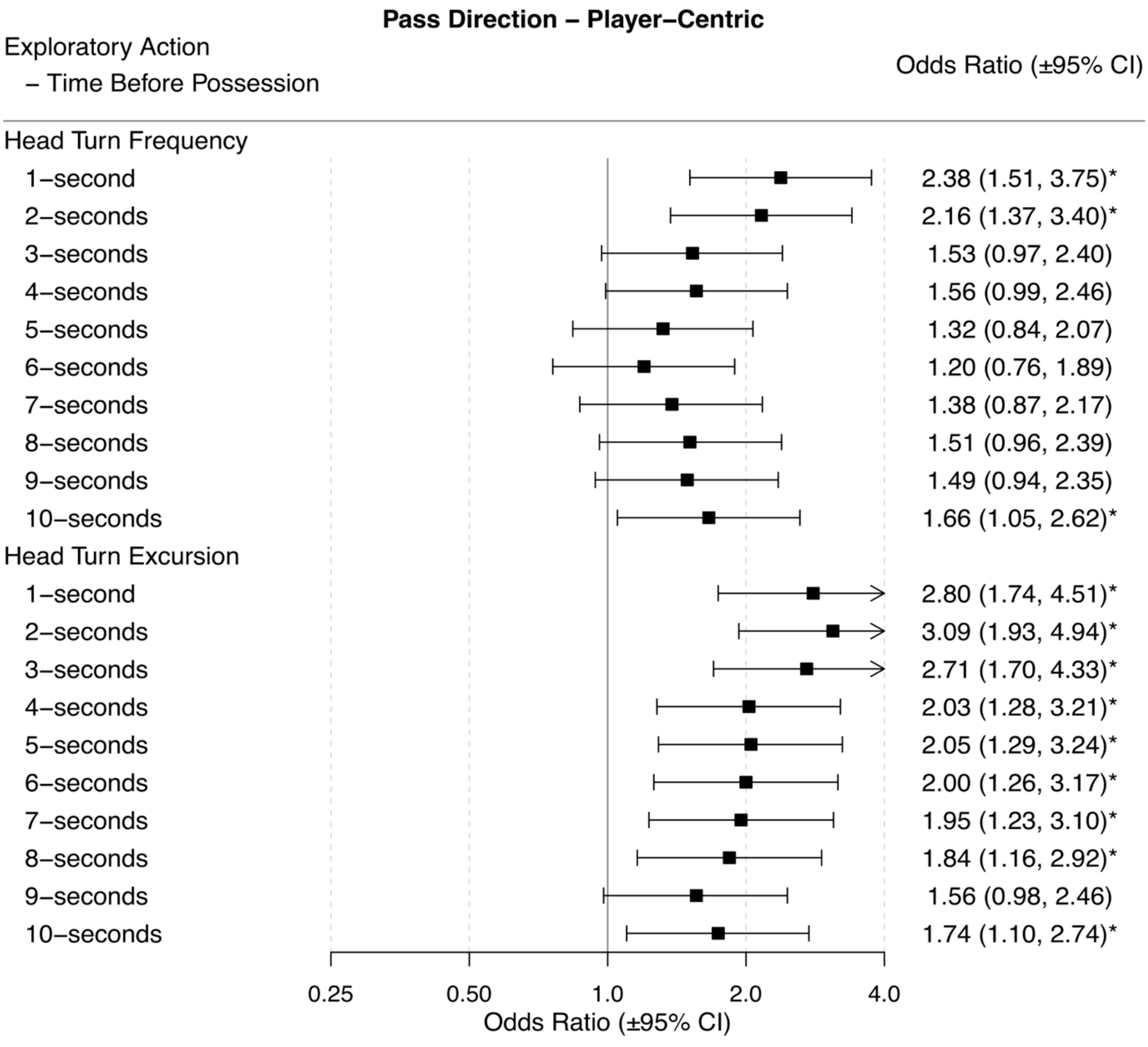


Figure 6.3 Odds ratios (±95% CI) for each time period before ball possession, describing the associations between HTF and HTE, and pass direction – player centric. * indicates statistical significance, as the 95% CIs do not cross 1.

Turn with the ball: When players had a higher HTF in the 1-second or 2-seconds before gaining possession they were more likely to turn with the ball. When players had a higher HTE they were more likely to turn with the ball for all time-periods before gaining possession of the ball (Figure 6.4).

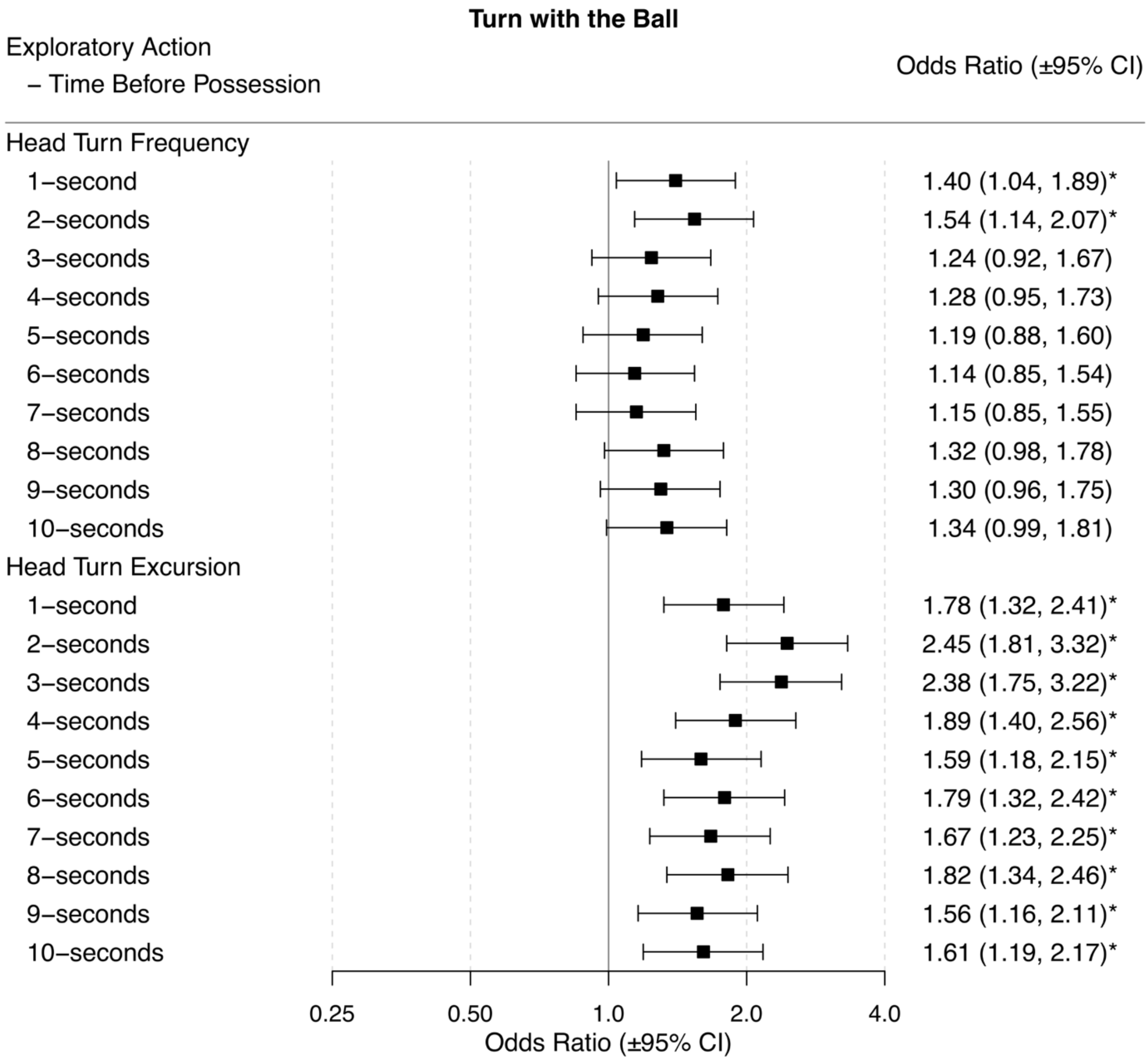


Figure 6.4 Odds ratios (±95% CI) for each time period before ball possession, describing the associations between HTF and HTE, and turns with the ball. * indicates statistical significance, as the 95% CIs do not cross 1.

One-touch pass: Players were more likely to play a one-touch pass when they had a lower HTF 2-seconds before gaining possession of the ball. Players were more likely to play a one-touch pass when they had a lower HTE in the 2-seconds, 3-seconds, 4-second, 9-seconds and 10-seconds before receiving ball possession (Figure 6.5).

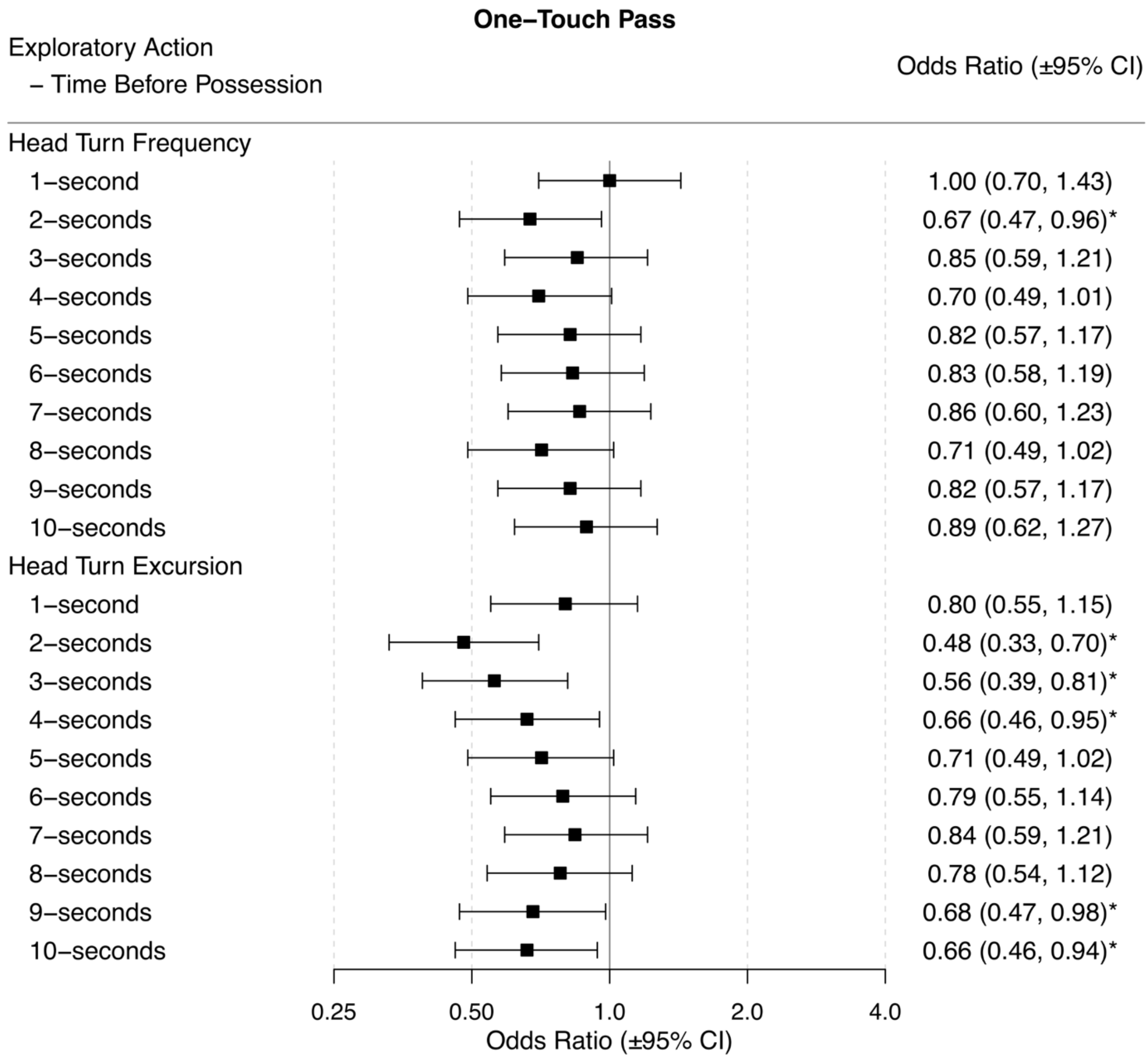
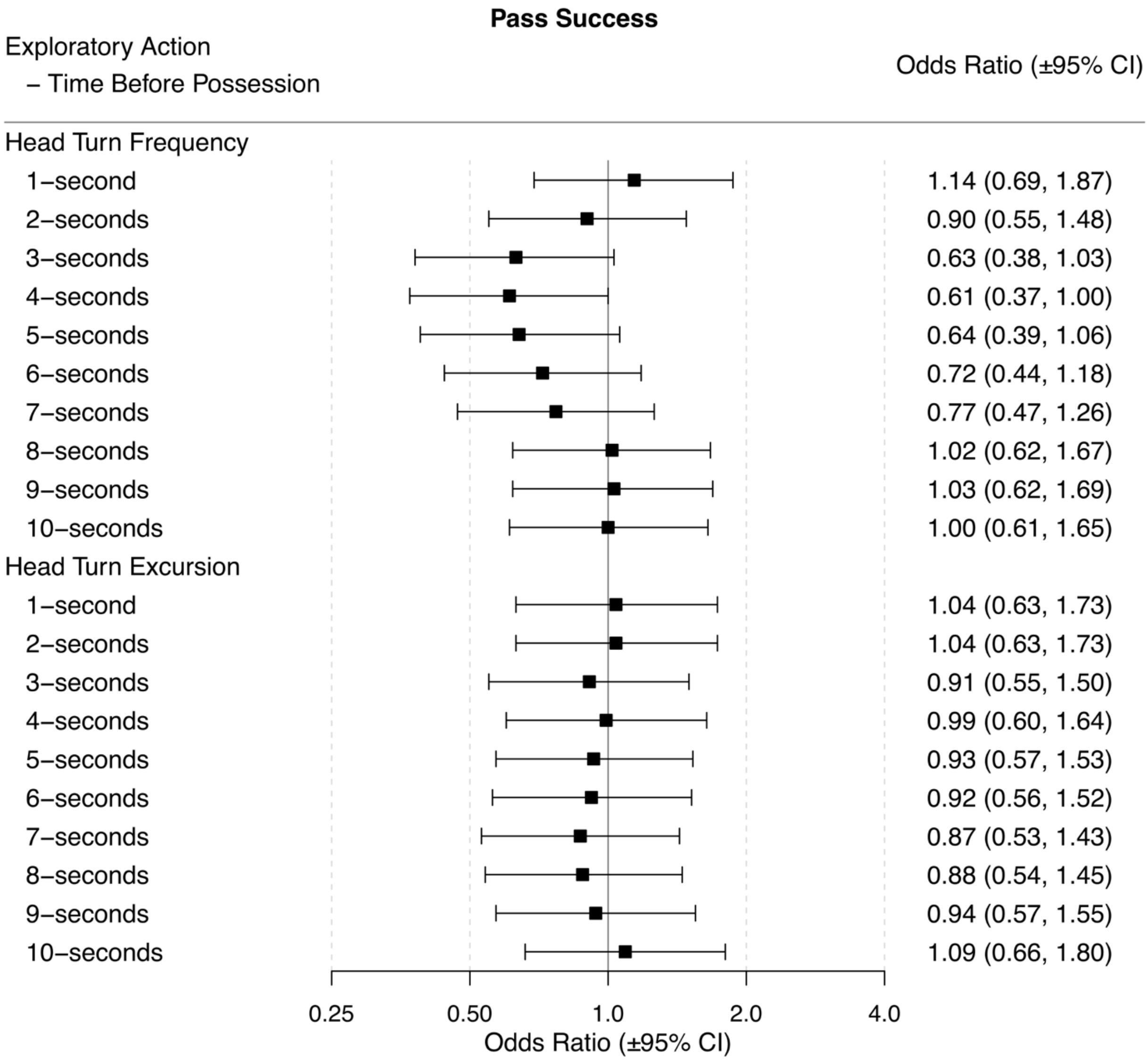


Figure 6.5 Odds ratios (±95% CI) for each time period before ball possession, describing the associations between HTF and HTE, and one-touch passes. * indicates statistical significance, as the 95% CIs do not cross 1.

Successful pass: Neither HTF nor HTE before ball possession were associated with the likelihood of playing a successful pass for any time-period before ball possession. However, for the 3-seconds, 4-seconds and 5-seconds before gaining possession of the ball, the likelihood of a successful pass with a lower HTF approached statistical significance (Figure 6.6).

Figure 6.6 Odds ratios (±95% CI) for each time period before ball possession, describing the



associations between HTF and HTE, and pass success. * indicates statistical significance, as the 95% CIs do not cross 1.

6.5 Discussion

With the aim of further understanding exploratory head movements before gaining ball possession and their relationship to performance with the ball, the frequency and excursion of head movements were quantified in time-periods of increasing duration, up to 10-seconds prior to taking possession of the ball. Given frequencies and excursions higher or lower than a player's individual average, the likelihood of completing various actions with the ball were calculated.

Players completed approximately one head turn per second in the five to ten seconds before receiving the ball, and the average excursion of these head turns was approximately 37 degrees per second. However, when players came very close to receiving the ball (i.e. in the 1-second before receiving the ball), the frequency and excursion increased to approximately 1.5 head turns per second and 56 degrees per second, respectively. The average frequency of players' head movements in the current study were higher than those recorded in previous investigations (Jordet et al., 2013; Pocock et al., 2019), with the average head turn frequency in the current study being approximately 0.3 head turns/second higher than the highest average frequencies recorded by top level English Premier League players (0.62 head turns/second). This finding is likely due to the alternative definition of exploration and the use of IMU technology to quantify head movements in the current study. The definition of a head turn used in previous research would classify a look away and back to the ball as one head turn, whereas our definition would classify this as *at least* two head turns. Further, the IMU technology is able to detect smaller head movements that would not be easily detected by the human eye, which further supports a greater number of head turns being recorded with the IMU-based method. For these reasons, we would argue that the IMU-based values represent a more objective and accurate measurement of head turns than the previous method of manually counting head movements (Chalkley et al., 2018; McGuckian & Pepping, 2016).

With a shorter time-period before possession, players showed a higher HTF and HTE, indicating that, as they became closer to gaining ball possession, they explored their surroundings more extensively. This indicates exploration in support of prospective performance with the ball (Adolph et al., 2000; Fajen, 2007; Fajen et al., 2009; Gibson, 1979), as when the player recognised they were likely to receive the ball they engaged in more exploratory activity to inform their imminent actions with the ball. The changes in correlation between HTF and HTE across different time periods may indicate that these exploratory movements differed as the players came closer to receiving the ball. That is, when players were temporally further from receiving the ball (i.e. 10-seconds before possession) they may have used different types of exploration (e.g. using large and less frequent head movements) compared to when they were very close to receiving the ball (e.g. using small and more frequent head movements). The current analyses are unable to answer this hypothesis; however, it is an important question for future research to consider.

Across all time periods before ball possession, higher exploration excursion was related to a higher likelihood of turning with the ball or playing a pass to an area opposite to which it was received. The same was found in the final two seconds before gaining ball possession in relation to exploration frequency. Together, these findings suggest that when a player has gained more information about their environment through expansive exploratory activity, they are more likely to make use of what is afforded by their surrounding environment. This is, if a player has gained more information about the positions of surrounding teammates, opponents, and free space through their exploratory activity (i.e. they are not blind to their surroundings), they are more likely to utilise this information by turning with the ball or playing a pass behind them. Further support for this conclusion comes from the findings regarding one-touch passes. For some time-periods before ball possession, a lower HTE resulted in a higher chance of playing a one-touch pass. Here, it may be that players completed a one-touch pass *because* they had not sufficiently explored their environment, and therefore were forced to complete a one-touch pass back to a teammate because there were no other options perceived by (i.e. afforded to) them. It may also be that players were afforded with good passing options in front of them before receiving the ball, resulting in the ability to play a one-touch pass without the need to explore, however the current analysis is unable to assess this hypothesis. Future research should include positional data to investigate the association between inter-player distances and exploratory activity.

In line with previous research, more frequent exploratory head movements resulted in a higher likelihood of a forward pass (Jordet et al., 2013); however, the strength of this association varied across different time-periods before ball possession. When players had a HTF that was higher than their individual average HTF, there were higher odds of playing an attacking pass, however, this relationship only appears when players have longer to explore (from 4-9 seconds) before gaining possession of the ball. This finding suggests that by gaining environmental information well in advance of receiving the ball, players are able to prospectively guide actions leading to an attacking pass (Adolph et al., 2000; Fajen, 2007). Interestingly, this relationship was not found when considering the HTE before receiving the ball. Although these findings are important from a performance perspective, it suggests that the relationships between exploratory actions and performance with the ball may be more complex than simple measures of head turn frequency and excursion. In fact, in such a dynamic sporting context, it is likely that the relationships between exploration and performance are also very dynamic, which may call for more sophisticated analyses in future investigations.

Head turn frequency and excursion were not associated with the successful completion of passes, regardless of the time-period before possession that was analysed. This finding is in contrast to previous research which has reported positive associations between head turn frequency and successful pass completions (Jordet et al., 2013). In their study, Jordet et al. (2013) only included instances when the player receiving the ball was positioned between the attacking goal and the player they received the ball from. In the current study, all possessions where a pass was attempted were included. The contrasting findings may also be due to the differences in the level of expertise of participants between studies. It may be that the action capabilities of the players in the current study were a limiting factor in their ability to successfully complete more difficult passes (Fajen, 2007; Paterson, Van der Kamp, Bressan, & Savelsbergh, 2016; Witt & Riley, 2014). For example, players may have been able to perceive certain passing opportunities through extensive exploration, but their individual action capabilities (i.e. technical passing ability) may not have been reliable enough to consistently complete the afforded pass successfully. In contrast, the English Premier League players included in the study by Jordet et al. (2013) would very likely be able to reliably play a wider range of passes, resulting in a higher pass completion rate when more difficult passing opportunities were perceived.

The current study extended previous research by investigating how HTF and HTE in various time-periods before ball possession related to actions with the ball. There are, however, limitations which should be considered when evaluating the current findings. Primarily, it is important to consider that the current analysis included all offensive actions with the ball when the outcome of interest occurred. By analysing the data in this way, the specific context in which the actions with the ball occurred, such as the location on the pitch, the amount of pressure from opponents, the time of the game, the score line, the playing style of the teams involved, the individual players technical ability, etc., were not considered. It is possible that these constraints would influence the relations between exploration and performance and they should be considered in future research (Dicks et al., 2010; McGuckian et al., 2017; Oppici et al., 2017; Orth, Davids, & Seifert, 2017; Timmerman et al., 2017). For example, it may be that players are afforded different passing options in defensive areas of the pitch, which could influence the likelihood of a successful pass regardless of their exploratory actions. Further, the current sample included semi-elite players in Australia (Swann et al., 2015) and, hence, a sample of athletes with a fairly homogenous level of expertise. While similar relationships between exploration and performance have been shown in elite English Premier League players (Jordet et al., 2013), further investigations across various levels of skill and expertise are required. Using IMU technology to quantify exploratory action in future investigations will provide much needed objective data, and would effectively supplement observational data coming from video-based approaches.

Another possible focus for future research, which the current study did not investigate, is the relations between exploration and defensive actions. Thus far, research has only investigated exploratory head movement in offensive situations (Eldridge et al., 2013; Jordet et al., 2013; Pocock et al., 2019), but successful defensive performance is also influenced by one’s awareness of their surroundings. Therefore, an understanding of how exploratory head movement relates to individual actions and team structure are warranted. For example, it is likely that exploratory head movement would be related to changes in tactical exploratory movement found in small-sided games with numerical imbalances (Ric et al., 2016; Ric, Hristovski, & Torrents, 2015; Torrents et al., 2016), however future research is needed to examine this hypothesis.

More detailed understanding of how players explore may help inform coaches about what to expect from their players during game play and before receiving the ball. Our investigation showed that the way in which players explore varies greatly between players. These differences indicate a need to individualise data collection and analysis when assessing exploratory activity in applied situations.

6.6 Conclusion

The current investigation has demonstrated the importance of ‘checking one’s shoulder’ before receiving the ball by investigating the head turn frequency and head turn excursion of football players in 11v11 match-play. In particular, in order for players to make successful use of their surrounding environment, the current study suggests that players must explore their environment sufficiently by employing an exploration strategy that involves high head turn frequencies and excursions. Playing a forward pass, passing to an area opposite to where the ball was received from, turning with the ball, and playing a one-touch pass were all associated with visual exploration. Hence, the advice to not ‘turn blind’ is sound, and applied practitioners would do well to utilise these findings by designing training situations which encourage high head turn frequency and excursion in order to perform successfully. In doing so, applied practitioners may wish to implement the use of IMUs in order to easily and objectively quantify the exploratory head movements of athletes during specific training drills, thus ensuring the drills accurately represent the exploratory requirements of athletes during competitive match-play.

Chapter 7: Constraints on Visual Exploration of Youth Football Players During 11v11 Match-Play: The Influence of Playing Role, Pitch Position and Phase of Play

As Study 3 established the performance benefits of extensive visual exploration, Study 4 aimed to begin to understand how various constraints influence the exploratory actions used by football players during 11v11 match-play. This study represents the first of many that will be required to gain an in depth understanding of visual exploration in football. Positional and phase of play constraints were chosen for this study due to the high relevance for applied settings. Study 4 methodologically progressed from Study 3 by integrating global positioning systems (GPS) technology to obtain positional data. The integration of GPS and inertial sensor technology offers a wearable technology package with vast applied opportunities.

This study is currently under peer review with the Journal of Sports Science. The content has been reformatted for the purposes of this thesis. Author contributions are given in Appendix 1. Full reference details of the unpublished manuscript are:

McGuckian, T. B., Cole, M. H., Chalkley, D., Jordet, G., & Pepping, G.-J. (under review). Constraints on visual exploration of youth football players during 11v11 match-play: The influence of playing role, pitch position and phase of play. *Journal of Sports Sciences.*

7.1 Abstract

Visual exploratory action, in which football players turn their head to perceive their surrounding environment, has been shown to improve prospective performance with the ball during match-play. This scanning action, however, is relevant for players throughout the entire match, as the visual information perceived through visual exploration is needed to guide movement around the pitch during offensive and defensive play. This study aimed to understand how a player's on-pitch position, playing role and phase of play influenced the visual exploratory head movements of players during 11v11 match-play. Twenty-two competitive-elite youth footballers played a total of 1,623 minutes (M = 73.8). Inertial measurement units, global positioning system units and notational analysis were used to quantify relevant variables. Analyses revealed that players explored more extensively when they were in possession of the ball, and less extensively during transition phases, as compared to both team ball-possession and opposition ball-possession phases of play. Full-backs and wide-midfielders explored more extensively during opposition ball-possession phases than team ball-possession phases, while centre-midfielders explored more extensively during team ball-possession phases than opposition ball-possession phases. These factors should be considered as constraints on players' visual exploratory actions when developing training situations aimed at improving the scanning actions of players.

7.2 Introduction

The fast-paced environment in which footballers compete necessitates that athletes make numerous time-constrained decisions throughout the match. In order to make the most appropriate decision for a particular situation, and consequently perform a successful action, athletes must integrate a vast amount of environmental information with their own action capabilities (Araújo et al., 2006; Araujo et al., 2009). Doing so requires that the athlete has an awareness of relevant environmental information for the particular situation, as making decisions without all relevant information results in a decision based on limited affordances (Gibson, 1979; Reed, 1996). Therefore, for an athlete to make the most appropriate decisions, they must be constantly aware of their surroundings and the options that are afforded to them at any given time.

The ways in which athletes gain this environmental information for decision-making have been an area of interest in the sport expertise domain for some time (Mann et al., 2007; McGuckian et al., 2018c). In invasion sports, such as football, where players are surrounded by opportunities for action, visual exploratory head movements allow players to gain information about their environment in 360-degrees (Gibson, 1979; McGuckian et al., 2019; Reed, 1996). Investigations of visual exploratory action have primarily utilised observational methods to understand the behaviours that players display outside of a laboratory environment (Eldridge et al., 2013; Jordet, 2005; Jordet et al., 2013; McGuckian et al., 2017; Pocock et al., 2019). By quantifying the frequency (Jordet et al., 2013; McGuckian et al., 2019) and excursion (McGuckian, Cole, Jordet, Chalkley, & Pepping, 2018b) of exploratory head movements shortly before a player receives a pass, this research has shown that players use environmental information to prospectively guide their actions with the ball. Specifically, when players explore their surroundings more extensively - as indicated by a higher frequency or greater excursion of head movements before receiving the ball - they are more likely to make use of their surrounding environment by turning with the ball, playing a pass behind them or playing a forward pass (McGuckian et al., 2018b). Furthermore, players are also more likely to play successful passes (Jordet et al., 2013) and are able to make a passing decision more quickly (McGuckian et al., 2019) when they explore with high-frequency head movements before needing to make the passing action. Given the importance of this exploratory action for prospective guidance of performance, gaining a more thorough understanding of these behaviours during 11v11 match-play is warranted.

As research investigating exploratory head movement is relatively new to the sport expertise domain (McGuckian et al., 2018c), it is currently unclear to what extent various constraints influence the exploratory actions of players in an 11v11 match context. An important consideration for the development of situation awareness in youth players is the influence of positional constraints on the use of exploratory actions. As play progresses throughout a match, players position themselves on the pitch according to tactical principles in order to exploit space and create scoring opportunities (Duarte et al., 2013; Gonçalves et al., 2017a; Ric et al., 2016, 2017). As these positional movements occur, the surrounding information that is used to guide the players' actions is constantly changing. For example, when a player is in a defensive area of the pitch, the majority of specifying environmental information for that player is likely to be in front of them (i.e. in an attacking direction). In contrast, a player who is situated in a midfield area of the pitch is likely to be completely surrounded by functional environmental information. Accordingly, it is likely that each player's positioning on the pitch influences the exploratory actions that are used to perceive their surrounding environment. In spite of its apparent importance, the ways in which a player's on pitch position influences and constrains their exploratory behaviours is currently unknown.

In addition to pitch position, a player's role within the team likely constrains their exploratory actions. While many positional terms exist, the outfield playing roles within a team can be split into general units; defenders, midfielders and strikers. Commonly, defenders and midfielders are further divided into central and wide areas, resulting in five general outfield playing roles; central defenders (centre-backs), wide defenders (full-backs), centre-midfielders, wide-midfielders, and strikers (Bush, Barnes, Archer, Hogg, & Bradley, 2015; Liu et al., 2016; Yi et al., 2018). Due to the specific role demands placed on footballers, researchers have sought to quantify differences in the technical, tactical and physical demands of football match-play for the different role specific groups (Dellal et al., 2012, 2010; Hughes et al., 2012; Nevill, Holder, & Watts, 2009; Saward, Morris, Nevill, Nevill, & Sunderland, 2016). Similarly, the visual exploratory action of players may be influenced by playing role constraints. Previous investigations have primarily focussed on the visual exploration of midfield players, likely because they are more often surrounded by other players. However, gaining an understanding of any role specific differences that might supersede or mediate purely positional differences is important for coaches to be able to tailor training sessions to best develop young talent (Pulling et al., 2018).

Off-ball actions are vitally important for informing a player's positioning and movements to create space, as well as various other actions needed when one's team is not in possession of the ball (e.g. defensive positioning, interception of passes, etc.). Consequently, it is of vital importance to gain an understanding of one's exploratory actions during moments that are not directly related to on-ball actions. Previous investigations of visual exploratory action have typically focussed on a player's behaviour shortly before, or during, on-ball performances (Eldridge et al., 2013; Jordet et al., 2013; McGuckian et al., 2019). Here we argue that the perception of visual information during off-ball periods is of equal, if not of higher, importance to a player's performance. In the current paper we investigate players' perception of action-relevant visual information during off-ball periods by presenting data on the exploratory actions of players across an entire game, irrespective of ball-possessions, and categorised according to various phases of play. In football, four important ball-possession phases can be identified; i) when a player him or herself is in ball-possession; ii) when a player's team is in ball-possession (i.e. offensive play); iii) when the opposition team is in ball-possession (i.e. defensive play); and iv) when the ball is in transition between team ball-possession and opposition ball-possession (i.e. ball-possession is in contention). Teams have clear tactical intentions during defensive and offensive phases of play, which are reflected in player positioning and movement profiles (Clemente, Couceiro, Martins, Mendes, & Figueiredo, 2013; Duarte et al., 2012; Frencken & Lemmink, 2008; Gréhaigne & Godbout, 2013; Yue, Broich, Seifriz, & Mester, 2008). Although these differing tactical intentions are likely to present constraints on exploratory action, the nature of these differences has yet to be investigated.

In order to inform applied practice and improve the development of exploratory activity, a comparison of visual exploratory action based on positional constraints is warranted (Pulling et al., 2018). Further, given that teams tactically position themselves differently when in possession and when not in possession of the ball, a consideration of ball- possession phase of play is necessary. Therefore, the current study aimed to compare the visual exploratory actions of youth football players based upon; i) their location on the pitch;
ii) their playing role within the team; and iii) the ball-possession phase of play of the game. It was expected that players would display more extensive exploratory actions when they were located in more central areas of the pitch. Similarly, as they are more likely to be surrounded by other players, it was expected that centre-midfield players would display more extensive exploratory actions than other positions. While it is possible that the ball-possession phase of

play would influence players' visual exploratory actions, this analysis was treated as explorative and there were no specific hypothesised differences identified *a priori*.

7.3 Methods

7.3.1 Participants

Participants were 22 male football players aged 15 to 17 years (*M* = 16.25, *SD* = 0.72) who had 8 to 13 years playing experience (*M* = 10.77, *SD* = 1.36). The players were categorised according to their playing role (Bush et al., 2015; Liu et al., 2016; Yi et al., 2018): full-backs (FB, *n* = 4), centre-backs (CB, *n* = 4), wide-midfielders (WM, *n* = 4), centre- midfielders (CM, *n* = 7), and strikers (ST, *n* = 3). Goalkeepers were not recruited due to the specificity of their role. Participants played for the same semi-professional club in the Australian National Premier League competition and represented a homogeneous group of competitive-elite youth players in Australia (Swann et al., 2015). Participants (and their parent/guardians, where appropriate) gave informed consent/assent prior to taking part in the experiment and were free to withdraw at any stage. The research protocol and study methods were approved by the lead institution's Human Research Ethics Committee (Application ID: 2017-154H).

7.3.2 Data collection

As the rules of football only permit the use of certain wearable technologies during sanctioned matches, data were collected while participants competed in 11v11 training matches that were played in accordance with official rules (International Football Association Board, 2017). Across all players and matches, a total of 1,623 minutes of playing time was collected. Following previous research (Chalkley et al., 2018; McGuckian et al., 2019, 2018b), head movement data were sampled at 250 Hz with inertial measurement units (IMU) which incorporate a ±7 Gauss 3 degrees of freedom (3DOF) magnetometer, a ±2000°/s 3DOF gyroscope, and a ±16g 3DOF accelerometer. IMUs were housed in an elastic headband and worn over the external occipital protuberance. Pitch position data were sampled at 10 Hz with global positioning system (GPS) units housed in an elastic bib (Catapult Minimax S4, Melbourne, Australia). Matches were record at 50 Hz with two high-definition video cameras (Sony FDR-AX100E, Tokyo, Japan) from an elevated position at the halfway line of the pitch. Video footage was coded in SportsCode v.11.2.15 (Hudl, Lincoln, USA) to record relevant match events (i.e. team possession, ball out of play, free kicks, etc.).

7.3.3 Variables

The IMU, GPS and video data sources were synchronised and processed in MATLAB (MathWorks, Natick, USA) to obtain variables relating to pitch position and visual exploratory head movement. Data were excluded when players were not located on the playing area and during stoppages in play. The resulting data structure included the pitch zone, ball-possession phase of play, head turn frequency and head turn excursion at every data-point of every player.

7.3.3.1 Playing role

Participants' primary playing role was manually noted in order to analyse differences in exploratory action between playing positions.

7.3.3.2 Pitch position

The playing area was divided into 30 pitch zones according to Figure 7.1. To ensure data accuracy, GPS longitude and latitude coordinates with a horizontal dilution of precision greater than 1.25 were excluded (Malone, Lovell, Varley, & Coutts, 2017; Massard, Eggers, & Lovell, 2017). GPS coordinates were then used to determine player location on the pitch at each time-point (Castellano, Fernández, Echeazarra, Barreira, & Garganta, 2017; Coutinho et al., 2019; Gonçalves et al., 2017b) and consequently categorised into the relevant pitch zone.

7.3.3.3 Ball-possession phase of play

The phase of play was coded as either; player himself was in possession (Player in Ball-possession, PBP), their team (but not the player) was in ball-possession (Team in Ball-possession, TBP), the opposition team was in ball-possession (Opposition in Ball-possession, OBP) or the ball was in transition (Ball in Transition, BT). PBP, TBP and OBP phases were coded when players had comfortable possession of the ball. BT phases were coded when ball-possession was in contention, such as when players were duelling for the ball or a long pass was played and either team could gain possession.

7.3.3.4 Exploratory head movement

Head turn frequency (HTF) and head turn excursion (HTE) were calculated using a validated algorithm (Chalkley et al., 2018) applied in previous investigations to quantify head movements with IMUs (McGuckian et al., 2019, 2018b). In order to quantify exploratory actions across the entire playing period, a 1-second rolling window (i.e. a 250 data-point window) was applied across the entire dataset. At each window, the HTF and HTE were calculated, which resulted in a continuous measurement of exploration.

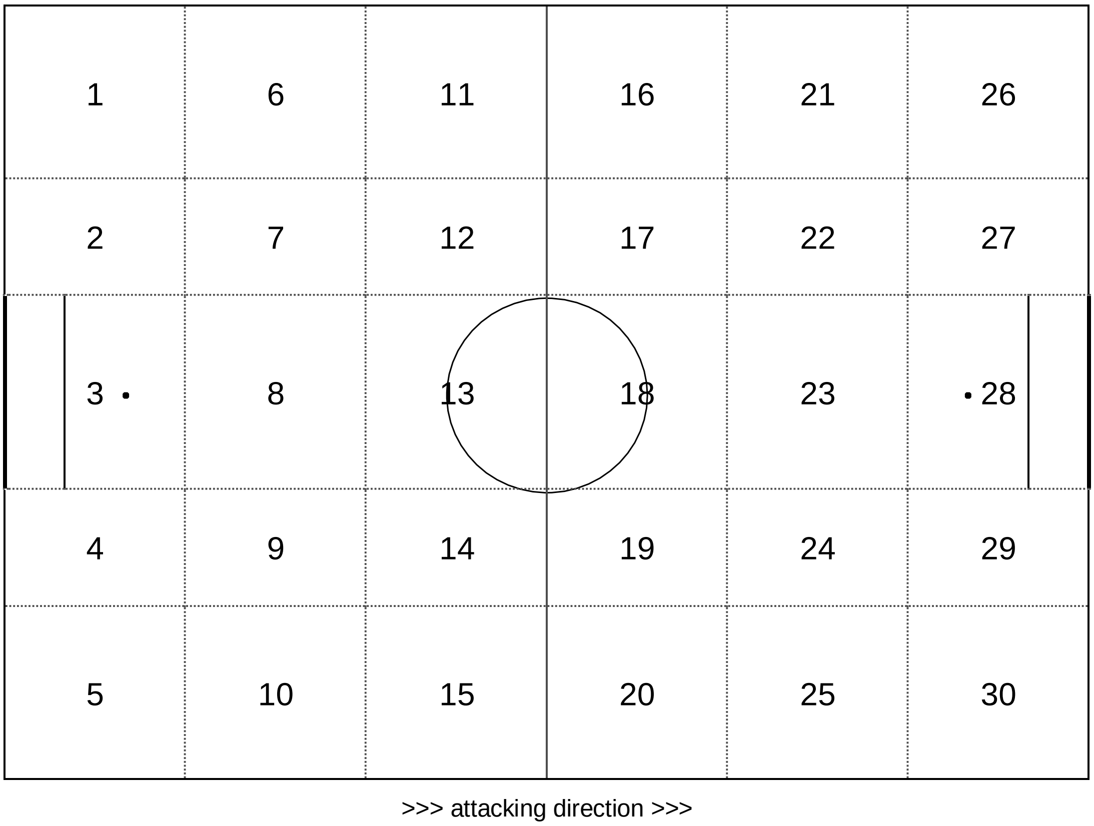


Figure 7.1 Defined pitch zones used for analyses. Attacking direction from left to right.

7.3.4 Statistical analysis

Each player's average HTF and HTE were calculated for each ball-possession phase of play while they were in each of the 30 pitch zones. Instances where there was less than 1-second of data were excluded from the analysis. Linear mixed model (LMM) analyses were employed as they are able to utilise uneven observations without the need to exclude participants from the analysis (West, Welch, & Galecki, 2007). To examine differences in HTF and HTE, separate LMM analyses with fixed factors of playing role (5 levels: FB, CB, WM, CM, ST), pitch position (30 levels) and ball-possession phase of play (4 levels: PBP, TBP, OBP, BT) were conducted for each exploratory variable. Post-hoc comparisons with Bonferroni corrections were used when significant effects were identified. Cohen's *d* was calculated as a measure of effect size, with values <0.20 indicating a trivial effect, 0.20-0.50 indicating a small to medium effect, 0.50-0.80 indicating a medium to large effect, and values >0.80 indicating a large to very large effect (Cohen, 1988, 1992). Analyses were conducted using IBM SPSS version 22 (IBM Corp., Chicago, IL) with statistical significance set at $p < 0.05$.

7.4 Results

For reference, Figure 7.2 shows the mean HTF and HTE when players were in each pitch zone. Note that these figures give a global understanding of exploration across the entire dataset, irrespective of playing role and ball-possession phase of play. As PBP and BT account for a small percentage of total playing time (2.27% and 11.52%, respectively), Figure 7.2 gives a more general understanding of exploration compared to the more detailed analyses reported below.

7.4.1 Head turn frequency

The LMM analysis on HTF revealed significant fixed effects for pitch position (F(29, 433.51) = 2.63, p < 0.001), playing role (F(4, 457.88) = 8.19, p = 0.109) and ball-possession phase of play (F(3, 1030.35) = 185.96, p < 0.001). Further, significant interactions were found for playing role by ball-possession phase of play (F(12, 1001.80) = 6.26, p < 0.001), playing role by pitch position (F(116, 392.25) = 1.33, p = 0.023) and pitch position by ball-possession phase of play (F(87, 1009.42) = 1.48, p = 0.004).

Pairwise comparisons for pitch position revealed only a small number of significant differences in HTF between zones. However, most of these comparisons showed at least small to medium effects, indicating meaningful differences in HTF between the zones (Figure 7.3).

Pairwise comparisons for the playing role by pitch position interaction showed only a small number of significant differences in HTF. Difference in means and effect sizes of pairwise comparisons for each zone according to playing role can be found in the supplementary material.

Pairwise comparisons showed that players had a higher HTF during PBP (M = 2.01) than during TBP (M = 0.89, *ES* = 1.219), OBP (M = 0.95, *ES* = 1.139) and BT (M = 0.73, *ES* = 1.314) phases. Players also had a higher HTF during OBP than during BT (*ES* = 0.305).

Pairwise comparisons for the phase of play by pitch position interaction showed that players had a higher HTF during PBP than during TBP, OBP and BT phases across a majority of pitch positions.

Pairwise comparisons showed that FB (M = 0.88) had a lower HTF than CM (M = 1.07, *ES* = 0.238), WM (M = 1.07, *ES* = 0.204) and ST (M = 1.14, *ES* = 0.281). Further, ST had a higher HTF than CB (*ES* = 0.188).

Analyses identified several significant playing role by phase of play interactions (Figure 7.4a). For all positions, players had a higher HTF during PBP than all other phases of play. Additionally, FB had a higher HTF during OBP than during both TBP and BT phases.

7.4.2 Head turn excursion

The LMM analysis on HTE revealed significant fixed effects for playing role ($F(4, 468.52) = 5.181$, $p < 0.001$) and ball-possession phase of play ($F(3, 1046.07) = 82.856$, $p < 0.001$), but not for pitch position ($F(29, 444.98) = 1.370$, $p = 0.098$). Further, significant interactions were found for playing role by ball-possession phase of play ($F(12, 1018.59) = 4.760$, $p < 0.001$) and pitch position by ball-possession phase of play ($F(87, 1025.44) = 1.523$, $p = 0.002$).

Despite not showing significance, the effect sizes for pairwise comparisons of pitch position show meaningful differences between various zones of the pitch (Figure 7.5). Generally, players had lower HTE when in central zones of the pitch compared to the defensive and attacking zones of the pitch. Difference in means and effect sizes of pairwise comparisons for each zone according to playing role can be found in the supplementary material.

Pairwise comparisons showed that players had a higher HTE during PBP (M = 58.28) than during TBP (M = 34.25, *ES* = 0.711), OBP (M = 34.40, *ES* = 0.705) and BT (M = 22.0 , *ES* = 1.117) phases. Players also had a higher HTE during TBP (*ES* = 0.506) and OBP (*ES* = 0.511) than during BT. Pairwise comparisons showed that CM (M = 38.57) had a higher HTE than FB (M = 29.54, *ES* = 0.310).

Pairwise comparisons for the phase of play by pitch position interaction showed that players had a higher HTE during PBP than during TBP, OBP and BT phases across a range of pitch positions.

Analyses identified several significant playing role by ball-possession phase of play interactions (Figure 7.4b). For CB, differences were found between all phases of play except for between TBP and OPB. For FB, differences were found between all phases of play except for between PBP and OBP, and TBP and BT. For CM, differences were found between all phases of play. For WM, differences were found between all phases of play except for between TBP and BT. For ST, differences were only found between PBP and all other phases of play.

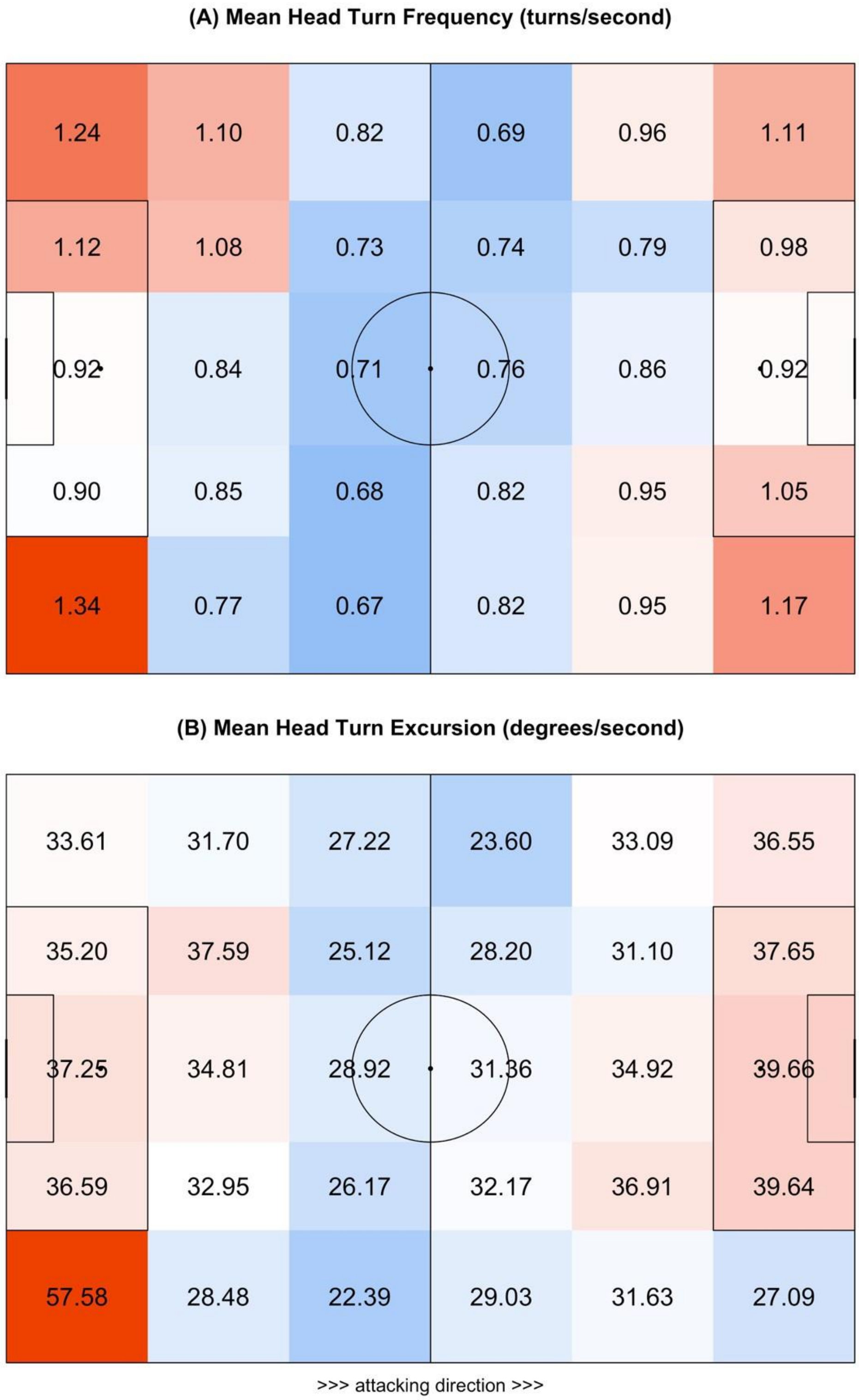


Figure 7.2 (A) Mean head turn frequency (turns/second) when in each pitch zone. Whole pitch mean HTF = 0.91 turns/second. **(B)** Mean head turn excursion (degrees/second) when in each pitch zone. Whole pitch mean HTE = 32.94 degrees/second. Attacking direction from left to right. Blue indicates zone value is less than whole pitch mean, red indicates zone value is more than whole pitch mean. Lighter shades indicate zone value is closer to the whole pitch mean.

Difference in mean head turn frequency, vertical - horizontal		Effect size: Defensive third										Midfield third										Attacking third									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Defensive third	1		0.14	0.09	0.04	0.28	0.36	0.05	0.19	0.12	0.08	0.15	0.28	0.21	0.27	0.07	0.16	0.26	0.30	0.31	0.07	0.17	0.19	0.05	0.05	0.23	0.15	0.04	0.04	0.09	0.42
	2	0.12		0.03	0.10	0.18	0.24	0.21	0.37	0.28	0.22	0.34	0.46	0.38	0.46	0.21	0.32	0.44	0.52	0.54	0.21	0.04	0.38	0.22	0.20	0.14	0.04	0.18	0.20	0.04	0.35
	3	0.09	-0.03		0.05	0.18	0.23	0.14	0.26	0.20	0.15	0.23	0.34	0.28	0.33	0.15	0.23	0.32	0.36	0.37	0.15	0.06	0.27	0.14	0.14	0.15	0.06	0.12	0.13	0.00	0.34
	4	0.04	-0.08	-0.05		0.25	0.32	0.09	0.24	0.16	0.12	0.20	0.33	0.25	0.32	0.11	0.20	0.31	0.35	0.37	0.11	0.13	0.24	0.09	0.09	0.20	0.12	0.08	0.08	0.05	0.40
	5	0.30	0.18	0.21	0.26		0.01	0.34	0.46	0.39	0.34	0.43	0.53	0.47	0.52	0.33	0.42	0.51	0.56	0.57	0.33	0.14	0.47	0.35	0.33	0.01	0.13	0.31	0.33	0.20	0.19
	6	0.31	0.19	0.22	0.27	0.01		0.44	0.60	0.51	0.42	0.57	0.67	0.60	0.67	0.42	0.54	0.66	0.75	0.78	0.42	0.18	0.61	0.46	0.42	0.02	0.16	0.38	0.43	0.26	0.20
	7	-0.04	-0.16	-0.13	-0.08	-0.34	-0.35		0.15	0.08	0.04	0.11	0.25	0.17	0.24	0.02	0.12	0.23	0.27	0.29	0.03	0.23	0.16	0.01	0.01	0.27	0.20	0.01	0.01	0.15	0.47
	8	-0.15	-0.27	-0.24	-0.19	-0.45	-0.46	-0.11		0.07	0.09	0.05	0.11	0.02	0.09	0.11	0.02	0.08	0.11	0.12	0.11	0.37	0.00	0.17	0.14	0.37	0.33	0.14	0.17	0.29	0.56
	9	-0.10	-0.21	-0.19	-0.13	-0.39	-0.40	-0.06	0.05		0.03	0.03	0.18	0.09	0.16	0.04	0.04	0.15	0.18	0.20	0.04	0.30	0.08	0.09	0.07	0.32	0.26	0.07	0.09	0.21	0.51
	10	-0.07	-0.19	-0.16	-0.11	-0.37	-0.38	-0.03	0.08	0.03		0.06	0.19	0.11	0.17	0.01	0.07	0.16	0.19	0.20	0.01	0.24	0.10	0.04	0.03	0.28	0.21	0.04	0.05	0.16	0.47
Midfield third	11	-0.12	-0.23	-0.21	-0.15	-0.41	-0.42	-0.08	0.03	-0.02	-0.05		0.16	0.07	0.15	0.07	0.02	0.13	0.17	0.19	0.07	0.34	0.05	0.13	0.10	0.35	0.30	0.10	0.13	0.25	0.54
	12	-0.23	-0.35	-0.32	-0.27	-0.53	-0.54	-0.20	-0.09	-0.14	-0.16	-0.12		0.09	0.03	0.20	0.13	0.03	0.03	0.02	0.20	0.45	0.11	0.28	0.24	0.43	0.40	0.23	0.27	0.37	0.61
	13	-0.17	-0.28	-0.26	-0.20	-0.46	-0.47	-0.13	-0.02	-0.07	-0.10	-0.05	0.07		0.07	0.13	0.05	0.06	0.07	0.09	0.13	0.39	0.02	0.19	0.16	0.38	0.34	0.16	0.19	0.30	0.57
	14	-0.21	-0.33	-0.30	-0.25	-0.51	-0.52	-0.18	-0.07	-0.12	-0.14	-0.10	0.02	-0.05		0.19	0.11	0.01	0.00	0.01	0.18	0.45	0.09	0.27	0.22	0.43	0.39	0.21	0.26	0.36	0.61
	15	-0.06	-0.18	-0.15	-0.10	-0.36	-0.37	-0.02	0.09	0.04	0.01	0.06	0.18	0.11	0.16		0.08	0.18	0.21	0.22	0.00	0.23	0.12	0.03	0.02	0.27	0.21	0.03	0.04	0.15	0.46
	16	-0.13	-0.25	-0.22	-0.17	-0.43	-0.44	-0.09	0.02	-0.03	-0.06	-0.01	0.10	0.04	0.08	-0.07		0.10	0.12	0.14	0.08	0.33	0.03	0.13	0.11	0.35	0.29	0.11	0.13	0.25	0.53
	17	-0.21	-0.33	-0.30	-0.25	-0.51	-0.52	-0.17	-0.06	-0.11	-0.14	-0.09	0.03	-0.04	0.01	-0.15	-0.08		0.01	0.02	0.18	0.44	0.08	0.25	0.21	0.42	0.39	0.21	0.25	0.35	0.60
	18	-0.21	-0.33	-0.30	-0.25	-0.51	-0.52	-0.17	-0.06	-0.12	-0.14	-0.10	0.02	-0.05	0.00	-0.15	-0.08	0.00		0.02	0.20	0.49	0.10	0.31	0.25	0.44	0.42	0.23	0.29	0.40	0.63
	19	-0.22	-0.34	-0.31	-0.26	-0.52	-0.53	-0.18	-0.07	-0.13	-0.15	-0.11	0.01	-0.06	-0.01	-0.16	-0.09	-0.01	-0.01		0.22	0.51	0.12	0.33	0.26	0.46	0.44	0.25	0.31	0.42	0.64
	20	-0.06	-0.18	-0.15	-0.10	-0.36	-0.37	-0.02	0.09	0.04	0.01	0.06	0.17	0.11	0.15	0.00	0.07	0.15	0.15	0.16		0.23	0.11	0.03	0.02	0.28	0.21	0.03	0.04	0.16	0.46
Attacking third	21	0.15	0.03	0.06	0.11	-0.15	-0.16	0.19	0.30	0.25	0.22	0.27	0.39	0.32	0.37	0.21	0.28	0.36	0.37	0.37	0.21		0.38	0.24	0.22	0.10	0.00	0.20	0.22	0.07	0.31
	22	-0.15	-0.27	-0.24	-0.19	-0.45	-0.46	-0.11	0.00	-0.06	-0.08	-0.04	0.08	0.01	0.06	-0.09	-0.02	0.06	0.06	0.07	-0.09	-0.30		0.18	0.14	0.38	0.33	0.14	0.18	0.29	0.57
	23	-0.04	-0.15	-0.12	-0.07	-0.33	-0.34	0.00	0.11	0.06	0.03	0.08	0.20	0.13	0.18	0.02	0.10	0.17	0.18	0.19	0.03	-0.19	0.12		0.01	0.28	0.21	0.00	0.01	0.15	0.48
	24	-0.04	-0.16	-0.13	-0.08	-0.34	-0.35	0.00	0.11	0.05	0.03	0.07	0.19	0.12	0.17	0.02	0.09	0.17	0.17	0.18	0.02	-0.20	0.11	-0.01		0.27	0.20	0.01	0.02	0.15	0.46
	25	0.28	0.16	0.19	0.24	-0.02	-0.03	0.32	0.43	0.38	0.35	0.40	0.52	0.45	0.50	0.34	0.41	0.49	0.49	0.50	0.34	0.13	0.43	0.32	0.32		0.10	0.25	0.26	0.16	0.18
	26	0.15	0.03	0.06	0.11	-0.15	-0.16	0.19	0.30	0.25	0.22	0.27	0.39	0.32	0.37	0.21	0.28	0.36	0.37	0.37	0.21	0.00	0.30	0.19	0.20	-0.13		0.18	0.19	0.07	0.29
	27	-0.03	-0.15	-0.12	-0.07	-0.33	-0.34	0.00	0.12	0.06	0.04	0.08	0.20	0.13	0.18	0.03	0.10	0.18	0.18	0.19	0.03	-0.19	0.12	0.00	0.01	-0.32	-0.19		0.01	0.13	0.44
	28	-0.03	-0.15	-0.12	-0.07	-0.33	-0.34	0.01	0.12	0.07	0.04	0.09	0.21	0.14	0.19	0.03	0.10	0.18	0.18	0.19	0.03	-0.18	0.12	0.01	0.01	-0.31	-0.18	0.00		0.14	0.46
	29	0.08	-0.03	0.00	0.05	-0.21	-0.22	0.12	0.23	0.18	0.15	0.20	0.32	0.25	0.30	0.14	0.22	0.29	0.30	0.31	0.14	-0.07	0.24	0.12	0.13	-0.20	-0.07	0.12	0.11		0.36
	30	0.57	0.45	0.48	0.53	0.27	0.26	0.61	0.72	0.66	0.64	0.68	0.80	0.73	0.78	0.63	0.70	0.78	0.78	0.79	0.63	0.42	0.72	0.60	0.61	0.29	0.41	0.60	0.60	0.48	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Figure 7.3 Difference in mean head turn frequency between the pitch zones and effect sizes of pairwise comparisons made between pitch zones. The bottom-left area outlines difference in zone means, vertical minus horizontal. Blue cells indicate the vertical zone value is less than the horizontal zone value, while red cells indicate the vertical zone value is greater than the horizontal zone value. The top-right area outlines the effect size of the comparisons made between zones. White cells indicate a trivial effect, light grey cells indicate a small to medium effect, medium grey cells indicate a medium to large effect, and dark grey cells indicate a large to very large effect.

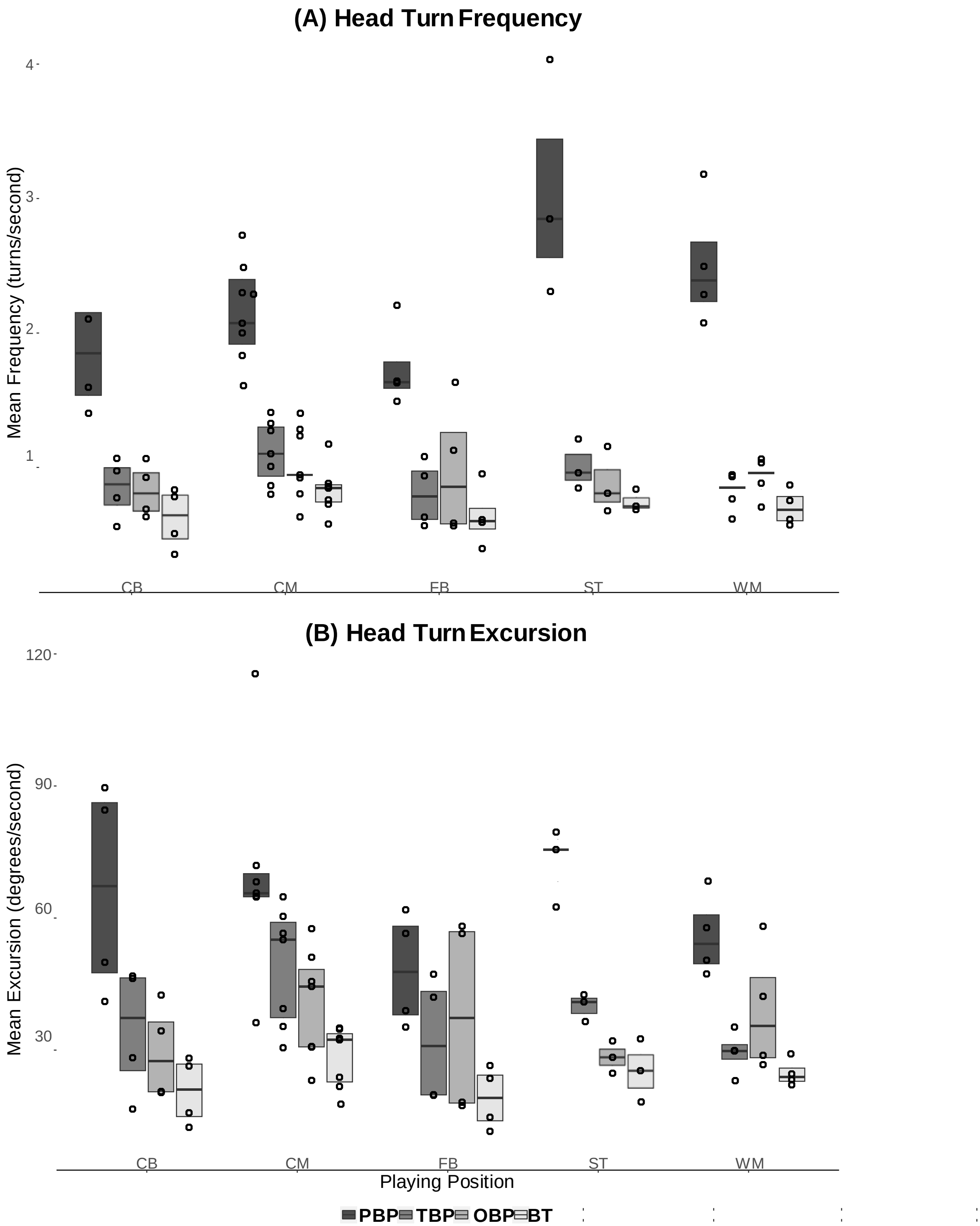


Figure 7.4 (A) Head turn frequency (turns/second) according to playing role and ball-possession phase of play. **(B)** Head turn excursion (degrees/second) according to playing role and ball-possession phase of play. Points indicate each participant's average. Boxes indicate lower quantile, median, and upper quantile. CB: Centre-back; CM: Centre-midfield; FB: Full-back; ST: Striker; WM: Wide-midfield; PBP: Player in Ball-possession; TBP: Team in Ball-possession; OBP: Opposition in Ball-possession; BT: Ball in Transition.

Difference in mean head turn excursion, vertical - horizontal	Effect size																														
		Defensive third										Midfield third										Attacking third									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Defensive third	1		0.26	0.56	0.54	0.68	0.56	0.40	0.32	0.38	0.28	0.20	0.16	0.32	0.12	0.19	0.13	0.15	0.38	0.21	0.24	0.44	0.19	0.46	0.22	0.31	0.36	0.23	0.56	0.51	0.19
	2	5.89		0.40	0.37	0.53	0.41	0.20	0.10	0.19	0.08	0.07	0.08	0.12	0.14	0.04	0.13	0.08	0.19	0.05	0.07	0.25	0.09	0.23	0.03	0.11	0.21	0.01	0.37	0.36	0.03
	3	18.26	12.37		0.06	0.13	0.02	0.22	0.30	0.22	0.29	0.44	0.42	0.27	0.48	0.39	0.48	0.42	0.21	0.42	0.25	0.17	0.46	0.26	0.40	0.28	0.13	0.35	0.09	0.03	0.38
	4	16.13	10.24	-2.14		0.19	0.08	0.17	0.26	0.17	0.25	0.41	0.39	0.22	0.45	0.35	0.45	0.39	0.16	0.38	0.21	0.12	0.43	0.21	0.37	0.23	0.08	0.32	0.03	0.03	0.34
	5	23.65	17.76	5.39	7.53		0.11	0.35	0.43	0.35	0.42	0.57	0.55	0.40	0.60	0.51	0.60	0.55	0.34	0.55	0.37	0.30	0.58	0.40	0.53	0.41	0.25	0.48	0.23	0.15	0.51
	6	19.12	13.23	0.85	2.99	-4.54		0.23	0.31	0.23	0.30	0.44	0.43	0.28	0.48	0.40	0.48	0.43	0.22	0.42	0.27	0.19	0.46	0.27	0.41	0.29	0.15	0.36	0.11	0.05	0.39
	7	10.86	4.97	-7.40	-5.27	-12.79	-8.26		0.09	0.01	0.10	0.25	0.24	0.07	0.30	0.20	0.30	0.24	0.00	0.23	0.08	0.05	0.27	0.02	0.21	0.08	0.05	0.16	0.15	0.18	0.20
	8	8.25	2.36	-10.02	-7.88	-15.40	-10.87	-2.61		0.08	0.01	0.16	0.16	0.02	0.22	0.12	0.21	0.16	0.09	0.14	0.00	0.14	0.18	0.09	0.12	0.01	0.13	0.08	0.25	0.26	0.11
	9	10.64	4.76	-7.62	-5.48	-13.01	-8.47	-0.22	2.40		0.09	0.23	0.23	0.06	0.29	0.19	0.28	0.23	0.01	0.21	0.07	0.06	0.25	0.01	0.20	0.07	0.06	0.15	0.15	0.18	0.18
	10	7.91	2.02	-10.35	-8.21	-15.74	-11.20	-2.95	-0.34	-2.73		0.12	0.13	0.03	0.18	0.09	0.17	0.13	0.09	0.11	0.01	0.14	0.14	0.09	0.09	0.02	0.13	0.06	0.24	0.25	0.09
Midfield third	11	4.55	-1.34	-13.71	-11.58	-19.10	-14.57	-6.31	-3.70	-6.09	-3.36		0.02	0.17	0.07	0.02	0.07	0.02	0.24	0.02	0.11	0.30	0.02	0.29	0.04	0.16	0.24	0.06	0.42	0.39	0.03
	12	4.06	-1.83	-14.20	-12.06	-19.59	-15.05	-6.80	-4.18	-6.58	-3.85	-0.49		0.17	0.04	0.03	0.04	0.00	0.23	0.03	0.12	0.29	0.00	0.27	0.05	0.16	0.24	0.08	0.40	0.38	0.04
	13	8.91	3.02	-9.36	-7.22	-14.74	-10.21	-1.95	0.66	-1.74	1.00	4.36	4.84		0.22	0.13	0.22	0.17	0.07	0.15	0.02	0.11	0.18	0.05	0.13	0.01	0.10	0.09	0.21	0.23	0.13
	14	2.94	-2.94	-15.32	-13.18	-20.71	-16.17	-7.92	-5.30	-7.70	-4.97	-1.61	-1.12	-5.96		0.08	0.01	0.04	0.29	0.09	0.16	0.35	0.06	0.35	0.10	0.21	0.28	0.12	0.47	0.43	0.09
	15	5.03	-0.86	-13.24	-11.10	-18.62	-14.09	-5.83	-3.22	-5.62	-2.88	0.48	0.96	-3.88	2.08		0.08	0.04	0.20	0.00	0.09	0.25	0.03	0.22	0.01	0.12	0.21	0.04	0.35	0.35	0.01
	16	3.12	-2.76	-15.14	-13.00	-20.53	-15.99	-7.74	-5.12	-7.52	-4.79	-1.43	-0.94	-5.78	0.18	-1.90		0.04	0.29	0.08	0.15	0.35	0.05	0.35	0.10	0.21	0.28	0.12	0.47	0.43	0.08
	17	4.01	-1.88	-14.26	-12.12	-19.64	-15.11	-6.85	-4.24	-6.64	-3.90	-0.54	-0.06	-4.90	1.06	-1.02	0.88		0.23	0.04	0.12	0.29	0.01	0.27	0.05	0.16	0.24	0.08	0.40	0.38	0.04
	18	10.94	5.05	-7.32	-5.19	-12.71	-8.18	0.08	2.69	0.29	3.03	6.39	6.88	2.03	8.00	5.91	7.81	6.93		0.22	0.08	0.05	0.26	0.02	0.20	0.07	0.05	0.16	0.14	0.17	0.19
	19	4.93	-0.96	-13.33	-11.20	-18.72	-14.19	-5.93	-3.32	-5.72	-2.98	0.38	0.87	-3.98	1.98	-0.10	1.80	0.92	-6.01		0.10	0.28	0.04	0.25	0.02	0.14	0.23	0.05	0.39	0.37	0.01
	20	8.16	2.27	-10.10	-7.96	-15.49	-10.95	-2.70	-0.08	-2.48	0.25	3.61	4.10	-0.74	5.22	3.13	5.04	4.16	-2.78	3.23		0.12	0.12	0.07	0.08	0.01	0.11	0.06	0.20	0.22	0.08
Attacking third	21	12.36	6.47	-5.90	-3.77	-11.29	-6.76	1.50	4.11	1.71	4.45	7.81	8.30	3.45	9.41	7.33	9.23	8.35	1.42	7.43	4.20		0.32	0.08	0.26	0.12	0.01	0.21	0.10	0.14	0.24
	22	4.18	-1.71	-14.09	-11.95	-19.47	-14.94	-6.68	-4.07	-6.47	-3.74	-0.37	0.11	-4.73	1.23	-0.85	1.05	0.17	-6.76	-0.75	-3.99	-8.18		0.31	0.05	0.18	0.26	0.08	0.44	0.41	0.04
	23	10.29	4.40	-7.98	-5.84	-13.36	-8.83	-0.57	2.04	-0.36	2.38	5.74	6.22	1.38	7.34	5.26	7.16	6.28	-0.65	5.36	2.12	-2.07	6.11		0.23	0.07	0.08	0.17	0.20	0.22	0.21
	24	5.34	-0.55	-12.92	-10.78	-18.31	-13.77	-5.52	-2.90	-5.30	-2.57	0.79	1.28	-3.56	2.40	0.32	2.22	1.34	-5.60	0.41	-2.82	-7.02	1.17	-4.94		0.12	0.22	0.03	0.37	0.36	0.01
	25	8.62	2.74	-9.64	-7.50	-15.03	-10.49	-2.24	0.38	-2.02	0.71	4.08	4.56	-0.28	5.68	3.60	5.50	4.62	-2.31	3.70	0.46	-3.73	4.45	-1.66	3.28		0.11	0.08	0.22	0.24	0.12
	26	12.85	6.96	-5.41	-3.28	-10.80	-6.26	1.99	4.60	2.21	4.94	8.30	8.79	3.94	9.91	7.82	9.73	8.84	1.91	7.92	4.69	0.49	8.67	2.56	7.51	4.23		0.18	0.07	0.10	0.21
	27	6.16	0.27	-12.10	-9.97	-17.49	-12.96	-4.70	-2.09	-4.48	-1.75	1.61	2.10	-2.75	3.22	1.13	3.04	2.15	-4.78	1.23	-2.00	-6.20	1.98	-4.13	0.82	-2.46	-6.69		0.31	0.32	0.03
	28	15.29	9.40	-2.98	-0.84	-8.37	-3.83	4.43	7.04	4.64	7.37	10.74	11.22	6.38	12.34	10.26	12.16	11.28	4.35	10.36	7.12	2.93	11.11	5.00	9.94	6.66	2.43	9.12		0.05	0.35
	29	17.22	11.33	-1.04	1.10	-6.43	-1.89	6.36	8.97	6.58	9.31	12.67	13.16	8.31	14.28	12.19	14.10	13.22	6.28	12.29	9.06	4.86	13.05	6.93	11.88	8.60	4.37	11.06	1.94		0.34
	30	5.19	-0.70	-13.08	-10.94	-18.47	-13.93	-5.67	-3.06	-5.46	-2.73	0.64	1.12	-3.72	2.24	0.16	2.06	1.18	-5.75	0.26	-2.98	-7.17	1.01	-5.10	-0.16	-3.44	-7.67	-0.98	-10.10	-12.04	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Figure 7.5 Difference in mean head turn excursion between pitch zones and the effect size of the pairwise comparisons made between pitch zones. The bottom-left area outlines the difference in zone means, vertical minus horizontal. Blue cells indicate the vertical zone value is less than the horizontal zone value, while red cells indicate the vertical zone value is greater than the horizontal zone value. The top-right area outlines the effect size of comparisons made between the zones. White cells indicate a trivial effect, light grey cells indicate a small to medium effect, medium grey cells indicate a medium to large effect, and dark grey cells indicate a large to very large effect.

7.5 Discussion

With the aim of understanding how pitch position, playing position and ball-possession phase of play constrain the visual exploratory actions of footballers, youth players' visual exploratory head movements were quantified during 11v11 match-play. Visual exploratory actions were analysed as continuous variables of head turn frequency and head turn excursion throughout the match. These data were synchronised with GPS and notationally analysed video data, enabling comparisons according to pitch location, playing position and ball-possession phase of play.

In general, ball-possession phase of play, location on the pitch and playing role all constrained the way players visually explored their surrounding environment. Primarily, players explored more extensively when they had possession of the ball compared to when they did not have possession of the ball. Players explored more extensively when they were in deep defensive or attacking areas of the pitch compared to central areas of the pitch. Full- backs tended to explore less extensively than other positions, particularly centre-midfielders and strikers.

When in possession of the ball, players explored much more extensively than when they did not have the ball. According to previous research (McGuckian et al., 2019), this suggests that players may not be exploring adequately before they gain possession of the ball, and therefore require high amounts of visual exploration when in possession in order to discover opportunities for action. If this is the case, it is likely that the group of youth players within this study would see performance benefits by exploring more extensively when not in possession (Jordet et al., 2013; McGuckian et al., 2018b). Further, given that players were only in possession of the ball for a very small percentage of playing time (~2%), exploratory actions off the ball should be prioritised as they contribute to situation awareness and positional movement for a vast majority of playing time.

Compared to transition phases of play, the athletes explored more extensively when either team had comfortable possession of the ball (i.e. TBP or OBP). Although it is difficult to explain this finding with the presented analyses, we posit that the difference in exploration occurred due to the uncertainty of task demands during transition phases of play. When in comfortable ball-possession or when defending against comfortable possession, players have clear intentions as governed by the team's style of play (Hewitt et al., 2016; Taylor, Mellalieu, & James, 2005). Further, the emergent behaviours of players during offensive and defensive phases, such as positional movement on and off the ball, are constrained by the interactions between teammates and opponents (Correia et al., 2012; Ometto et al., 2018; Torrents et al., 2016). In order to integrate these dynamic interactions with team strategy, players visually explore their surrounding environment to prospectively guide their actions on and off the ball. During offensive and defensive play, players are better able to explore the surrounding environment as the constraining interactions are more stable than during transition phases, which are highly unstable. That is, during unstable transition phases players are unsure if they should attack or defend, and therefore will watch the ball (which results in less exploratory actions) until the task constraints become clear. While we cannot confirm from this study that players revert to 'ball-watching' during transition phases, it presents as a logical hypothesis for future investigations.

Wide players (FB and WM) explored more extensively when defending than when attacking, which is opposite to the general trend of central players (CB, CM, ST), who explored more extensively during attacking phases. This is an interesting finding, which speaks to the constraints placed upon different playing positions at certain times during a match. When in ball-possession, full-backs and wide-midfielders are typically the widest players on the pitch. Further, these players will orient their bodies to have their back facing the side-line. As a result, wide players will often have a good understanding of what is afforded behind them without the need to explore this area, as most other players are located in-front of them and only the side-line is behind them. When defending, however, wide players will move into more central areas of the pitch in order to create a more compact defensive structure (Clemente et al., 2013; Duarte et al., 2012; Frencken & Lemmink, 2008; Yue et al., 2008). By occupying more central areas of the pitch, the wide players are now surrounded by wide players from the other team and must therefore explore more extensively to maintain an understanding of opposition movements. Again, this finding supports the need to maintain representative training environments, and to make these training situations position specific when possible.

Unexpectedly, we found that when players were in more central areas of the pitch (i.e. zones 12 – 14 and 17 – 19), they used less frequent (HTF) and smaller sized (HTE) head turns than when in most other areas of the pitch. While these differences were not often statistically significant, the differences between central and other areas often showed medium to large effects, indicating the differences were meaningful. While it is positive that players explored extensively while in some areas of the pitch, the central areas of the pitch appear to be the most important area to explore extensively given that players are more likely to be completely surrounded by teammates and opponents. Indeed, situations in which players are surrounded by other players have often been the focus of previous investigations of visual exploratory action (Eldridge et al., 2013; Jordet et al., 2013). Although not expected, there are a few possible explanations for this finding which should be considered for future investigations.

The time that players spent in the deep areas of their own half (i.e. zones 1 – 5) would often be when their team was in possession of the ball and play was starting from the goalkeeper. At these times, players would move to these deep areas of their own half to receive the ball. Further, in the matches included in this analysis, the opposing team would not apply pressure to the team with ball-possession at these times, but rather allow the players time to bring the ball forward. It is likely that this combination of events enabled the players in the deep areas the ability to explore extensively between their goalkeeper and the rest of the pitch, resulting in higher head turn frequencies and larger excursions. Given this finding may be influenced by the tactical play of the teams involved in this study, it is possible that teams employing different tactical principles would display different visual exploratory actions in these areas of the pitch.

When in a deep area of the opposition half (i.e. zones 26 – 30), players will experience high levels of defensive pressure as these are areas in which shots on goal are more likely to occur (Gómez, Gómez-Lopez, Lago, & Sampaio, 2012). The more extensive visual exploratory action, therefore, may be a result of this increased defensive pressure when in these attacking areas of the pitch. This reasoning is supported by an investigation of 3v3 small-sided games, which indicated that a very small playing area resulted in players using a higher frequency of exploratory head movements (McGuckian et al., 2017), likely as a function of the time constraints placed upon players when competing in a more confined space. That is, players explore more frequently to gain environmental information and prospectively control their actions with the ball, and this exploratory action occurs at a higher frequency when players have less time and space.

Partially supporting the hypothesis, centre-midfield players had the highest head turn excursions, albeit with small effects, but did not have the highest head turn frequency. Centre-midfield players are most often surrounded by teammates and opposition players, imposing a greater need to explore for relevant environmental information. For these players, however, being surrounded by other players in 360-degrees necessitates that the exploratory head movements are larger, allowing the player to perceive a wider range of environmental information, and not necessarily more frequent. For players in other positions, it is likely that they can perceive relevant information with equally frequent, but smaller head movements. This finding has important practical implications for coaches. Given that the exploratory demands are role and position specific, and due to the differing constraints placed on players during a match, it is important that coaches design training environments that allow the development of these behaviours (Pulling et al., 2018). For example, designing representative learning environments (Brunswik, 1956; Dhami et al., 2004; Dicks et al., 2009; Pinder et al., 2011) that completely surround players with functional environmental information may be an effective way to develop visual exploratory actions in training. Specifically, by completely surrounding the players with relevant environmental information during training, players will be encouraged to experience specifying interactions between themselves, teammates and opponents (Passos & Davids, 2014; Travassos, Araujo, Davids, Esteves, & Fernandes, 2012). Furthermore, by creating training situations that require athletes to visually explore their environments, there is an increased potential for these behaviours to be transferred to match- play (Oppici, Panchuk, Serpiello, & Farrow, 2018; Travassos et al., 2013).

While this study revealed important constraints on the visual exploratory actions of football players during match-play, there are some limitations that should be considered when evaluating the findings. First, the study population sampled was a relatively homogenous group of youth football players from one club. Therefore, the tactical principles and skill level of the players may have represented only a small portion of what would be found in the wider population of footballers. Despite the homogeneity of the study sample, the findings related to playing role would be expected to be transferrable to other teams and age groups. It is possible that more elite players would have a smaller difference between PBP and other phases of play, as they are likely to explore more extensively during TBP and OBP in order to prospectively guide their actions with the ball and positional movements. Given differences in team formations and playing strategies, the transferability of the findings related to exploration in different pitch positions may be less valid. Second, the analysis revealed differences in visual exploration according to constraints related to pitch position, playing role and ball-possession phase of play, however, these differences were found without any context of exact ball location or individual player ball-possession. A deeper understanding of rate of exploration as a function of a player’s distance from the ball, for example, will further contribute to our understanding of the behaviour. To understand this complex interaction, it is suggested that future research integrate accurate ball tracking technologies with similar visual exploratory action and player position quantification methods as used in the current study.

The current study has important implications for applied practice. In particular, the differences in exploration according to ball-possession phase of play present as clear areas for improvement. If players are able to explore more extensively during team ball-possession, they will be better able to prospectively control their actions once gaining possession of the ball (Jordet et al., 2013; McGuckian et al., 2019, 2018b). Further, if players are able to gain information during transition phases, it is likely that their actions will be more effective when either team gains comfortable possession of the ball. For example, being able to prospectively control actions more quickly with more extensive exploration before ball-possession (McGuckian et al., 2019) could assist with fast counter-attacking sequences, which have been shown to result in more successful offensive opportunities than sustained possession attacking sequences (Sarmento et al., 2018c). Conversely, players are likely to be better able to effectively position themselves defensively if they have explored extensively during transition phases of play, therefore putting themselves in a better situation to be able to stop the opposition from attacking directly from transition phases of play.

7.6 Conclusion

The visual exploratory head movements of football players during 11v11 match-play were shown to be constrained by pitch position, playing position and phase of play. In particular, players explored more extensively when in ball-possession and less extensively during transition phases of play compared to either team or opposition ball-possession, and centre-midfielders generally explored with larger head turns than other positions. It is recommended that applied practitioners consider the impact their training design has on the visual exploratory actions of players, and that training designs maintain the relevant specifying information used by players in their 360-degree environment.

7.7 Supplementary material

Supp. 1 Difference in mean head turn frequency between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for centre-backs.

Difference in mean head turn frequency, vertical - horizontal		Effect size: Defensive third										Midfield third										Attacking third									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Defensive third	**1**		0.17	0.17	0.29	0.02	0.18	0.45	0.45	0.03	0.11	0.47	0.78	0.43	0.65	0.14	0.52	0.99	0.64	0.95	0.93	0.20	0.47	0.14	0.22	1.12	0.13	0.37	0.29	0.12	0.19
	2	0.12		0.42	0.53	0.18	0.00	0.86	0.78	0.22	0.05	0.80	1.22	0.67	1.03	0.27	0.84	1.60	1.04	1.50	1.46	0.07	0.76	0.38	0.44	1.08	0.03	0.73	0.14	0.05	0.04
	3	-0.11	-0.23		0.16	0.14	0.45	0.36	0.35	0.14	0.30	0.38	0.77	0.34	0.60	0.03	0.44	1.09	0.59	1.01	0.98	0.39	0.38	0.02	0.08	1.21	0.32	0.25	0.56	0.33	0.38
	4	-0.21	-0.33	-0.10		0.25	0.55	0.12	0.14	0.26	0.41	0.17	0.49	0.18	0.37	0.06	0.24	0.71	0.35	0.67	0.65	0.49	0.19	0.17	0.07	1.25	0.43	0.03	0.66	0.44	0.49
	5	-0.01	-0.13	0.10	0.20		0.19	0.40	0.40	0.01	0.12	0.42	0.70	0.39	0.59	0.12	0.47	0.88	0.58	0.85	0.84	0.21	0.43	0.12	0.19	1.12	0.14	0.32	0.29	0.13	0.19
	6	0.12	0.00	0.23	0.33	0.13		0.93	0.83	0.23	0.05	0.84	1.30	0.69	1.08	0.27	0.89	1.75	1.10	1.62	1.57	0.07	0.80	0.39	0.45	1.09	0.03	0.78	0.15	0.05	0.04
	7	-0.28	-0.40	-0.16	-0.06	-0.26	-0.39		0.05	0.44	0.60	0.10	0.55	0.11	0.36	0.14	0.18	0.98	0.34	0.86	0.82	0.69	0.13	0.35	0.20	1.33	0.65	0.12	1.02	0.67	0.70
	8	-0.30	-0.42	-0.19	-0.09	-0.29	-0.42	-0.02		0.43	0.58	0.04	0.41	0.07	0.26	0.15	0.12	0.68	0.24	0.63	0.60	0.67	0.07	0.35	0.22	1.33	0.62	0.14	0.92	0.64	0.67
	9	-0.02	-0.14	0.09	0.19	-0.01	-0.14	0.25	0.28		0.15	0.45	0.77	0.41	0.64	0.12	0.51	1.00	0.63	0.95	0.93	0.24	0.45	0.11	0.19	1.14	0.16	0.35	0.34	0.16	0.22
	10	0.09	-0.03	0.20	0.30	0.10	-0.03	0.36	0.39	0.11		0.60	0.92	0.54	0.79	0.22	0.65	1.14	0.78	1.10	1.08	0.10	0.60	0.27	0.33	1.07	0.01	0.51	0.16	0.00	0.08
Midfield third	**11**	-0.32	-0.44	-0.21	-0.11	-0.31	-0.44	-0.05	-0.02	-0.30	-0.41		0.35	0.03	0.22	0.18	0.08	0.60	0.19	0.56	0.54	0.69	0.03	0.37	0.25	1.33	0.64	0.18	0.94	0.66	0.69
	12	-0.50	-0.62	-0.39	-0.29	-0.49	-0.62	-0.22	-0.20	-0.48	-0.59	-0.18		0.23	0.12	0.36	0.25	0.23	0.17	0.20	0.18	0.98	0.28	0.73	0.56	1.45	0.97	0.62	1.37	1.01	1.01
	13	-0.35	-0.46	-0.23	-0.13	-0.33	-0.46	-0.07	-0.05	-0.32	-0.43	-0.02	0.15		0.14	0.18	0.03	0.39	0.11	0.37	0.36	0.62	0.01	0.34	0.24	1.31	0.57	0.18	0.78	0.58	0.61
	14	-0.44	-0.56	-0.33	-0.23	-0.42	-0.56	-0.16	-0.14	-0.41	-0.53	-0.12	0.06	-0.09		0.29	0.13	0.34	0.04	0.31	0.30	0.86	0.16	0.58	0.43	1.40	0.83	0.43	1.16	0.86	0.87
	15	-0.15	-0.27	-0.03	0.07	-0.13	-0.27	0.13	0.15	-0.12	-0.23	0.17	0.35	0.20	0.29		0.22	0.47	0.28	0.46	0.45	0.29	0.19	0.04	0.01	1.11	0.23	0.09	0.35	0.23	0.27
	16	-0.37	-0.48	-0.25	-0.15	-0.35	-0.48	-0.09	-0.07	-0.34	-0.45	-0.04	0.14	-0.02	0.07	-0.22		0.47	0.10	0.44	0.42	0.73	0.04	0.43	0.31	1.35	0.69	0.26	0.97	0.71	0.73
	17	-0.59	-0.71	-0.47	-0.37	-0.57	-0.70	-0.31	-0.29	-0.56	-0.67	-0.26	-0.09	-0.24	-0.15	-0.44	-0.22		0.42	0.01	0.03	1.20	0.49	1.00	0.77	1.52	1.22	1.01	1.76	1.28	1.24
	18	-0.42	-0.54	-0.31	-0.21	-0.41	-0.54	-0.14	-0.12	-0.39	-0.51	-0.10	0.08	-0.07	0.02	-0.27	-0.05	0.17		0.38	0.36	0.85	0.14	0.57	0.42	1.40	0.82	0.42	1.18	0.86	0.87
	19	-0.58	-0.70	-0.47	-0.37	-0.57	-0.70	-0.31	-0.28	-0.56	-0.67	-0.26	-0.08	-0.24	-0.14	-0.44	-0.22	0.00	-0.16		0.01	1.15	0.46	0.94	0.73	1.51	1.16	0.91	1.65	1.22	1.19
	20	-0.58	-0.70	-0.46	-0.36	-0.56	-0.70	-0.30	-0.28	-0.55	-0.66	-0.26	-0.08	-0.23	-0.14	-0.43	-0.21	0.01	-0.16	0.01		1.13	0.44	0.92	0.71	1.50	1.14	0.87	1.61	1.19	1.17
Attacking third	**21**	0.17	0.05	0.28	0.38	0.18	0.05	0.44	0.47	0.19	0.08	0.49	0.67	0.51	0.61	0.31	0.53	0.75	0.59	0.75	0.74		0.67	0.36	0.42	1.02	0.09	0.60	0.04	0.10	0.03
	22	-0.34	-0.46	-0.23	-0.13	-0.33	-0.46	-0.07	-0.04	-0.32	-0.43	-0.02	0.16	0.00	0.10	-0.19	0.02	0.24	0.08	0.24	0.24	-0.51		0.38	0.26	1.33	0.63	0.20	0.89	0.64	0.68
	23	-0.10	-0.22	0.01	0.11	-0.09	-0.22	0.17	0.20	-0.08	-0.19	0.22	0.40	0.24	0.34	0.05	0.26	0.49	0.32	0.48	0.48	-0.27	0.24		0.09	1.20	0.29	0.25	0.51	0.29	0.35
	24	-0.16	-0.28	-0.05	0.05	-0.15	-0.28	0.11	0.14	-0.14	-0.25	0.16	0.34	0.18	0.28	-0.02	0.20	0.42	0.26	0.42	0.41	-0.33	0.18	-0.06		1.22	0.35	0.12	0.56	0.36	0.41
	25	1.99	1.87	2.10	2.20	2.00	1.87	2.26	2.29	2.01	1.90	2.31	2.49	2.33	2.43	2.13	2.35	2.57	2.41	2.57	2.56	1.82	2.33	2.09	2.15		1.07	1.30	1.03	1.08	1.04
	26	0.10	-0.02	0.21	0.31	0.11	-0.02	0.37	0.40	0.12	0.01	0.42	0.60	0.44	0.54	0.24	0.46	0.68	0.52	0.68	0.67	-0.07	0.44	0.20	0.26	-1.89		0.55	0.15	0.01	0.07
	27	-0.23	-0.35	-0.12	-0.02	-0.22	-0.35	0.04	0.07	-0.21	-0.32	0.09	0.27	0.11	0.21	-0.09	0.13	0.35	0.19	0.35	0.34	-0.40	0.11	-0.13	-0.07	-2.22	-0.33		0.88	0.57	0.61
	28	0.20	0.08	0.31	0.41	0.21	0.08	0.47	0.50	0.22	0.11	0.52	0.70	0.54	0.64	0.34	0.56	0.78	0.62	0.78	0.78	0.03	0.54	0.30	0.36	-1.79	0.10	0.43		0.17	0.07
	29	0.09	-0.03	0.20	0.30	0.10	-0.03	0.36	0.39	0.11	0.00	0.41	0.59	0.43	0.53	0.24	0.45	0.67	0.51	0.67	0.67	-0.08	0.43	0.19	0.25	-1.90	-0.01	0.32	-0.11		0.08
	30	0.15	0.03	0.26	0.36	0.16	0.03	0.42	0.45	0.17	0.06	0.47	0.65	0.49	0.59	0.29	0.51	0.73	0.57	0.73	0.72	-0.02	0.49	0.25	0.31	-1.84	0.05	0.38	-0.05	0.06	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Supp. 2 Difference in mean head turn excursion between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for centre-backs.

Difference in mean head turn excursion, vertical - horizontal		Effect size: Defensive third										Midfield third										Attacking third									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Defensive third	1		0.37	0.50	0.26	0.40	0.09	0.01	0.08	0.12	0.10	0.19	0.60	0.06	0.58	0.47	0.12	0.66	0.06	0.61	0.55	0.16	0.01	0.25	0.11	0.66	0.10	0.58	0.98	0.76	0.54
	2	7.25		0.27	0.04	0.25	0.43	0.39	0.22	0.26	0.21	0.57	1.12	0.33	1.08	0.93	0.49	1.23	0.43	1.14	0.99	0.19	0.36	0.05	0.50	0.36	0.26	0.27	0.66	0.54	0.27
	3	15.12	7.87		0.16	0.08	0.51	0.51	0.39	0.43	0.39	0.63	0.92	0.48	0.91	0.83	0.58	0.96	0.54	0.93	0.89	0.38	0.49	0.28	0.58	0.01	0.43	0.07	0.12	0.22	0.05
	4	8.58	1.33	-6.54		0.20	0.24	0.26	0.18	0.19	0.17	0.38	0.62	0.27	0.61	0.55	0.33	0.64	0.30	0.63	0.60	0.15	0.25	0.07	0.33	0.18	0.19	0.13	0.31	0.37	0.14
	5	19.46	12.21	4.34	10.88		0.39	0.40	0.35	0.35	0.34	0.48	0.64	0.41	0.64	0.60	0.45	0.65	0.43	0.65	0.63	0.33	0.40	0.27	0.45	0.09	0.36	0.13	0.02	0.08	0.12
	6	1.38	-5.86	-13.74	-7.20	-18.08		0.09	0.03	0.07	0.06	0.34	1.11	0.13	1.02	0.80	0.24	1.33	0.17	1.13	0.87	0.13	0.07	0.24	0.24	0.78	0.04	0.67	1.38	0.80	0.59
	7	0.24	-7.01	-14.89	-8.35	-19.23	-1.15		0.07	0.12	0.10	0.22	0.69	0.08	0.66	0.53	0.14	0.77	0.08	0.71	0.61	0.16	0.00	0.26	0.13	0.70	0.09	0.61	1.08	0.78	0.56
	8	2.02	-5.23	-13.11	-6.56	-17.45	0.63	1.78		0.02	0.02	0.24	0.57	0.12	0.56	0.47	0.18	0.61	0.13	0.58	0.54	0.06	0.07	0.15	0.17	0.49	0.00	0.42	0.71	0.63	0.41
	9	2.44	-4.81	-12.68	-6.14	-17.02	1.06	2.21	0.43		0.00	0.32	0.79	0.15	0.76	0.63	0.24	0.86	0.18	0.80	0.71	0.05	0.11	0.16	0.24	0.58	0.02	0.49	0.91	0.69	0.46
	10	2.46	-4.79	-12.66	-6.12	-17.00	1.07	2.22	0.44	0.01		0.27	0.63	0.14	0.62	0.52	0.21	0.68	0.16	0.64	0.59	0.04	0.09	0.14	0.20	0.50	0.01	0.42	0.74	0.64	0.41
Midfield third	11	-4.17	-11.42	-19.29	-12.75	-23.63	-5.56	-4.41	-6.19	-6.61	-6.63		0.36	0.08	0.35	0.25	0.07	0.40	0.13	0.38	0.34	0.35	0.21	0.42	0.09	0.84	0.29	0.75	1.18	0.88	0.70
	12	-10.84	-18.09	-25.96	-19.42	-30.30	-12.23	-11.08	-12.86	-13.29	-13.30	-6.67		0.35	0.01	0.12	0.43	0.03	0.53	0.02	0.02	0.78	0.63	0.80	0.48	1.33	0.70	1.22	1.94	1.19	1.09
	13	-1.84	-9.09	-16.96	-10.42	-21.30	-3.23	-2.08	-3.86	-4.28	-4.30	2.33	9.00		0.34	0.27	0.03	0.37	0.02	0.35	0.34	0.19	0.07	0.26	0.02	0.57	0.14	0.51	0.76	0.70	0.49
	14	-10.75	-18.00	-25.87	-19.33	-30.21	-12.14	-10.99	-12.77	-13.20	-13.21	-6.58	0.09	-8.91		0.11	0.42	0.04	0.51	0.02	0.02	0.75	0.60	0.78	0.46	1.29	0.68	1.19	1.86	1.17	1.07
	15	-9.01	-16.26	-24.13	-17.59	-28.47	-10.39	-9.24	-11.02	-11.45	-11.46	-4.84	1.84	-7.17	1.75		0.31	0.15	0.40	0.13	0.12	0.63	0.49	0.68	0.35	1.16	0.56	1.06	1.66	1.09	0.96
	16	-2.70	-9.94	-17.82	-11.28	-22.16	-4.08	-2.93	-4.71	-5.14	-5.15	1.48	8.15	-0.85	8.06	6.31		0.47	0.06	0.44	0.40	0.28	0.14	0.36	0.02	0.76	0.21	0.68	1.08	0.83	0.63
	17	-11.24	-18.49	-26.36	-19.82	-30.70	-12.62	-11.47	-13.25	-13.68	-13.70	-7.07	-0.40	-9.40	-0.49	-2.23	-8.54		0.58	0.01	0.01	0.84	0.68	0.85	0.53	1.41	0.76	1.30	2.12	1.22	1.14
	18	-1.29	-8.53	-16.41	-9.87	-20.75	-2.67	-1.52	-3.30	-3.73	-3.74	2.89	9.56	0.56	9.47	7.72	1.41	9.95		0.54	0.48	0.22	0.07	0.31	0.05	0.72	0.16	0.63	1.04	0.80	0.59
	19	-11.08	-18.33	-26.20	-19.66	-30.54	-12.46	-11.31	-13.09	-13.52	-13.54	-6.91	-0.24	-9.24	-0.33	-2.07	-8.38	0.16	-9.79		0.00	0.79	0.64	0.81	0.50	1.34	0.71	1.24	1.96	1.20	1.10
	20	-11.11	-18.36	-26.24	-19.69	-30.57	-12.50	-11.35	-13.13	-13.56	-13.57	-6.94	-0.27	-9.27	-0.36	-2.11	-8.42	0.12	-9.83	-0.04		0.71	0.57	0.74	0.44	1.21	0.64	1.12	1.67	1.14	1.02
Attacking third	21	3.50	-3.75	-11.62	-5.08	-15.96	2.11	3.26	1.48	1.05	1.04	7.67	14.34	5.34	14.25	12.50	6.19	14.74	4.78	14.58	14.61		0.15	0.11	0.27	0.50	0.06	0.41	0.78	0.64	0.40
	22	0.25	-7.00	-14.87	-8.33	-19.21	-1.13	0.02	-1.76	-2.19	-2.21	4.42	11.09	2.09	11.00	9.26	2.95	11.49	1.54	11.33	11.37	-3.25		0.25	0.12	0.66	0.09	0.57	0.98	0.75	0.54
	23	6.12	-1.13	-9.00	-2.46	-13.34	4.74	5.88	4.10	3.68	3.66	10.29	16.96	7.96	16.87	15.13	8.81	17.36	7.40	17.20	17.23	2.62	5.87		0.36	0.35	0.16	0.27	0.57	0.53	0.27
	24	-2.33	-9.58	-17.45	-10.91	-21.79	-3.71	-2.56	-4.34	-4.77	-4.78	1.84	8.52	-0.49	8.43	6.68	0.37	8.91	-1.04	8.75	8.79	-5.82	-2.58	-8.45		0.78	0.21	0.69	1.13	0.84	0.64
	25	14.86	7.61	-0.27	6.27	-4.61	13.47	14.62	12.84	12.41	12.40	19.03	25.70	16.70	25.61	23.86	17.55	26.09	16.14	25.93	25.97	11.36	14.60	8.74	17.18		0.56	0.08	0.18	0.27	0.05
	26	2.10	-5.15	-13.02	-6.48	-17.36	0.71	1.86	0.08	-0.35	-0.36	6.27	12.94	3.94	12.85	11.10	4.79	13.34	3.38	13.18	13.21	-1.40	1.85	-4.02	4.42	-12.76		0.48	0.85	0.68	0.45
	27	12.99	5.74	-2.13	4.41	-6.47	11.61	12.76	10.98	10.55	10.53	17.16	23.83	14.83	23.74	22.00	15.69	24.23	14.28	24.07	24.10	9.49	12.74	6.87	15.32	-1.86	10.89		0.27	0.33	0.02
	28	18.54	11.29	3.42	9.96	-0.92	17.16	18.31	16.53	16.10	16.09	22.71	29.39	20.38	29.30	27.55	21.24	29.78	19.83	29.62	29.66	15.05	18.29	12.42	20.87	3.69	16.45	5.55		0.17	0.21
	29	23.50	16.25	8.38	14.92	4.04	22.12	23.26	21.48	21.06	21.04	27.67	34.34	25.34	34.25	32.51	26.19	34.74	24.79	34.58	34.61	20.00	23.25	17.38	25.83	8.64	21.40	10.51	4.96		0.29
	30	13.61	6.37	-1.51	5.03	-5.85	12.23	13.38	11.60	11.17	11.16	17.79	24.46	15.46	24.37	22.62	16.31	24.85	14.90	24.69	24.73	10.12	13.36	7.50	15.94	-1.24	11.52	0.62	-4.93	-9.88	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Supp. 3 Difference in mean head turn frequency between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for centre-midfielders.

Difference in mean head turn frequency, vertical - horizontal		Effect size: Defensive third 1	2	3	4	5	6	7	8	9	10	Midfield third 11	12	13	14	15	16	17	18	19	20	Attacking third 21	22	23	24	25	26	27	28	29	30
Defensive third	1		0.28	0.76	0.02	0.47	1.18	0.51	0.44	0.50	0.17	0.65	0.32	0.52	0.41	0.55	0.48	0.52	0.47	0.50	0.46	0.56	0.21	0.47	0.67	0.52	0.51	0.19	0.19	0.58	0.18
	2	0.25		0.57	0.37	0.16	0.82	0.22	0.14	0.15	0.09	0.28	0.02	0.18	0.03	0.24	0.20	0.24	0.09	0.13	0.10	0.28	0.15	0.10	0.35	0.29	0.23	0.12	0.14	0.32	0.07
	3	1.05	0.80		0.83	0.48	0.09	0.43	0.49	0.52	0.60	0.44	0.61	0.49	0.61	0.42	0.42	0.41	0.57	0.54	0.56	0.38	0.70	0.56	0.36	0.31	0.41	0.66	0.69	0.32	0.58
	4	-0.01	-0.26	-1.06		0.61	1.58	0.65	0.57	0.73	0.21	0.93	0.45	0.73	0.68	0.71	0.58	0.65	0.76	0.77	0.70	0.69	0.35	0.73	0.87	0.60	0.63	0.26	0.29	0.68	0.22
	5	0.38	0.13	-0.66	0.39		0.70	0.07	0.02	0.03	0.23	0.12	0.20	0.01	0.18	0.09	0.06	0.10	0.11	0.06	0.09	0.14	0.37	0.10	0.20	0.17	0.09	0.30	0.34	0.19	0.21
	6	0.92	0.67	-0.12	0.93	0.54		0.59	0.70	0.84	0.82	0.70	1.00	0.78	1.11	0.59	0.55	0.53	1.03	0.93	0.95	0.48	1.29	0.99	0.49	0.33	0.53	1.05	1.19	0.37	0.78
	7	0.44	0.20	-0.60	0.46	0.06	-0.48		0.08	0.10	0.28	0.03	0.26	0.07	0.25	0.02	0.00	0.03	0.19	0.14	0.16	0.07	0.42	0.17	0.12	0.11	0.02	0.36	0.40	0.13	0.26
	8	0.37	0.12	-0.68	0.38	-0.01	-0.55	-0.07		0.01	0.21	0.13	0.18	0.03	0.15	0.11	0.08	0.11	0.09	0.04	0.07	0.15	0.33	0.07	0.21	0.18	0.11	0.28	0.32	0.20	0.19
	9	0.37	0.12	-0.68	0.38	-0.02	-0.56	-0.08	0.00		0.23	0.17	0.21	0.04	0.19	0.13	0.09	0.13	0.11	0.04	0.08	0.18	0.42	0.09	0.26	0.20	0.13	0.32	0.38	0.23	0.20
	10	0.16	-0.09	-0.89	0.17	-0.22	-0.76	-0.28	-0.21	-0.20		0.35	0.08	0.25	0.13	0.31	0.27	0.30	0.18	0.22	0.19	0.34	0.02	0.19	0.40	0.34	0.29	0.01	0.02	0.37	0.02
Midfield third	11	0.47	0.22	-0.58	0.48	0.08	-0.46	0.02	0.09	0.10	0.30		0.37	0.12	0.39	0.01	0.03	0.01	0.30	0.22	0.26	0.06	0.61	0.27	0.12	0.11	0.00	0.47	0.55	0.12	0.31
	12	0.24	-0.01	-0.81	0.25	-0.15	-0.69	-0.21	-0.13	-0.13	0.08	-0.23		0.24	0.06	0.30	0.24	0.29	0.14	0.19	0.15	0.33	0.17	0.14	0.42	0.33	0.28	0.12	0.16	0.36	0.06
	13	0.39	0.14	-0.66	0.40	0.01	-0.53	-0.05	0.02	0.03	0.23	-0.07	0.15		0.22	0.09	0.06	0.10	0.15	0.08	0.11	0.15	0.44	0.13	0.22	0.18	0.09	0.34	0.40	0.20	0.23
	14	0.27	0.02	-0.78	0.28	-0.11	-0.65	-0.17	-0.10	-0.10	0.11	-0.20	0.03	-0.12		0.29	0.22	0.27	0.10	0.17	0.11	0.32	0.29	0.11	0.43	0.31	0.26	0.20	0.26	0.36	0.10
	15	0.46	0.21	-0.59	0.47	0.08	-0.46	0.02	0.09	0.10	0.30	0.00	0.22	0.07	0.19		0.02	0.01	0.23	0.17	0.20	0.05	0.47	0.21	0.10	0.10	0.01	0.39	0.44	0.11	0.28
	16	0.44	0.19	-0.61	0.45	0.06	-0.48	0.00	0.07	0.08	0.28	-0.02	0.21	0.05	0.17	-0.02		0.03	0.17	0.12	0.15	0.07	0.38	0.16	0.12	0.11	0.03	0.33	0.36	0.12	0.24
	17	0.47	0.22	-0.58	0.48	0.09	-0.45	0.03	0.10	0.11	0.31	0.01	0.23	0.08	0.20	0.01	0.03		0.21	0.16	0.19	0.04	0.43	0.20	0.09	0.09	0.00	0.37	0.41	0.10	0.27
	18	0.31	0.06	-0.74	0.32	-0.07	-0.61	-0.13	-0.06	-0.05	0.15	-0.15	0.07	-0.08	0.04	-0.15	-0.13	-0.16		0.07	0.02	0.27	0.38	0.02	0.37	0.27	0.21	0.27	0.33	0.31	0.15
	19	0.35	0.10	-0.70	0.36	-0.04	-0.58	-0.10	-0.03	-0.02	0.18	-0.12	0.11	-0.05	0.08	-0.12	-0.10	-0.13	0.03		0.04	0.21	0.42	0.05	0.30	0.23	0.16	0.31	0.38	0.26	0.19
	20	0.32	0.07	-0.73	0.33	-0.06	-0.60	-0.12	-0.05	-0.04	0.16	-0.14	0.09	-0.07	0.05	-0.14	-0.12	-0.15	0.01	-0.02		0.24	0.36	0.01	0.33	0.25	0.18	0.27	0.33	0.28	0.16
Attacking third	21	0.51	0.26	-0.54	0.52	0.13	-0.41	0.07	0.14	0.15	0.35	0.05	0.27	0.12	0.24	0.05	0.07	0.04	0.20	0.17	0.19		0.48	0.25	0.04	0.05	0.04	0.42	0.46	0.06	0.31
	22	0.14	-0.11	-0.91	0.15	-0.24	-0.78	-0.30	-0.23	-0.22	-0.02	-0.32	-0.09	-0.25	-0.13	-0.32	-0.30	-0.33	-0.17	-0.20	-0.18	-0.37		0.37	0.62	0.44	0.42	0.01	0.01	0.50	0.04
	23	0.32	0.07	-0.73	0.33	-0.06	-0.61	-0.13	-0.05	-0.05	0.16	-0.15	0.08	-0.07	0.05	-0.14	-0.12	-0.15	0.01	-0.03	0.00	-0.19	0.18		0.35	0.26	0.19	0.27	0.33	0.29	0.16
	24	0.55	0.30	-0.50	0.56	0.16	-0.38	0.10	0.18	0.18	0.39	0.08	0.31	0.16	0.28	0.09	0.11	0.08	0.24	0.20	0.23	0.04	0.40	0.23		0.02	0.09	0.51	0.58	0.03	0.37
	25	0.57	0.32	-0.48	0.58	0.19	-0.35	0.13	0.20	0.21	0.41	0.11	0.34	0.18	0.30	0.11	0.13	0.10	0.26	0.23	0.25	0.06	0.43	0.25	0.02		0.09	0.40	0.43	0.00	0.32
	26	0.47	0.22	-0.58	0.48	0.08	-0.46	0.02	0.10	0.10	0.31	0.00	0.23	0.08	0.20	0.01	0.03	0.00	0.16	0.12	0.14	-0.04	0.32	0.15	-0.08	-0.11		0.36	0.40	0.10	0.27
	27	0.15	-0.10	-0.90	0.16	-0.23	-0.77	-0.29	-0.22	-0.22	-0.01	-0.32	-0.09	-0.24	-0.12	-0.31	-0.29	-0.32	-0.16	-0.20	-0.17	-0.36	0.01	-0.17	-0.40	-0.42	-0.32		0.01	0.44	0.03
	28	0.14	-0.11	-0.91	0.15	-0.24	-0.78	-0.30	-0.23	-0.23	-0.02	-0.33	-0.10	-0.25	-0.13	-0.32	-0.30	-0.33	-0.17	-0.21	-0.18	-0.37	0.00	-0.18	-0.41	-0.43	-0.33	-0.01		0.48	0.04
	29	0.57	0.33	-0.47	0.59	0.19	-0.35	0.13	0.20	0.21	0.41	0.11	0.34	0.18	0.30	0.11	0.13	0.10	0.26	0.23	0.25	0.06	0.43	0.26	0.03	0.00	0.11	0.42	0.43		0.35
	30	0.18	-0.07	-0.87	0.19	-0.20	-0.74	-0.26	-0.19	-0.18	0.02	-0.28	-0.06	-0.21	-0.09	-0.28	-0.26	-0.29	-0.13	-0.16	-0.14	-0.33	0.04	-0.14	-0.37	-0.39	-0.29	0.03	0.04	-0.39	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Supp. 4 Difference in mean head turn excursion between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for centre-midfielders.

		Effect size																													
		Defensive third										Midfield third										Attacking third									
Difference in mean head turn excursion, vertical - horizontal		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Defensive third	**1**		0.67	1.01	1.16	1.27	1.30	1.04	1.10	1.25	0.73	1.54	0.99	1.22	1.21	0.98	1.03	1.07	1.13	1.38	0.98	1.00	0.99	1.45	1.31	1.15	0.73	0.52	0.83	1.08	0.37
	2	13.34		0.70	0.54	0.75	0.95	0.50	0.56	0.63	0.33	0.77	0.38	0.70	0.50	0.51	0.40	0.61	0.68	0.69	0.40	0.46	0.30	0.70	0.67	0.62	0.02	0.08	0.38	0.73	0.27
	3	44.14	30.80		0.41	0.22	0.13	0.38	0.35	0.36	0.38	0.37	0.49	0.25	0.47	0.32	0.49	0.26	0.19	0.37	0.46	0.40	0.56	0.40	0.35	0.31	0.70	0.73	0.39	0.03	0.83
	4	25.60	12.26	-18.54		0.28	0.63	0.04	0.09	0.10	0.03	0.13	0.14	0.24	0.09	0.10	0.13	0.19	0.27	0.10	0.09	0.01	0.27	0.06	0.12	0.15	0.54	0.57	0.02	0.41	0.77
	5	33.61	20.27	-10.53	8.01		0.41	0.22	0.18	0.19	0.24	0.20	0.39	0.04	0.37	0.14	0.40	0.06	0.02	0.20	0.35	0.26	0.52	0.25	0.18	0.12	0.75	0.77	0.25	0.21	0.94
	6	51.42	38.08	7.29	25.83	17.81		0.58	0.54	0.57	0.56	0.59	0.71	0.44	0.70	0.50	0.71	0.44	0.37	0.58	0.68	0.61	0.80	0.62	0.56	0.50	0.95	0.97	0.58	0.17	1.09
	7	26.58	13.24	-17.56	0.98	-7.03	-24.85		0.05	0.05	0.06	0.07	0.16	0.18	0.11	0.06	0.15	0.14	0.23	0.05	0.12	0.04	0.27	0.02	0.07	0.10	0.50	0.54	0.05	0.37	0.71
	8	28.00	14.66	-16.14	2.40	-5.61	-23.42	1.42		0.00	0.10	0.01	0.21	0.14	0.17	0.02	0.21	0.10	0.19	0.00	0.17	0.08	0.33	0.04	0.02	0.06	0.56	0.59	0.09	0.34	0.76
	9	27.99	14.65	-16.15	2.39	-5.62	-23.43	1.41	-0.01		0.10	0.02	0.23	0.15	0.19	0.02	0.23	0.11	0.20	0.00	0.18	0.09	0.37	0.05	0.02	0.06	0.63	0.66	0.10	0.35	0.86
	10	24.39	11.05	-19.75	-1.21	-9.22	-27.03	-2.19	-3.61	-3.60		0.12	0.06	0.21	0.02	0.10	0.06	0.18	0.25	0.11	0.03	0.03	0.15	0.08	0.12	0.14	0.32	0.37	0.01	0.38	0.49
Midfield third	**11**	28.33	14.99	-15.81	2.73	-5.28	-23.09	1.75	0.33	0.34	3.94		0.28	0.16	0.25	0.01	0.28	0.11	0.20	0.02	0.22	0.12	0.46	0.08	0.01	0.05	0.79	0.78	0.12	0.36	1.04
	12	22.16	8.82	-21.97	-3.43	-11.45	-29.26	-4.41	-5.84	-5.83	-2.22	-6.17		0.35	0.06	0.20	0.01	0.29	0.38	0.25	0.04	0.12	0.12	0.22	0.26	0.27	0.38	0.43	0.08	0.50	0.62
	13	32.39	19.05	-11.75	6.79	-1.22	-19.04	5.81	4.39	4.40	8.00	4.06	10.22		0.33	0.11	0.35	0.03	0.06	0.16	0.31	0.22	0.48	0.21	0.14	0.08	0.70	0.73	0.21	0.24	0.90
	14	23.62	10.28	-20.52	-1.98	-9.99	-27.81	-2.96	-4.38	-4.37	-0.77	-4.71	1.45	-8.77		0.17	0.06	0.26	0.35	0.21	0.02	0.07	0.21	0.17	0.22	0.23	0.50	0.54	0.04	0.48	0.76
	15	28.59	15.26	-15.54	3.00	-5.02	-22.83	2.02	0.60	0.60	4.21	0.26	6.43	-3.79	4.98		0.20	0.08	0.16	0.02	0.17	0.09	0.31	0.06	0.00	0.03	0.50	0.54	0.10	0.31	0.69
	16	22.33	8.99	-21.80	-3.26	-11.28	-29.09	-4.24	-5.67	-5.66	-2.05	-6.00	0.17	-10.05	-1.28	-6.26		0.29	0.38	0.25	0.03	0.11	0.13	0.22	0.25	0.27	0.39	0.44	0.08	0.50	0.64
	17	31.41	18.07	-12.72	5.82	-2.20	-20.01	4.84	3.41	3.42	7.03	3.08	9.25	-0.97	7.80	2.82	9.08		0.08	0.11	0.26	0.18	0.40	0.15	0.09	0.05	0.60	0.64	0.17	0.25	0.79
	18	34.47	21.13	-9.66	8.88	0.86	-16.95	7.90	6.48	6.48	10.09	6.14	12.31	2.09	10.86	5.88	12.14	3.06		0.21	0.34	0.26	0.49	0.25	0.18	0.14	0.68	0.71	0.25	0.18	0.86
	19	28.03	14.69	-16.11	2.43	-5.58	-23.39	1.45	0.03	0.04	3.64	-0.30	5.87	-4.36	4.41	-0.57	5.70	-3.38	-6.45		0.20	0.10	0.41	0.05	0.02	0.06	0.70	0.71	0.10	0.36	0.94
	20	23.15	9.81	-20.99	-2.45	-10.46	-28.28	-3.43	-4.85	-4.84	-1.24	-5.18	0.98	-9.24	-0.47	-5.45	0.81	-8.27	-11.33	-4.88		0.08	0.15	0.16	0.21	0.22	0.40	0.45	0.05	0.46	0.63
Attacking third	**21**	25.41	12.07	-18.73	-0.19	-8.20	-26.01	-1.17	-2.59	-2.58	1.02	-2.92	3.25	-6.98	1.79	-3.18	3.08	-6.00	-9.06	-2.62	2.26		0.23	0.06	0.11	0.14	0.46	0.50	0.02	0.40	0.67
	22	19.45	6.11	-24.69	-6.14	-14.16	-31.97	-7.13	-8.55	-8.54	-4.94	-8.88	-2.71	-12.93	-4.16	-9.14	-2.88	-11.96	-15.02	-8.58	-3.70	-5.96		0.39	0.40	0.39	0.29	0.35	0.18	0.58	0.56
	23	26.96	13.62	-17.18	1.36	-6.65	-24.46	0.38	-1.04	-1.03	2.57	-1.37	4.79	-5.43	3.34	-1.64	4.63	-4.45	-7.52	-1.07	3.81	1.55	7.51		0.07	0.11	0.71	0.71	0.07	0.40	0.96
	24	28.51	15.17	-15.63	2.91	-5.10	-22.92	1.93	0.51	0.52	4.12	0.18	6.34	-3.88	4.89	-0.09	6.17	-2.91	-5.97	0.48	5.36	3.10	9.05	1.55		0.04	0.67	0.69	0.11	0.35	0.90
	25	29.71	16.37	-14.43	4.11	-3.90	-21.71	3.13	1.71	1.72	5.32	1.38	7.54	-2.68	6.09	1.11	7.38	-1.70	-4.77	1.68	6.56	4.30	10.26	2.75	1.20		0.62	0.65	0.14	0.30	0.82
	26	13.78	0.44	-30.35	-11.81	-19.83	-37.64	-12.79	-14.22	-14.21	-10.60	-14.55	-8.38	-18.60	-9.83	-14.81	-8.55	-17.63	-20.69	-14.25	-9.36	-11.63	-5.67	-13.18	-14.72	-15.93		0.10	0.37	0.73	0.30
	27	11.48	-1.86	-32.66	-14.12	-22.13	-39.94	-15.10	-16.52	-16.51	-12.91	-16.85	-10.68	-20.91	-12.14	-17.12	-10.85	-19.93	-22.99	-16.55	-11.67	-13.93	-7.97	-15.48	-17.03	-18.23	-2.30		0.42	0.76	0.16
	28	24.89	11.55	-19.24	-0.70	-8.72	-26.53	-1.68	-3.10	-3.10	0.51	-3.44	2.73	-7.49	1.28	-3.70	2.56	-6.52	-9.58	-3.13	1.75	-0.52	5.44	-2.06	-3.61	-4.81	11.11	13.41		0.39	0.56
	29	42.72	29.38	-1.42	17.12	9.11	-8.70	16.14	14.72	14.73	18.33	14.39	20.56	10.33	19.10	14.12	20.39	11.31	8.25	14.69	19.57	17.31	23.27	15.76	14.21	13.01	28.94	31.24	17.83		0.87
	30	7.64	-5.70	-36.50	-17.96	-25.97	-43.79	-18.94	-20.36	-20.35	-16.75	-20.69	-14.53	-24.75	-15.98	-20.96	-14.70	-23.78	-26.84	-20.39	-15.51	-17.77	-11.82	-19.32	-20.87	-22.07	-6.15	-3.84	-17.26	-35.08	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Supp. 5 Difference in mean head turn frequency between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for full-backs.

Difference in mean head turn frequency, vertical - horizontal		Effect size: Defensive third 1	2	3	4	5	6	7	8	9	10	Midfield third 11	12	13	14	15	16	17	18	19	20	Attacking third 21	22	23	24	25	26	27	28	29	30
Defensive third	1		0.15	0.68	0.53	0.46	0.26	0.05	0.70	0.00	0.52	0.62	0.46	1.09	0.42	0.55	0.81	0.61	1.13	0.84	0.92	0.07	0.21	0.63	0.05	0.98	1.32	1.02	0.75	1.89	0.17
	2	0.10		1.15	0.89	0.41	0.45	0.24	1.08	0.10	0.77	0.89	0.67	1.63	0.63	0.90	1.20	0.93	1.72	1.23	1.34	0.19	0.43	0.93	0.19	1.40	2.14	1.38	1.15	3.07	0.36
	3	-0.40	-0.50		0.16	0.85	0.36	0.85	0.13	0.47	0.04	0.10	0.05	0.73	0.09	0.12	0.30	0.02	0.80	0.35	0.47	0.40	0.56	0.09	0.60	0.57	1.26	0.64	0.18	2.69	0.50
	4	-0.34	-0.43	0.06		0.78	0.23	0.63	0.24	0.38	0.07	0.20	0.05	0.77	0.01	0.03	0.39	0.14	0.82	0.44	0.55	0.31	0.38	0.20	0.46	0.63	1.14	0.70	0.30	2.12	0.35
	5	0.58	0.49	0.98	0.92		0.62	0.51	0.87	0.41	0.78	0.84	0.74	1.08	0.72	0.79	0.93	0.83	1.09	0.95	1.00	0.47	0.60	0.84	0.49	1.04	1.16	1.08	0.90	1.42	0.57
	6	-0.20	-0.29	0.21	0.14	-0.78		0.26	0.41	0.20	0.25	0.36	0.22	0.80	0.18	0.25	0.52	0.32	0.82	0.55	0.64	0.13	0.08	0.36	0.21	0.71	0.99	0.76	0.45	1.58	0.09
	7	-0.03	-0.13	0.37	0.31	-0.61	0.17		0.83	0.03	0.57	0.68	0.48	1.36	0.45	0.65	0.95	0.70	1.43	0.99	1.09	0.05	0.20	0.71	0.01	1.16	1.80	1.17	0.89	2.69	0.16
	8	-0.46	-0.55	-0.05	-0.12	-1.04	-0.26	-0.43		0.51	0.12	0.00	0.12	0.48	0.16	0.21	0.15	0.08	0.52	0.20	0.30	0.44	0.58	0.01	0.63	0.39	0.74	0.48	0.04	1.61	0.53
	9	0.00	-0.09	0.40	0.34	-0.58	0.20	0.03	0.46		0.40	0.47	0.36	0.78	0.34	0.40	0.59	0.45	0.79	0.61	0.67	0.06	0.16	0.48	0.04	0.73	0.88	0.78	0.54	1.25	0.13
	10	-0.38	-0.48	0.02	-0.04	-0.96	-0.18	-0.35	0.07	-0.38		0.10	0.02	0.52	0.05	0.05	0.25	0.05	0.54	0.28	0.37	0.33	0.37	0.10	0.46	0.44	0.70	0.52	0.16	1.31	0.36
Midfield third	11	-0.45	-0.55	-0.05	-0.12	-1.04	-0.26	-0.42	0.00	-0.46	-0.07		0.11	0.39	0.14	0.17	0.13	0.06	0.41	0.17	0.25	0.41	0.49	0.01	0.55	0.33	0.55	0.42	0.04	1.16	0.46
	12	-0.37	-0.46	0.03	-0.03	-0.95	-0.17	-0.34	0.09	-0.37	0.01	0.09		0.47	0.03	0.02	0.23	0.06	0.48	0.27	0.34	0.30	0.32	0.11	0.41	0.41	0.60	0.49	0.16	1.11	0.31
	13	-0.68	-0.78	-0.28	-0.35	-1.26	-0.49	-0.65	-0.23	-0.69	-0.30	-0.23	-0.31		0.51	0.73	0.30	0.53	0.01	0.25	0.15	0.71	1.06	0.43	1.00	0.04	0.16	0.11	0.45	1.12	0.95
	14	-0.34	-0.44	0.06	0.00	-0.92	-0.15	-0.31	0.11	-0.34	0.04	0.11	0.03	0.34		0.02	0.27	0.10	0.53	0.30	0.38	0.27	0.28	0.14	0.37	0.45	0.65	0.52	0.20	1.16	0.28
	15	-0.35	-0.45	0.05	-0.01	-0.93	-0.16	-0.32	0.10	-0.35	0.03	0.10	0.02	0.33	-0.01		0.36	0.11	0.77	0.40	0.51	0.32	0.40	0.17	0.48	0.60	1.07	0.66	0.26	2.01	0.37
	16	-0.53	-0.63	-0.13	-0.20	-1.12	-0.34	-0.50	-0.08	-0.54	-0.15	-0.08	-0.17	0.15	-0.19	-0.18		0.22	0.33	0.04	0.14	0.52	0.71	0.14	0.73	0.24	0.51	0.34	0.11	1.30	0.65
	17	-0.41	-0.51	-0.01	-0.08	-0.99	-0.22	-0.38	0.04	-0.42	-0.03	0.04	-0.04	0.27	-0.07	-0.06	0.12		0.56	0.26	0.35	0.38	0.47	0.06	0.54	0.44	0.76	0.52	0.12	1.51	0.44
	18	-0.69	-0.78	-0.28	-0.35	-1.27	-0.49	-0.66	-0.23	-0.69	-0.30	-0.23	-0.32	0.00	-0.34	-0.33	-0.15	-0.27		0.27	0.16	0.73	1.11	0.45	1.04	0.05	0.18	0.11	0.49	1.26	0.98
	19	-0.56	-0.65	-0.16	-0.22	-1.14	-0.36	-0.53	-0.10	-0.56	-0.18	-0.10	-0.19	0.12	-0.22	-0.21	-0.02	-0.15	0.13		0.10	0.55	0.74	0.18	0.76	0.19	0.44	0.30	0.16	1.21	0.68
	20	-0.61	-0.71	-0.21	-0.27	-1.19	-0.42	-0.58	-0.16	-0.61	-0.23	-0.16	-0.24	0.07	-0.27	-0.26	-0.08	-0.20	0.07	-0.05		0.61	0.84	0.27	0.84	0.09	0.31	0.22	0.27	1.09	0.77
Attacking third	21	-0.07	-0.17	0.33	0.27	-0.65	0.13	-0.04	0.38	-0.07	0.31	0.38	0.30	0.61	0.27	0.28	0.46	0.34	0.62	0.49	0.54		0.08	0.41	0.04	0.66	0.82	0.72	0.47	1.20	0.06
	22	-0.14	-0.24	0.26	0.20	-0.72	0.06	-0.11	0.31	-0.14	0.24	0.31	0.23	0.54	0.20	0.21	0.39	0.27	0.54	0.42	0.47	-0.07		0.50	0.15	0.92	1.39	0.95	0.63	2.18	0.02
	23	-0.45	-0.54	-0.05	-0.11	-1.03	-0.25	-0.42	0.01	-0.45	-0.07	0.01	-0.08	0.23	-0.11	-0.10	0.09	-0.04	0.24	0.11	0.16	-0.38	-0.31		0.57	0.35	0.61	0.44	0.05	1.28	0.48
	24	-0.04	-0.13	0.37	0.30	-0.62	0.16	-0.01	0.42	-0.04	0.35	0.42	0.33	0.65	0.31	0.32	0.50	0.38	0.65	0.52	0.58	0.04	0.11	0.41		0.91	1.21	0.95	0.67	1.75	0.12
	25	-0.66	-0.76	-0.26	-0.33	-1.25	-0.47	-0.63	-0.21	-0.67	-0.28	-0.21	-0.29	0.02	-0.32	-0.31	-0.13	-0.25	0.02	-0.11	-0.05	-0.59	-0.52	-0.22	-0.63		0.18	0.13	0.36	0.92	0.84
	26	-0.74	-0.84	-0.34	-0.40	-1.32	-0.54	-0.71	-0.28	-0.74	-0.36	-0.29	-0.37	-0.06	-0.40	-0.39	-0.21	-0.33	-0.05	-0.18	-0.13	-0.67	-0.60	-0.29	-0.70	-0.08		0.01	0.72	2.00	1.18
	27	-0.75	-0.84	-0.34	-0.41	-1.33	-0.55	-0.72	-0.29	-0.75	-0.36	-0.29	-0.38	-0.06	-0.40	-0.39	-0.21	-0.33	-0.06	-0.19	-0.13	-0.67	-0.60	-0.30	-0.71	-0.08	-0.01		0.46	0.59	0.89
	28	-0.48	-0.57	-0.07	-0.14	-1.06	-0.28	-0.45	-0.02	-0.48	-0.10	-0.02	-0.11	0.21	-0.13	-0.12	0.06	-0.06	0.21	0.08	0.14	-0.41	-0.33	-0.03	-0.44	0.19	0.26	0.27		1.64	0.58
	29	-1.03	-1.13	-0.63	-0.70	-1.62	-0.84	-1.00	-0.58	-1.04	-0.65	-0.58	-0.66	-0.35	-0.69	-0.68	-0.50	-0.62	-0.35	-0.48	-0.42	-0.96	-0.89	-0.58	-1.00	-0.37	-0.29	-0.29	-0.56		1.81
	30	-0.13	-0.22	0.27	0.21	-0.71	0.07	-0.10	0.33	-0.13	0.25	0.33	0.24	0.56	0.21	0.22	0.41	0.29	0.56	0.43	0.48	-0.06	0.01	0.32	-0.09	0.54	0.61	0.62	0.35	0.91	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Supp. 6 Difference in mean head turn excursion between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for full-backs.

Difference in mean head turn excursion, vertical - horizontal	Effect size	Defensive third										Midfield third										Attacking third									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Defensive third	1		0.36	0.54	0.38	1.38	0.24	0.71	0.17	0.50	0.01	0.48	0.18	0.27	0.06	0.17	0.47	0.18	0.45	0.15	0.10	0.15	0.66	0.37	0.18	0.65	0.67	0.45	0.45	2.08	0.66
	2	6.69		0.18	0.09	1.13	0.61	0.44	0.17	0.32	0.33	0.83	0.09	0.60	0.23	0.12	0.80	0.54	0.80	0.39	0.35	0.12	1.08	0.80	0.17	1.00	1.12	0.76	0.19	2.45	1.08
	3	10.08	3.39		0.06	1.01	0.80	0.31	0.33	0.23	0.49	1.01	0.22	0.76	0.38	0.26	0.97	0.72	0.98	0.51	0.47	0.26	1.29	1.02	0.34	1.18	1.34	0.93	0.06	2.68	1.29
	4	8.77	2.07	-1.31		0.96	0.58	0.32	0.22	0.25	0.36	0.76	0.15	0.58	0.28	0.18	0.75	0.53	0.74	0.42	0.38	0.18	0.91	0.70	0.23	0.89	0.91	0.72	0.10	1.85	0.91
	5	38.95	32.26	28.87	30.18		1.55	0.62	1.22	0.47	1.31	1.69	1.05	1.51	1.20	1.10	1.65	1.50	1.67	1.23	1.20	1.08	1.85	1.69	1.23	1.80	1.87	1.62	0.81	2.58	1.85
	6	-4.10	-10.80	-14.19	-12.87	-43.06		0.89	0.40	0.62	0.20	0.26	0.36	0.07	0.25	0.36	0.26	0.06	0.22	0.01	0.05	0.32	0.40	0.08	0.41	0.43	0.39	0.25	0.62	1.91	0.40
	7	18.14	11.45	8.06	9.38	-20.81	22.25		0.55	0.01	0.67	1.05	0.45	0.87	0.58	0.48	1.03	0.84	1.02	0.68	0.64	0.48	1.19	1.01	0.56	1.16	1.20	1.00	0.21	2.00	1.19
	8	3.38	-3.31	-6.70	-5.38	-35.57	7.49	-14.76		0.40	0.16	0.62	0.04	0.42	0.09	0.02	0.60	0.34	0.59	0.27	0.22	0.01	0.79	0.53	0.00	0.77	0.80	0.58	0.30	2.01	0.79
	9	18.60	11.91	8.52	9.83	-20.35	22.70	0.46	15.22		0.49	0.73	0.35	0.63	0.44	0.37	0.73	0.59	0.72	0.54	0.51	0.37	0.79	0.67	0.41	0.81	0.79	0.72	0.17	1.29	0.79
	10	-0.22	-6.92	-10.30	-8.99	-39.17	3.88	-18.37	-3.61	-18.82		0.41	0.18	0.23	0.06	0.17	0.40	0.14	0.37	0.14	0.09	0.14	0.53	0.29	0.17	0.55	0.52	0.39	0.43	1.61	0.53
Midfield third	11	-8.48	-15.17	-18.56	-17.25	-47.43	-4.37	-26.62	-11.86	-27.08	-8.26		0.53	0.16	0.44	0.54	0.02	0.31	0.04	0.15	0.21	0.50	0.07	0.23	0.63	0.15	0.04	0.02	0.78	1.44	0.07
	12	4.49	-2.20	-5.59	-4.28	-34.46	8.60	-13.65	1.11	-14.11	4.71	12.97		0.38	0.11	0.02	0.53	0.31	0.51	0.27	0.23	0.03	0.64	0.44	0.04	0.65	0.63	0.52	0.23	1.47	0.64
	13	-5.42	-12.12	-15.50	-14.19	-44.38	-1.32	-23.57	-8.81	-24.02	-5.20	3.06	-9.91		0.28	0.38	0.17	0.12	0.12	0.04	0.09	0.35	0.24	0.01	0.42	0.30	0.22	0.16	0.62	1.37	0.24
	14	1.35	-5.34	-8.73	-7.42	-37.60	5.45	-16.79	-2.03	-17.25	1.57	9.83	-3.14	6.77		0.10	0.44	0.20	0.41	0.18	0.14	0.08	0.54	0.33	0.09	0.56	0.54	0.42	0.35	1.47	0.54
	15	3.95	-2.74	-6.13	-4.81	-35.00	8.06	-14.19	0.57	-14.65	4.18	12.43	-0.54	9.38	2.60		0.54	0.31	0.52	0.26	0.22	0.01	0.66	0.45	0.02	0.67	0.65	0.52	0.26	1.57	0.66
	16	-8.85	-15.55	-18.94	-17.62	-47.81	-4.75	-27.00	-12.24	-27.45	-8.63	-0.38	-13.35	-3.43	-10.20	-12.81		0.30	0.06	0.16	0.22	0.49	0.04	0.23	0.61	0.12	0.01	0.00	0.77	1.23	0.04
	17	-3.14	-9.83	-13.22	-11.90	-42.09	0.97	-21.28	-6.52	-21.73	-2.91	5.34	-7.63	2.29	-4.48	-7.09	5.72		0.27	0.04	0.01	0.28	0.45	0.15	0.34	0.47	0.45	0.29	0.57	1.87	0.45
	18	-7.79	-14.48	-17.87	-16.56	-46.74	-3.68	-25.93	-11.17	-26.39	-7.57	0.69	-12.28	-2.37	-9.14	-11.74	1.07	-4.65		0.13	0.19	0.47	0.12	0.19	0.60	0.20	0.09	0.05	0.76	1.52	0.12
	19	-4.25	-10.94	-14.33	-13.02	-43.20	-0.15	-22.39	-7.63	-22.85	-4.03	4.23	-8.74	1.17	-5.60	-8.20	4.61	-1.11	3.54		0.04	0.24	0.21	0.04	0.27	0.25	0.19	0.16	0.48	0.90	0.21
	20	-2.76	-9.46	-12.84	-11.53	-41.72	1.34	-20.91	-6.15	-21.36	-2.54	5.72	-7.26	2.66	-4.11	-6.72	6.09	0.37	5.03	1.49		0.20	0.27	0.10	0.22	0.31	0.26	0.22	0.44	0.99	0.27
Attacking third	21	3.59	-3.10	-6.49	-5.18	-35.36	7.70	-14.55	0.21	-15.01	3.81	12.07	-0.90	9.01	2.24	-0.36	12.45	6.73	11.38	7.84	6.35		0.59	0.40	0.01	0.61	0.59	0.48	0.26	1.42	0.59
	22	-9.50	-16.19	-19.58	-18.27	-48.45	-5.39	-27.64	-12.88	-28.10	-9.28	-1.02	-13.99	-4.08	-10.85	-13.45	-0.64	-6.36	-1.71	-5.25	-6.73	-13.09		0.45	0.81	0.12	0.07	0.04	0.89	2.43	0.00
	23	-5.23	-11.92	-15.31	-14.00	-44.18	-1.12	-23.37	-8.61	-23.83	-5.01	3.25	-9.72	0.19	-6.58	-9.18	3.63	-2.09	2.56	-0.98	-2.47	-8.82	4.27		0.55	0.44	0.48	0.22	0.71	3.16	0.45
	24	3.37	-3.32	-6.71	-5.40	-35.58	7.48	-14.77	-0.01	-15.23	3.59	11.85	-1.12	8.79	2.02	-0.58	12.23	6.51	11.16	7.62	6.14	-0.22	12.87	8.60		0.79	0.83	0.58	0.31	2.08	0.81
	25	-11.11	-17.81	-21.19	-19.88	-50.07	-7.01	-29.26	-14.50	-29.71	-10.89	-2.63	-15.60	-5.69	-12.46	-15.07	-2.26	-7.98	-3.32	-6.86	-8.35	-14.70	-1.61	-5.88	-14.48		0.18	0.12	0.89	1.29	0.12
	26	-8.94	-15.63	-19.02	-17.71	-47.89	-4.84	-27.08	-12.32	-27.54	-8.72	-0.46	-13.43	-3.52	-10.29	-12.89	-0.08	-5.80	-1.15	-4.69	-6.18	-12.53	0.56	-3.71	-12.31	2.17		0.00	0.89	4.09	0.07
	27	-8.86	-15.56	-18.95	-17.63	-47.82	-4.76	-27.01	-12.25	-27.46	-8.64	-0.38	-13.36	-3.44	-10.21	-12.82	-0.01	-5.73	-1.07	-4.61	-6.10	-12.46	0.63	-3.64	-12.24	2.25	0.08		0.75	1.13	0.04
	28	11.59	4.90	1.51	2.82	-27.36	15.69	-6.55	8.21	-7.01	11.81	20.07	7.10	17.01	10.24	7.64	20.45	14.73	19.38	15.84	14.35	8.00	21.09	16.82	8.22	22.70	20.53	20.45		1.67	0.89
	29	-26.31	-33.01	-36.39	-35.08	-65.27	-22.21	-44.46	-29.70	-44.91	-26.09	-17.83	-30.81	-20.89	-27.66	-30.27	-17.46	-23.18	-18.52	-22.06	-23.55	-29.90	-16.82	-21.08	-29.68	-15.20	-17.37	-17.45	-37.90		2.46
	30	-9.48	-16.18	-19.56	-18.25	-48.44	-5.38	-27.63	-12.87	-28.08	-9.26	-1.00	-13.98	-4.06	-10.83	-13.44	-0.63	-6.35	-1.69	-5.23	-6.72	-13.07	0.01	-4.25	-12.86	1.63	-0.54	-0.62	-21.07	16.83	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Supp. 7 Difference in mean head turn frequency between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for strikers.

		Effect size																													
		Defensive third										Midfield third										Attacking third									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Difference in mean head turn frequency, vertical - horizontal: Defensive third	1		1.13	2.12	0.15	0.95	0.13	1.22	0.94	2.35	2.68	1.55	0.58	1.17	0.95	0.55	1.37	1.83	2.30	2.31	0.09	0.71	1.38	1.19	1.29	0.40	3.12	0.07	0.81	0.64	0.35
	2	-0.99		0.18	0.66	0.20	0.57	0.33	0.27	0.32	0.26	0.03	0.29	0.13	0.10	0.27	0.03	0.21	0.22	0.13	0.48	0.53	0.04	0.15	0.08	0.26	0.78	0.95	0.25	0.36	0.52
	3	-1.14	-0.15		0.95	0.46	0.77	0.87	0.59	0.25	0.15	0.33	0.49	0.40	0.29	0.46	0.27	0.07	0.07	0.14	0.62	1.03	0.30	0.45	0.09	0.40	1.13	1.39	0.50	0.64	0.80
	4	-0.16	0.83	0.98		0.51	0.01	0.52	0.48	1.06	1.04	0.74	0.33	0.61	0.56	0.32	0.71	0.93	0.99	0.93	0.01	0.29	0.70	0.61	0.75	0.24	1.43	0.18	0.44	0.33	0.15
	5	-0.78	0.20	0.35	-0.62		0.44	0.10	0.07	0.60	0.57	0.21	0.13	0.09	0.09	0.12	0.20	0.46	0.51	0.41	0.37	0.33	0.19	0.07	0.28	0.14	1.10	0.79	0.06	0.19	0.37
	6	-0.17	0.82	0.97	-0.01	0.61		0.42	0.40	0.86	0.84	0.61	0.29	0.51	0.48	0.28	0.59	0.77	0.80	0.75	0.01	0.24	0.59	0.51	0.64	0.22	1.16	0.16	0.38	0.28	0.12
	7	-0.71	0.28	0.43	-0.54	0.08	-0.53		0.02	1.10	1.22	0.43	0.08	0.22	0.19	0.07	0.38	0.77	0.99	0.89	0.35	0.32	0.37	0.21	0.45	0.09	1.91	0.86	0.02	0.14	0.35
	8	-0.72	0.27	0.42	-0.56	0.06	-0.55	-0.02		0.75	0.73	0.31	0.08	0.17	0.15	0.07	0.29	0.58	0.65	0.55	0.34	0.27	0.28	0.15	0.37	0.10	1.29	0.76	0.00	0.13	0.32
	9	-1.25	-0.26	-0.11	-1.09	-0.46	-1.08	-0.54	-0.53		0.19	0.54	0.60	0.57	0.42	0.56	0.45	0.12	0.20	0.45	0.69	1.21	0.48	0.62	0.24	0.48	0.88	1.52	0.63	0.77	0.91
	10	-1.19	-0.20	-0.05	-1.03	-0.40	-1.02	-0.48	-0.47	0.06		0.51	0.57	0.53	0.37	0.52	0.40	0.02	0.07	0.48	0.66	1.26	0.44	0.59	0.17	0.45	1.42	1.54	0.60	0.74	0.89
Midfield third	11	-0.96	0.03	0.18	-0.80	-0.17	-0.79	-0.25	-0.24	0.29	0.23		0.31	0.13	0.08	0.29	0.01	0.34	0.41	0.27	0.50	0.67	0.01	0.15	0.13	0.27	1.26	1.11	0.27	0.41	0.59
	12	-0.62	0.36	0.51	-0.46	0.16	-0.45	0.08	0.10	0.63	0.57	0.34		0.21	0.20	0.00	0.30	0.50	0.53	0.46	0.26	0.12	0.29	0.20	0.37	0.03	0.97	0.54	0.08	0.03	0.19
	13	-0.87	0.12	0.27	-0.70	-0.08	-0.69	-0.16	-0.14	0.38	0.32	0.09	-0.24		0.01	0.19	0.12	0.41	0.46	0.35	0.43	0.46	0.11	0.02	0.22	0.20	1.14	0.92	0.15	0.28	0.46
	14	-0.88	0.11	0.26	-0.72	-0.10	-0.71	-0.17	-0.16	0.37	0.31	0.08	-0.26	-0.02		0.19	0.08	0.31	0.33	0.25	0.41	0.39	0.07	0.03	0.17	0.19	0.85	0.82	0.14	0.26	0.42
	15	-0.63	0.36	0.51	-0.47	0.15	-0.46	0.08	0.09	0.62	0.56	0.33	-0.01	0.23	0.25		0.28	0.47	0.49	0.42	0.26	0.12	0.27	0.18	0.34	0.03	0.90	0.52	0.07	0.03	0.19
	16	-0.96	0.02	0.17	-0.80	-0.18	-0.79	-0.26	-0.24	0.29	0.22	0.00	-0.34	-0.10	-0.08	-0.33		0.29	0.33	0.21	0.49	0.61	0.02	0.15	0.12	0.26	1.05	1.05	0.26	0.39	0.56
	17	-1.18	-0.19	-0.04	-1.02	-0.39	-1.01	-0.47	-0.46	0.07	0.01	-0.22	-0.56	-0.31	-0.30	-0.55	-0.21		0.02	0.18	0.63	0.95	0.32	0.45	0.13	0.42	0.79	1.33	0.50	0.63	0.79
	18	-1.17	-0.18	-0.03	-1.01	-0.38	-1.00	-0.46	-0.45	0.08	0.02	-0.21	-0.54	-0.30	-0.29	-0.54	-0.20	0.01		0.25	0.64	1.12	0.36	0.51	0.13	0.43	1.15	1.45	0.55	0.69	0.84
	19	-1.09	-0.10	0.05	-0.92	-0.30	-0.92	-0.38	-0.37	0.16	0.10	-0.13	-0.46	-0.22	-0.21	-0.46	-0.12	0.09	0.08		0.60	1.04	0.24	0.40	0.03	0.37	1.55	1.39	0.46	0.61	0.77
	20	-0.15	0.84	0.99	0.01	0.64	0.02	0.56	0.57	1.10	1.04	0.81	0.48	0.72	0.73	0.48	0.82	1.03	1.02	0.94		0.21	0.49	0.42	0.54	0.20	0.93	0.12	0.33	0.25	0.12
Attacking third	21	-0.49	0.50	0.65	-0.33	0.29	-0.32	0.21	0.23	0.76	0.70	0.47	0.13	0.37	0.39	0.14	0.47	0.69	0.68	0.60	-0.34		0.60	0.45	0.65	0.05	1.84	0.57	0.24	0.09	0.12
	22	-0.95	0.04	0.19	-0.79	-0.17	-0.78	-0.24	-0.23	0.30	0.24	0.01	-0.33	-0.09	-0.07	-0.32	0.01	0.23	0.22	0.14	-0.80	-0.46		0.13	0.13	0.26	1.10	1.05	0.24	0.38	0.55
	23	-0.85	0.14	0.29	-0.69	-0.06	-0.68	-0.14	-0.13	0.40	0.34	0.11	-0.22	0.02	0.03	-0.22	0.12	0.33	0.32	0.24	-0.70	-0.36	0.10		0.24	0.19	1.22	0.92	0.13	0.27	0.45
	24	-1.07	-0.08	0.07	-0.91	-0.28	-0.90	-0.36	-0.35	0.18	0.12	-0.11	-0.44	-0.20	-0.19	-0.44	-0.10	0.11	0.10	0.02	-0.92	-0.58	-0.12	-0.22		0.32	0.73	1.06	0.33	0.45	0.61
	25	-0.57	0.42	0.57	-0.41	0.21	-0.40	0.13	0.15	0.68	0.62	0.39	0.05	0.29	0.31	0.06	0.39	0.61	0.60	0.51	-0.42	-0.08	0.38	0.28	0.50		0.75	0.40	0.09	0.01	0.13
	26	-1.62	-0.63	-0.48	-1.46	-0.84	-1.45	-0.92	-0.90	-0.37	-0.43	-0.66	-1.00	-0.76	-0.74	-0.99	-0.66	-0.44	-0.45	-0.53	-1.47	-1.13	-0.67	-0.77	-0.55	-1.05		1.97	1.09	1.21	1.30
	27	0.06	1.05	1.20	0.22	0.85	0.23	0.77	0.78	1.31	1.25	1.02	0.68	0.93	0.94	0.69	1.03	1.24	1.23	1.15	0.21	0.55	1.01	0.91	1.13	0.63	1.68		0.70	0.57	0.34
	28	-0.72	0.27	0.42	-0.56	0.07	-0.55	-0.01	0.00	0.53	0.47	0.24	-0.10	0.15	0.16	-0.09	0.24	0.46	0.45	0.37	-0.57	-0.23	0.23	0.13	0.35	-0.15	0.90	-0.78		0.12	0.30
	29	-0.58	0.40	0.55	-0.42	0.20	-0.41	0.12	0.14	0.67	0.61	0.38	0.04	0.28	0.30	0.05	0.38	0.60	0.58	0.50	-0.44	-0.09	0.37	0.26	0.48	-0.01	1.04	-0.64	0.14		0.18
	30	-0.36	0.63	0.78	-0.20	0.42	-0.19	0.35	0.36	0.89	0.83	0.60	0.26	0.51	0.52	0.27	0.60	0.82	0.81	0.73	-0.21	0.13	0.59	0.49	0.71	0.21	1.26	-0.42	0.36	0.22	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

strikers.

Difference in mean head turn excursion, vertical - horizontal		Effect size: Defensive third 1	2	3	4	5	6	7	8	9	10	Midfield third 11	12	13	14	15	16	17	18	19	20	Attacking third 21	22	23	24	25	26	27	28	29	30
Defensive third	1		0.85	1.08	0.71	1.01	0.18	0.56	1.11	1.26	1.38	1.21	0.34	0.74	1.12	1.25	0.89	1.28	1.17	1.31	0.03	0.34	0.86	0.83	1.36	0.60	1.95	0.46	0.35	0.91	1.42
	2	-27.47		0.00	0.30	0.04	0.32	0.50	0.03	0.18	0.22	0.17	0.40	0.24	0.12	0.18	0.13	0.19	0.07	0.12	0.37	0.55	0.12	0.24	0.31	0.12	0.76	0.46	0.43	0.06	0.34
	3	-27.45	0.02		0.43	0.05	0.34	0.75	0.05	0.27	0.36	0.24	0.47	0.34	0.17	0.26	0.19	0.29	0.11	0.20	0.39	0.72	0.16	0.36	0.45	0.14	1.21	0.62	0.53	0.09	0.50
	4	-18.93	8.53	8.51		0.41	0.17	0.24	0.47	0.67	0.79	0.62	0.20	0.07	0.53	0.65	0.23	0.69	0.54	0.67	0.26	0.35	0.22	0.11	0.81	0.11	1.54	0.23	0.23	0.29	0.87
	5	-28.57	-1.10	-1.12	-9.63		0.36	0.67	0.01	0.17	0.23	0.16	0.48	0.34	0.10	0.17	0.21	0.19	0.04	0.09	0.40	0.69	0.19	0.35	0.33	0.16	0.92	0.59	0.52	0.12	0.37
	6	-9.90	17.57	17.55	9.04	18.67		0.08	0.36	0.44	0.46	0.43	0.04	0.20	0.40	0.44	0.27	0.45	0.38	0.41	0.10	0.00	0.27	0.22	0.51	0.22	0.74	0.07	0.04	0.30	0.52
	7	-14.21	13.26	13.24	4.72	14.36	-4.31		0.79	1.02	1.23	0.93	0.06	0.30	0.81	0.99	0.50	1.05	0.89	1.14	0.19	0.17	0.46	0.39	1.14	0.26	2.09	0.04	0.08	0.54	1.23
	8	-28.27	-0.80	-0.82	-9.33	0.30	-18.37	-14.06		0.22	0.30	0.20	0.50	0.38	0.13	0.22	0.23	0.25	0.06	0.14	0.40	0.76	0.20	0.40	0.40	0.16	1.16	0.65	0.55	0.13	0.45
	9	-32.38	-4.91	-4.93	-13.44	-3.81	-22.48	-18.17	-4.11		0.04	0.01	0.63	0.57	0.07	0.00	0.43	0.02	0.17	0.13	0.46	0.92	0.39	0.62	0.19	0.28	0.89	0.83	0.69	0.31	0.23
	10	-33.09	-5.62	-5.65	-14.16	-4.52	-23.19	-18.88	-4.82	-0.71		0.05	0.68	0.67	0.11	0.05	0.53	0.02	0.25	0.23	0.48	1.03	0.47	0.77	0.18	0.32	1.02	0.94	0.75	0.38	0.22
Midfield third	11	-32.17	-4.70	-4.72	-13.23	-3.60	-22.27	-17.96	-3.90	0.21	0.92		0.60	0.53	0.05	0.01	0.39	0.03	0.15	0.11	0.46	0.87	0.36	0.57	0.19	0.27	0.83	0.78	0.66	0.29	0.23
	12	-12.34	15.13	15.11	6.60	16.23	-2.44	1.88	15.93	20.04	20.76	19.83		0.24	0.55	0.62	0.35	0.64	0.54	0.60	0.15	0.06	0.34	0.27	0.73	0.25	1.13	0.03	0.01	0.39	0.76
	13	-20.43	7.04	7.02	-1.49	8.14	-10.53	-6.21	7.84	11.95	12.67	11.74	-8.09		0.45	0.56	0.15	0.59	0.44	0.56	0.28	0.40	0.15	0.03	0.71	0.07	1.39	0.28	0.27	0.22	0.77
	14	-30.95	-3.48	-3.50	-12.01	-2.38	-21.05	-16.73	-2.68	1.43	2.15	1.22	-18.61	-10.52		0.06	0.32	0.08	0.08	0.03	0.44	0.79	0.29	0.47	0.24	0.23	0.83	0.70	0.61	0.22	0.27
	15	-32.32	-4.85	-4.88	-13.39	-3.75	-22.42	-18.11	-4.05	0.06	0.77	-0.15	-19.99	-11.90	-1.38		0.42	0.02	0.16	0.13	0.46	0.91	0.38	0.61	0.19	0.28	0.87	0.82	0.68	0.31	0.23
	16	-23.80	3.67	3.65	-4.87	4.77	-13.90	-9.59	4.47	8.58	9.29	8.37	-11.47	-3.38	7.14	8.52		0.45	0.29	0.39	0.33	0.54	0.01	0.14	0.59	0.03	1.29	0.43	0.39	0.08	0.64
	17	-32.73	-5.26	-5.28	-13.79	-4.16	-22.83	-18.52	-4.46	-0.35	0.36	-0.56	-20.39	-12.30	-1.78	-0.41	-8.93		0.19	0.16	0.47	0.94	0.41	0.65	0.18	0.30	0.88	0.85	0.70	0.33	0.22
	18	-29.33	-1.87	-1.89	-10.40	-0.77	-19.44	-15.12	-1.07	3.04	3.76	2.83	-17.00	-8.91	1.61	2.99	-5.53	3.39		0.07	0.42	0.82	0.26	0.48	0.36	0.20	1.14	0.72	0.60	0.18	0.41
	19	-30.38	-2.91	-2.93	-11.44	-1.81	-20.48	-16.17	-2.11	2.00	2.71	1.79	-18.04	-9.95	0.57	1.94	-6.58	2.35	-1.04		0.44	0.94	0.34	0.64	0.35	0.24	1.35	0.84	0.67	0.26	0.41
	20	-2.15	25.32	25.30	16.79	26.42	7.75	12.07	26.12	30.23	30.95	30.02	10.19	18.28	28.80	30.18	21.66	30.58	27.19	28.23		0.12	0.33	0.29	0.52	0.29	0.70	0.17	0.14	0.35	0.53
Attacking third	21	-10.17	17.30	17.28	8.77	18.40	-0.27	4.05	18.10	22.21	22.93	22.00	2.17	10.26	20.78	22.16	13.64	22.56	19.17	20.21	-8.02		0.52	0.46	1.04	0.34	1.64	0.12	0.06	0.58	1.09
	22	-23.98	3.49	3.47	-5.05	4.59	-14.08	-9.77	4.29	8.40	9.11	8.19	-11.65	-3.56	6.97	8.34	-0.18	8.75	5.35	6.40	-21.83	-13.81		0.14	0.54	0.03	1.17	0.42	0.38	0.06	0.58
	23	-21.03	6.43	6.41	-2.10	7.53	-11.14	-6.82	7.23	11.34	12.06	11.13	-8.70	-0.61	9.91	11.29	2.77	11.69	8.30	9.34	-18.89	-10.87	2.95		0.78	0.05	1.62	0.34	0.31	0.21	0.85
	24	-36.20	-8.73	-8.75	-17.26	-7.63	-26.30	-21.99	-7.93	-3.82	-3.11	-4.03	-23.86	-15.77	-5.25	-3.88	-12.40	-3.47	-6.86	-5.82	-34.05	-26.03	-12.22	-15.17		0.39	0.61	0.95	0.80	0.47	0.03
	25	-22.85	4.62	4.60	-3.92	5.72	-12.95	-8.64	5.42	9.53	10.24	9.32	-10.51	-2.42	8.10	9.47	0.95	9.88	6.48	7.53	-20.70	-12.68	1.13	-1.82	13.35		0.75	0.26	0.27	0.08	0.41
	26	-47.09	-19.62	-19.64	-28.16	-18.52	-37.19	-32.88	-18.82	-14.71	-14.00	-14.92	-34.76	-26.67	-16.14	-14.77	-23.29	-14.36	-17.76	-16.71	-44.94	-36.92	-23.11	-26.06	-10.89	-24.24		1.59	1.24	1.08	0.60
	27	-13.40	14.07	14.05	5.54	15.17	-3.50	0.82	14.87	18.98	19.70	18.77	-1.06	7.03	17.55	18.93	10.41	19.33	15.94	16.98	-11.25	-3.23	10.58	7.64	22.80	9.45	33.69		0.04	0.48	1.01
	28	-12.00	15.47	15.45	6.94	16.57	-2.10	2.21	16.27	20.38	21.09	20.17	0.34	8.43	18.95	20.32	11.80	20.73	17.34	18.38	-9.85	-1.83	11.98	9.04	24.20	10.85	35.09	1.40		0.43	0.83
	29	-25.56	1.90	1.88	-6.63	3.00	-15.66	-11.35	2.71	6.82	7.53	6.61	-13.23	-5.14	5.38	6.76	-1.76	7.17	3.77	4.82	-23.42	-15.40	-1.58	-4.53	10.64	-2.71	21.53	-12.17	-13.57		0.51
	30	-36.83	-9.36	-9.38	-17.89	-8.26	-26.93	-22.62	-8.56	-4.45	-3.74	-4.66	-24.49	-16.40	-5.88	-4.51	-13.03	-4.10	-7.49	-6.45	-34.68	-26.66	-12.85	-15.79	-0.63	-13.98	10.26	-23.43	-24.83	-11.26	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Supp. 9 Difference in mean head turn frequency between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for wide-midfielders.

Supp. 8 Difference in mean head turn excursion between the pitch zones and effect sizes of pairwise comparisons made between pitch zones for

Difference in mean head turn frequency, vertical - horizontal		Effect size: Defensive third										Midfield third										Attacking third									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Defensive third	**1**		0.34	0.15	0.29	0.38	0.09	0.44	0.53	0.60	0.04	0.24	0.76	0.17	0.44	0.39	0.21	0.51	0.06	0.27	0.08	0.07	0.10	0.02	0.39	0.10	0.43	0.06	0.10	0.01	0.95
	2	0.54		0.53	0.13	0.02	0.34	0.74	0.84	0.89	0.30	0.60	1.02	0.53	0.75	0.72	0.57	0.83	0.45	0.63	0.34	0.45	0.46	0.37	0.71	0.30	0.06	0.40	0.48	0.41	0.61
	3	-0.17	-0.71		0.59	0.59	0.40	0.43	0.69	0.78	0.20	0.15	1.13	0.04	0.45	0.37	0.09	0.65	0.15	0.19	0.35	0.12	0.06	0.26	0.37	0.35	0.66	0.08	0.09	0.23	1.15
	4	0.35	-0.19	0.51		0.16	0.29	0.87	1.14	1.20	0.24	0.68	1.44	0.56	0.91	0.87	0.64	1.11	0.46	0.78	0.29	0.45	0.47	0.34	0.85	0.24	0.22	0.36	0.51	0.40	0.81
	5	0.57	0.03	0.74	0.22		0.38	0.81	0.93	0.99	0.34	0.66	1.13	0.58	0.83	0.79	0.63	0.92	0.50	0.71	0.38	0.50	0.52	0.42	0.79	0.35	0.05	0.44	0.54	0.46	0.62
	6	0.10	-0.45	0.26	-0.25	-0.47		0.75	1.23	1.27	0.04	0.52	1.67	0.37	0.81	0.77	0.46	1.16	0.23	0.67	0.01	0.23	0.26	0.09	0.74	0.02	0.45	0.17	0.29	0.15	1.00
	7	-0.52	-1.06	-0.35	-0.86	-1.09	-0.61		0.01	0.12	0.47	0.28	0.33	0.34	0.03	0.11	0.33	0.00	0.53	0.32	0.70	0.48	0.42	0.61	0.09	0.67	0.88	0.37	0.48	0.60	1.31
	8	-0.52	-1.06	-0.36	-0.87	-1.09	-0.62	-0.01		0.22	0.56	0.43	0.73	0.47	0.05	0.19	0.50	0.03	0.82	0.63	1.06	0.69	0.57	0.88	0.14	0.93	1.01	0.45	0.74	0.94	1.40
	9	-0.61	-1.15	-0.44	-0.95	-1.18	-0.70	-0.09	-0.08		0.63	0.54	0.38	0.56	0.18	0.31	0.60	0.22	0.89	0.73	1.12	0.78	0.66	0.96	0.26	1.00	1.06	0.52	0.83	1.01	1.44
	10	0.06	-0.49	0.22	-0.29	-0.51	-0.04	0.57	0.58	0.66		0.29	0.79	0.21	0.48	0.43	0.25	0.55	0.11	0.31	0.03	0.11	0.14	0.02	0.43	0.05	0.39	0.10	0.14	0.06	0.91
Midfield third	**11**	-0.27	-0.81	-0.10	-0.62	-0.84	-0.37	0.25	0.25	0.34	-0.33		0.82	0.08	0.28	0.21	0.05	0.41	0.27	0.01	0.47	0.24	0.18	0.37	0.22	0.45	0.73	0.17	0.22	0.36	1.20
	12	-0.76	-1.30	-0.59	-1.10	-1.33	-0.85	-0.24	-0.23	-0.15	-0.81	-0.48		0.80	0.44	0.61	0.90	0.68	1.22	1.21	1.45	1.05	0.90	1.25	0.51	1.26	1.21	0.69	1.15	1.35	1.54
	13	-0.20	-0.74	-0.03	-0.55	-0.77	-0.30	0.32	0.32	0.41	-0.26	0.07	0.55		0.34	0.27	0.04	0.45	0.16	0.10	0.34	0.14	0.09	0.26	0.28	0.34	0.65	0.10	0.11	0.23	1.13
	14	-0.49	-1.03	-0.33	-0.84	-1.06	-0.59	0.03	0.03	0.12	-0.55	-0.22	0.26	-0.29		0.09	0.33	0.04	0.56	0.33	0.75	0.50	0.43	0.64	0.06	0.71	0.90	0.37	0.51	0.64	1.32
	15	-0.42	-0.96	-0.26	-0.77	-0.99	-0.52	0.09	0.10	0.19	-0.48	-0.15	0.33	-0.22	0.07		0.26	0.16	0.50	0.24	0.69	0.44	0.36	0.58	0.02	0.65	0.86	0.31	0.44	0.58	1.30
	16	-0.23	-0.77	-0.07	-0.58	-0.80	-0.33	0.28	0.29	0.38	-0.29	0.04	0.52	-0.03	0.26	0.19		0.47	0.22	0.07	0.42	0.19	0.13	0.33	0.27	0.41	0.70	0.13	0.17	0.30	1.18
	17	-0.51	-1.06	-0.35	-0.86	-1.08	-0.61	0.00	0.01	0.09	-0.57	-0.24	0.24	-0.31	-0.02	-0.09	-0.28		0.77	0.57	1.01	0.66	0.55	0.85	0.12	0.90	0.99	0.44	0.70	0.89	1.39
	18	-0.06	-0.61	0.10	-0.41	-0.63	-0.16	0.45	0.46	0.54	-0.12	0.21	0.69	0.14	0.43	0.36	0.17	0.45		0.35	0.20	0.02	0.06	0.12	0.49	0.21	0.57	0.02	0.06	0.08	1.09
	19	-0.28	-0.82	-0.11	-0.62	-0.85	-0.37	0.24	0.25	0.33	-0.33	-0.01	0.48	-0.08	0.22	0.15	-0.04	0.24	-0.21		0.58	0.29	0.21	0.45	0.25	0.54	0.78	0.19	0.28	0.45	1.24
	20	0.09	-0.46	0.25	-0.26	-0.49	-0.01	0.60	0.61	0.69	0.03	0.36	0.84	0.29	0.58	0.51	0.32	0.60	0.15	0.36		0.20	0.24	0.07	0.67	0.03	0.45	0.16	0.26	0.13	1.00
Attacking third	**21**	-0.08	-0.62	0.09	-0.42	-0.65	-0.17	0.44	0.45	0.53	-0.13	0.19	0.68	0.12	0.41	0.34	0.15	0.44	-0.01	0.20	-0.16		0.05	0.12	0.44	0.22	0.56	0.01	0.04	0.09	1.08
	22	-0.12	-0.66	0.05	-0.46	-0.69	-0.21	0.40	0.41	0.49	-0.17	0.15	0.64	0.08	0.37	0.30	0.11	0.40	-0.05	0.16	-0.20	-0.04		0.16	0.37	0.25	0.58	0.03	0.01	0.13	1.08
	23	0.03	-0.51	0.19	-0.32	-0.54	-0.07	0.54	0.55	0.63	-0.03	0.30	0.78	0.23	0.52	0.45	0.26	0.54	0.09	0.30	-0.06	0.10	0.14		0.57	0.10	0.49	0.10	0.17	0.05	1.02
	24	-0.44	-0.98	-0.27	-0.79	-1.01	-0.54	0.08	0.08	0.17	-0.50	-0.17	0.32	-0.24	0.05	-0.02	-0.21	0.07	-0.38	-0.16	-0.53	-0.36	-0.32	-0.47		0.64	0.85	0.32	0.44	0.57	1.29
	25	0.11	-0.43	0.28	-0.23	-0.46	0.02	0.63	0.64	0.72	0.06	0.38	0.87	0.31	0.60	0.54	0.34	0.63	0.18	0.39	0.03	0.19	0.23	0.09	0.55		0.41	0.17	0.26	0.15	0.96
	26	0.65	0.11	0.81	0.30	0.08	0.55	1.17	1.17	1.26	0.59	0.92	1.40	0.85	1.14	1.07	0.88	1.16	0.71	0.92	0.56	0.73	0.77	0.62	1.09	0.54		0.50	0.60	0.53	0.58
	27	-0.09	-0.63	0.08	-0.43	-0.66	-0.18	0.43	0.44	0.52	-0.14	0.19	0.67	0.12	0.41	0.34	0.15	0.43	-0.02	0.19	-0.17	-0.01	0.03	-0.11	0.35	-0.20	-0.73		0.02	0.07	1.00
	28	-0.11	-0.65	0.06	-0.45	-0.68	-0.20	0.41	0.42	0.50	-0.16	0.16	0.65	0.09	0.39	0.32	0.13	0.41	-0.04	0.17	-0.19	-0.03	0.01	-0.13	0.33	-0.22	-0.75	-0.02		0.14	1.11
	29	-0.01	-0.55	0.16	-0.35	-0.58	-0.10	0.51	0.52	0.60	-0.06	0.26	0.75	0.19	0.48	0.41	0.22	0.51	0.06	0.27	-0.09	0.07	0.11	-0.03	0.43	-0.12	-0.66	0.08	0.10		1.05
	30	1.81	1.27	1.98	1.46	1.24	1.72	2.33	2.33	2.42	1.76	2.08	2.57	2.01	2.30	2.23	2.04	2.33	1.88	2.09	1.73	1.89	1.93	1.78	2.25	1.70	1.16	1.90	1.92	1.82	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

wide-midfielders.

Difference in mean head turn excursion, vertical - horizontal		Effect size																													
		Defensive third										Midfield third										Attacking third									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Defensive third	1		0.53	0.15	0.70	0.45	0.55	0.17	0.10	0.03	0.27	0.02	0.54	0.07	0.09	0.26	0.20	0.40	0.44	0.00	0.21	0.32	0.00	0.18	0.23	0.02	0.83	0.13	0.18	0.23	0.48
	2	-14.99		1.05	1.34	1.23	1.49	0.30	0.75	0.66	0.93	0.87	0.05	0.67	0.53	0.47	0.65	0.25	1.15	1.00	0.81	0.91	1.04	1.43	0.47	0.85	1.23	0.67	1.59	1.09	1.22
	3	4.88	19.87		0.67	0.38	0.51	0.35	0.35	0.21	0.17	0.23	1.02	0.07	0.29	0.58	0.50	0.79	0.37	0.22	0.10	0.23	0.22	0.02	0.52	0.18	0.80	0.02	0.02	0.10	0.42
	4	30.26	45.24	25.37		0.33	0.27	0.86	0.92	0.80	0.47	0.84	1.33	0.66	0.85	1.07	1.02	1.20	0.32	0.84	0.51	0.39	0.85	0.70	1.03	0.80	0.29	0.56	0.71	0.59	0.28
	5	16.66	31.65	11.78	-13.59		0.08	0.63	0.69	0.55	0.17	0.58	1.21	0.39	0.60	0.87	0.81	1.04	0.00	0.59	0.23	0.09	0.60	0.40	0.82	0.53	0.55	0.29	0.42	0.28	0.05
	6	19.32	34.31	14.44	-10.93	2.66		0.74	0.85	0.67	0.26	0.73	1.46	0.49	0.73	1.06	1.00	1.26	0.07	0.75	0.32	0.17	0.76	0.55	0.99	0.67	0.52	0.38	0.57	0.40	0.03
	7	-6.63	8.36	-11.51	-36.88	-23.29	-25.95		0.11	0.17	0.44	0.19	0.31	0.25	0.10	0.04	0.02	0.17	0.61	0.22	0.38	0.48	0.22	0.39	0.02	0.22	0.95	0.30	0.40	0.42	0.65
	8	-3.18	11.81	-8.07	-33.44	-19.84	-22.50	3.45		0.09	0.45	0.13	0.73	0.20	0.00	0.25	0.14	0.47	0.66	0.16	0.36	0.48	0.16	0.44	0.19	0.17	0.97	0.26	0.47	0.44	0.71
	9	-0.94	14.05	-5.82	-31.19	-17.60	-20.26	5.69	2.24		0.34	0.02	0.65	0.11	0.07	0.29	0.21	0.47	0.53	0.04	0.26	0.38	0.04	0.26	0.25	0.06	0.90	0.18	0.27	0.30	0.58
	10	10.41	25.40	5.53	-19.85	-6.25	-8.91	17.04	13.59	11.35		0.35	0.92	0.21	0.40	0.62	0.55	0.77	0.17	0.35	0.06	0.06	0.35	0.17	0.57	0.31	0.65	0.12	0.18	0.08	0.21
Midfield third	11	-0.49	14.50	-5.37	-30.75	-17.15	-19.81	6.14	2.69	0.45	-10.90		0.84	0.11	0.10	0.37	0.27	0.59	0.56	0.03	0.27	0.40	0.02	0.29	0.31	0.04	0.91	0.18	0.30	0.32	0.61
	12	-15.53	-0.54	-20.41	-45.79	-32.19	-34.85	-8.90	-12.35	-14.59	-25.94	-15.04		0.67	0.54	0.47	0.63	0.26	1.14	0.96	0.81	0.91	0.99	1.34	0.47	0.83	1.24	0.67	1.46	1.07	1.21
	13	2.74	17.73	-2.14	-27.52	-13.92	-16.58	9.37	5.92	3.68	-7.67	3.23	18.27		0.18	0.37	0.30	0.52	0.38	0.09	0.14	0.26	0.10	0.09	0.34	0.07	0.80	0.07	0.09	0.15	0.42
	14	-3.12	11.87	-8.00	-33.37	-19.78	-22.44	3.51	0.06	-2.18	-13.53	-2.63	12.41	-5.86		0.19	0.11	0.36	0.58	0.12	0.32	0.44	0.12	0.34	0.16	0.13	0.93	0.23	0.35	0.37	0.63
	15	-7.99	7.00	-12.88	-38.25	-24.65	-27.31	-1.36	-4.81	-7.05	-18.40	-7.50	7.54	-10.73	-4.87		0.12	0.22	0.83	0.42	0.53	0.64	0.43	0.72	0.04	0.39	1.07	0.41	0.77	0.66	0.89
	16	-5.89	9.10	-10.78	-36.15	-22.55	-25.22	0.74	-2.71	-4.96	-16.30	-5.40	9.64	-8.63	-2.78	2.10		0.35	0.77	0.32	0.46	0.58	0.33	0.63	0.07	0.31	1.03	0.35	0.67	0.58	0.83
	17	-11.80	3.19	-16.68	-42.05	-28.46	-31.12	-5.17	-8.62	-10.86	-22.21	-11.31	3.73	-14.54	-8.68	-3.81	-5.91		0.98	0.67	0.67	0.77	0.69	1.01	0.24	0.61	1.15	0.54	1.09	0.86	1.05
	18	16.73	31.72	11.84	-13.53	0.07	-2.60	23.35	19.91	17.66	6.32	17.22	32.26	13.99	19.84	24.72	22.62	28.53		0.56	0.22	0.09	0.57	0.38	0.78	0.51	0.54	0.28	0.40	0.27	0.04
	19	0.03	15.02	-4.86	-30.23	-16.63	-19.29	6.66	3.21	0.96	-10.38	0.52	15.56	-2.71	3.14	8.02	5.92	11.83	-16.70		0.26	0.39	0.00	0.29	0.36	0.02	0.91	0.17	0.30	0.32	0.62
	20	8.14	23.13	3.25	-22.12	-8.52	-11.18	14.77	11.32	9.08	-2.27	8.63	23.67	5.40	11.26	16.13	14.03	19.94	-8.59	8.11		0.12	0.27	0.09	0.49	0.23	0.69	0.07	0.10	0.01	0.27
Attacking third	21	12.99	27.97	8.10	-17.27	-3.68	-6.34	19.61	16.17	13.92	2.57	13.48	28.52	10.25	16.10	20.98	18.88	24.78	-3.74	12.96	4.85		0.40	0.23	0.60	0.36	0.59	0.18	0.24	0.15	0.13
	22	-0.06	14.93	-4.94	-30.32	-16.72	-19.38	6.57	3.12	0.88	-10.47	0.43	15.47	-2.80	3.06	7.93	5.83	11.74	-16.79	-0.09	-8.20	-13.04		0.30	0.36	0.03	0.92	0.17	0.32	0.33	0.63
	23	5.32	20.31	0.44	-24.93	-11.34	-14.00	11.95	8.50	6.26	-5.09	5.81	20.85	2.58	8.44	13.31	11.22	17.12	-11.40	5.30	-2.82	-7.66	5.38		0.64	0.23	0.82	0.00	0.00	0.10	0.44
	24	-7.22	7.77	-12.10	-37.47	-23.88	-26.54	-0.59	-4.04	-6.28	-17.63	-6.73	8.31	-9.96	-4.10	0.77	-1.32	4.58	-23.94	-7.25	-15.36	-20.20	-7.16	-12.54		0.34	1.04	0.38	0.67	0.60	0.84
	25	0.53	15.52	-4.35	-29.72	-16.13	-18.79	7.16	3.71	1.47	-9.88	1.02	16.06	-2.21	3.65	8.52	6.42	12.33	-16.20	0.50	-7.61	-12.45	0.59	-4.79	7.75		0.89	0.14	0.23	0.27	0.57
	26	47.68	62.67	42.80	17.43	31.02	28.36	54.31	50.87	48.62	37.27	48.17	63.21	44.94	50.80	55.68	53.58	59.48	30.96	47.66	39.55	34.70	47.74	42.36	54.90	47.15		0.72	0.82	0.74	0.51
	27	5.43	20.42	0.54	-24.83	-11.23	-13.90	12.05	8.61	6.36	-4.98	5.92	20.96	2.69	8.54	13.42	11.32	17.23	-11.30	5.40	-2.71	-7.56	5.49	0.10	12.64	4.90	-42.26		0.01	0.06	0.33
	28	5.26	20.25	0.38	-24.99	-11.40	-14.06	11.89	8.44	6.20	-5.15	5.75	20.79	2.52	8.38	13.25	11.16	17.06	-11.46	5.24	-2.88	-7.72	5.32	-0.06	12.48	4.73	-42.42	-0.16		0.11	0.46
	29	7.63	22.62	2.75	-22.62	-9.03	-11.69	14.26	10.81	8.57	-2.78	8.12	23.16	4.89	10.75	15.62	13.52	19.43	-9.09	7.60	-0.51	-5.35	7.69	2.31	14.85	7.10	-40.05	2.21	2.37		0.33
	30	18.39	33.38	13.51	-11.87	1.73	-0.93	25.02	21.57	19.33	7.98	18.88	33.92	15.65	21.51	26.38	24.28	30.19	1.66	18.36	10.25	5.40	18.45	13.07	25.61	17.86	-29.29	12.96	13.13	10.76	

Legend					
Vertical zone > horizontal zone	Vertical zone < horizontal zone	Trivial effect	Small - medium effect	Medium - large effect	Large - very large effect

Supp. 10 Difference in mean head turn excursion between the pitch zones and effect sizes of pairwise comparis

Chapter 8: General Discussion

This chapter provides a general discussion of the thesis, including a summary of the findings, major contributions to theory, methodology and practice, research strengths and limitations, and recommendations for future research.

8.1 Summary of findings

This thesis presents several novel findings in relation to the visual exploratory actions used by football players. Table 8.1 gives a summary of the aims and main findings of each study within this thesis. In general, the findings provide support for the value of extensive visual exploratory action prior to possession of the ball and showed that visual exploratory actions are constrained by a number of factors.

The current thesis found some similarities to the small body of existing evidence relating to visual exploratory action of football players. At the broadest level, a higher frequency of visual exploratory head movements before receiving the ball was related to improved performance with the ball. This finding is in line with previous investigations of elite senior (Jordet et al., 2013; Pedersen, 2016) and elite youth players (Spearritt, 2013). In the current thesis, better performance was operationalised as faster pass responses (Chapter 5), more attacking passes (Chapter 6), more passes to a different area of the field (Chapter 6), and more turns with the ball (Chapter 6). Similarly, previous investigations found that players were more likely to play an attacking pass when they had explored with a higher frequency before receiving the ball (Jordet et al., 2013; Spearritt, 2013). Previous investigations also found that players who completed more frequent exploratory actions before receiving the ball were more likely to play a successful pass (Jordet et al., 2013; Spearritt, 2013), however this was not replicated in the group of players recruited for this thesis.

Table 8.1 Summary of study aims and findings.

Thesis Chapter	Study title	Aims	Findings
Chapter 2	A Systematic Review of the Technology-Based Assessment of Visual Perception and Exploration Behaviour in Association Football	To gain a direction for future research by systematically collating extant research that uses technology to assist with the quantification of visual exploratory action in football situations.	- No studies have used technology to quantify the visual exploratory head movement of football players. - Previous studies rarely utilised representative environmental information or action requirements.
Chapter 5	Visual Exploration when Surrounded by Affordances: Frequency of Head Movements is Predictive of Response Speed	Aim 1: To understand how teammate location and time constraints influence visual exploratory head movement and the speed of a football specific performatory response. Aim 2: To understand the relationship between visual exploratory head movement and the speed of a football specific performatory response.	- Players were able to complete a pass more quickly when they had two or three seconds before gaining ball possession than when they had one second. - Players were able to complete a pass more quickly when they explored with a higher head turn frequency before gaining ball possession.
Chapter 6	Don't Turn Blind! The Relationship Between Exploration Before Ball Possession and On-Ball Performance in Association Football	Aim 1: To understand the relationships between visual exploratory head movement and performatory actions with the ball during 11v11 football match-play. Aim 2: To understand how the relationships between visual exploratory head movement and performatory actions change according to the time-period before possession that is investigated.	- Players were more likely to turn with the ball, play an attacking pass, and play a pass to a different area of the pitch when they had explored with a higher than average head turn frequency and excursion before receiving ball possession. - The strength of the above relationships varied according to the time-period before ball possession that was investigated.
Chpater 7	Constraints on Visual Exploration of Youth Football Players During 11v11 Match-Play: The Influence of Playing Role, Pitch Position and Phase of Play	Aim 1: To understand how playing role constrains visual exploratory head movements in 11v11 football match-play. Aim 2: To understand how pitch position constrains visual exploratory head movements in 11v11 football match-play. Aim 3: To understand how phase of play constrains visual exploratory head movements in 11v11 football match-play.	- Playing role, pitch position and phase of play all constrained visual exploratory head movement of football players. - Players generally explored more extensively when in possession of the ball, and less extensively during transition phases of play, compared to team ball possession and opposition ball possession. - Wide players generally explored more extensively during opposition ball possession than team ball possession phases, while central players generally explored more extensively during team ball possession than during opposition ball possession.

In response to a lack of research investigating the visual exploratory actions of football players (McGuckian et al., 2018c), this thesis contributes a number of novel findings to the literature. Chapters 5 and 6 both found evidence to support the value of visual exploration for prospective control of action. When exploring more extensively before gaining possession of the ball, players were able to complete passing actions with the ball more quickly and were more likely to complete actions with the ball that made use of the surrounding environment. Further, players explored with a higher frequency and excursion of head movements as they became closer to ball possession, particularly in the 2-3 seconds before possession. It is likely that 2-3 seconds before ball possession, players recognized ball possession was likely, and therefore needed to prospectively discover afforded actions for when they gained possession. Compared to when ball interaction is less likely, this extensive exploration immediately before ball possession may indicate an increased requirement for prospective control of action when players are required to interact with the ball.

Chapter 7 found that players explored with an average head turn frequency of 0.91 turns/second and excursion of 32.94 degrees/second across an entire match, regardless of ball possession. These values are similar to those found in the 10-seconds prior to ball possession (0.95 turns/seconds and 35.29 degrees/seconds, respectively; Chapter 6), which has important implications for future research and applied work. It may be that previous investigations of visual exploratory action (Eldridge et al., 2013; Jordet et al., 2013; Pedersen, 2016; Spearritt, 2013), which have quantified visual exploration in the 10-seconds before ball possession, are not quantifying visual exploration in the most informative time-period before ball possession. By quantifying visual exploration over a range of time periods before possession, Chapter 6 determined that players explored more extensively closer to ball possession, and that this extensive exploration closer to ball possession was more strongly related to performatory actions with the ball. Therefore, in order to understand relationships between exploration and actions with the ball, a shorter time-period before ball possession is likely to be more informative. Additionally, quantifying exploration in a 10-second period before ball possession may be sufficient to gain an approximate measure of exploration across an entire match. This information could be used to understand general differences in exploration, for example between players or at different time periods over a season, when it is not possible to quantify exploratory actions across an entire match.

A general measure of players' visual exploration across an entire match is useful to monitor developmental progress. In order to maximise the effectiveness of training interventions it is important to understand the constraining factors on the outcome of interest

(Araújo et al., 2010; Clark, McEwan, & Christie, 2018; Davids, Button, & Bennett, 2008; Kinnerk, Harvey, MacDonncha, & Lyons, 2018; Ometto et al., 2018; Passos et al., 2008; Pinder & Renshaw, 2019; Seifert, Araújo, Komar, & Davids, 2017; Uehara, Button, & Davids, 2019). Chapter 7 made significant progress in this area by quantifying players' visual exploratory actions according to playing role, pitch position and phase of play. Several differences were found according to these constraints, with the interaction between playing role and phase of play being of particular interest. Wide players (full-backs and wide- midfielders) tended to explore more extensively when the opposition had ball possession compared to when their own team had ball possession, whereas central players (centre-backs, centre-midfielders and strikers) tended to explore more extensively when their own team had ball possession compared to when the opposition had ball possession. While visual exploratory action is always important during a match, these differences suggest that the task demands on players are different according to their playing role and the phase of play. Consequently, it is important that coaches understand these differing demands, and that they develop training situations that create opportunities for players to attune to the requirement of their roles at different phases of the game.

During 11v11 match-play, players explored much more extensively when they had possession of the ball compared to phases of play when they did not have the ball (Chapter 7). In the lab-based passing task (Chapter 5), players also explored with a higher frequency of head turns when in possession of the ball compared to the time before they gained possession of the ball, but only when they had 1-second of exploration time before receiving the ball. When players had 2-seconds or 3-seconds of exploration time before receiving the ball, there was no difference in the frequency of head turns between the two phases. These differences in findings between Chapter 5 and Chapter 7 show the value of investigating these complex visual exploratory actions in a natural performance environment (Araújo et al., 2007; Brunswik, 1956; Dhami et al., 2004; Dicks et al., 2009; Pinder et al., 2011). While efforts were made to ensure the experimental setup used in Chapter 5 was representative of the natural performance environment, the task could be considered to be simpler than the demands placed on players performing passing actions during dynamic football match-play. The findings from Chapter 5 give valuable insight into prospective control of movement and the relationship between exploratory and performatory action, however, Chapter 7 gave a deeper understanding of athlete actions during competitive football match-play.

Together, the findings from this thesis provide comprehensive insight into the visual exploratory actions used by football players. Extensive visual exploratory action prior to ball possession assists in the prospective control of performatory actions, here expressed as faster passing responses and a higher likelihood of using the surroundings environment. Further, visual exploratory actions are constrained by playing role, pitch position and phase of play.

8.2 Major contributions

This thesis makes significant contributions to theory, methodology and applied practice related to visual perception of football athletes. A discussion of each of these contributions is given below.

8.2.1 Contributions to theory

This thesis, underpinned by the Ecological approach to visual perception, provides sound evidence to the theorised function of visual exploratory action – to support prospective control of action through the perception of affordances. Chapter 5 showed that extensive exploratory action before performing an action leads to faster prospective guidance of actions. Further, Chapter 6 showed the strong relationship between exploratory action and subsequent performatory actions. Together, these findings support the theoretical underpinnings of the thesis, and add support to the Ecological approach to visual perception (Gibson, 1979).

Of primary importance to the Ecological approach to visual perception is the coupled relationship between an actor and their environment (Gibson, 1979). Accordingly, this thesis made every attempt to ensure that the actors (i.e. the football players) were coupled with their natural performance environment (i.e. 11v11 football match-play). In doing so, constraining factors on visual exploration were able to be investigated as the natural perception-action couplings were maintained. As a result, the thesis provided evidence to constraining factors of playing role, pitch position and phase of play on visual exploratory head movement. Further, the differences in visual exploration according to ball possession found between Chapter 5 and Chapter 7 further support the need for natural actor-environment pairing in order to maintain representative perception-action coupling.

Finally, this thesis provides evidence for the visual perception chain, which includes eye, head and body movement (Gibson, 1966, 1979; Reed, 1996). Eye-movement had previously been extensively investigated (Mann et al., 2007), however head movement had rarely been considered when investigating visual perception (McGuckian et al., 2018c). Here, the need for head movement in order to effectively visually perceive one's environment was established, providing sound evidence for Gibson's (1979) Ecological approach to visual perception.

8.2.2 Contributions to methodology

Previously, research investigating visual perception in a football setting primarily utilised eye-tracking technology in a lab-based setting (McGuckian et al., 2018c). These studies often projected information onto a large screen in attempts to make the image close to life-size. However, no previous investigation presented information surrounding the participant, which greatly limited the representative value of the information presented and removed the need for participants to use exploratory head movement. Chapter 5 of this thesis presents the first study to surround the participants with visual information, therefore bringing the value of visual exploratory head movement to the forefront. The remaining chapters of this thesis built on this work by utilising open match-play, which presented visual information in 360-degrees; representing a novel contribution to methodology in visual perception research.

This thesis represents the first series of studies to utilise IMUs to quantify the visual exploratory head movement of football players. In doing so, a new method to collect head movement data was developed and implemented for the first time. This new method can detect head movement events computationally, resulting in outcomes that are objective and more accurate than previously used notational methods. Further, the new methods require substantially less human time to process data, enabling the analysis of multiple player's data in a short period of time.

The use of IMUs to quantify exploratory head movements also allows analysis of additional kinematic qualities of the movement, such as excursion. The addition of this variable allowed a deeper understanding of visual exploration, as it gives an indication of the range of visual information that can be perceived. Together with head turn frequency, the variables obtained from the IMUs provide a more descriptive understanding of the movements used by players to visually perceive their environment in 360-degrees.

Finally, the integration of IMU, GPS and notational analysis methods offers a substantial contribution to methodology in sport science. Each of these have traditionally been used for specific applications, however, their value perhaps lies in their ability to offer solutions to problems that they have not previously been used for. Chapter 7 made use of all three methods, allowing a novel investigation into the constraining factors on visual exploratory action. Importantly, context was added to the analysis of visual exploration with the addition of player position on the pitch (via GPS data) and phase of play (via notational analysis of possession). Time-synchronisation of these variables gave the ability to analyse visual exploratory action at specific game moments. Additional context to analysis is often needed in sport science research (Bradley, Evans, Laws, & Ade, 2018), and the methods used in Chapter 7 may be used as an example of adding context to analysis in complex settings.

8.2.3 Contributions to applied practice

The major contributions from this thesis can be interpreted and applied in practical settings in a range of ways. Primarily, the use of IMUs and associated analysis methods to quantify visual exploratory head movements present opportunities to improve: i) training design and athlete development, and ii) player monitoring and return to play protocols.

i. Training design and athlete development

To ensure optimal player development, coaches must ensure their training environments expose players to the situations which they are likely to experience during competitive play, as this allows the players the opportunity to experience the specifying interactions between constraints of match-play and develop solutions to complex match-play problems (Araújo et al., 2010, 2017; Ometto et al., 2018; Passos et al., 2008; Seifert et al., 2017). In doing so, it is important for coaches to understand the visual exploratory actions that are required during match-play as well as the ability to quantify these actions. This thesis provides preliminary evidence of the visual exploratory requirements of match-play for competitive-elite youth players in Australia, which may be used to inform benchmarks for coaches of similar athletes.

To ensure training environments are producing the desired behavioural outcomes, coaches may use similar quantification methods as used throughout this thesis. By using IMUs to quantify visual exploratory actions during training, they will be able to gain accurate and time-efficient measures of visual exploration at a relatively small financial cost. The short time-period required between data collection and reporting allows coaches to adjust training environments on a session-to-session basis, resulting in a practical method to inform training design for optimal player development.

ii. Player monitoring and return to play

Long-term player monitoring is commonly used to quantify workload and fatigue, with the aim of maximising performance and minimising injury risk (Gabbett, 2016; Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017; Halson, 2014; Kelly & Coutts, 2007; Thornton, Delaney, Duthie, & Dascombe, 2019; Thorpe, Atkinson, Drust, & Gregson, 2017). These measures, however, can also be used to inform return to play protocols for injured athletes. This is done by comparing measures of an injured player's strength or speed, for example, with their normative individual values collected when healthy. With continued use of IMUs to quantify exploratory action in training, practitioners are also able to obtain normative exploratory data over extended training periods, which could be used to inform return to play protocols. While further research is needed to evidence this application, it is very likely that, due to differing action capabilities when injured (Mark et al., 1990), a player's visual exploratory actions would be different when they are injured compared to when they are healthy. Therefore, a measure of visual exploratory action could potentially be used to indicate a player's readiness to return to play.

8.3 Research strengths

Primarily, the strength of this thesis can be summarised as an advancement of the current understanding of visual exploratory head movement in a representative football environment. In doing so, this program of research extended previous research in several ways.

i. The program of research was developed from a sound theoretical background of how humans actively visually perceive their surrounding environment. This Ecological approach to visual perception considers the unique characteristics of both the individual and environment, and therefore the study designs which stem from this approach aim to sample information that is representative of the natural performance environment. As a result, the findings from these study designs can be generalised to the natural performance environment with confidence.

ii. The thesis addresses a real-world problem in applied settings. The visual exploratory actions of football players is considered an important skill in applied settings (Hughes et al., 2012), however the delivery of training situations specifically aimed at developing visual exploration is rare, particularly among less qualified coaches (Pulling et al., 2018). The findings from this research can directly inform practical applications and provide a basis for future studies into optimal training methods to develop visual exploratory actions.

iii. Inertial measurement units were used to quantify the exploratory head movements of players across Chapters 5, 6 and 7. The use of these devices enabled 1) highly accurate data collection compared to previous methods, 2) highly efficient data collection and analysis compared to previous methods, and 3) the ability to quantify novel aspects of exploratory head movements (such as the excursion of movements).

iv. Chapters 5, 6 and 7 utilised a validated algorithm (Chalkley et al., 2018) to analyse head movement data obtained from the inertial measurement units, resulting in objective and reproducible data analysis. The outcomes derived from this algorithm are therefore free from any subjective bias, are not influenced by viewing angle or interference (as may happen with notational methods), and they can be easily compared between studies using the same methods.

v. Chapter 5 utilised a lab-based setting that completely surrounded the participants with action relevant information. In doing so, the participants' visual exploratory head movements became the focus of the experimental design, and they could be investigated in a controlled environment for the first time. Further, this study attempted to maintain natural perception-action couplings as much as possible, by requiring a passing response from the participants.

vi. Chapters 6 and 7 investigated the visual exploratory head movements of players in their natural performance environment, 11v11 football match-play. This adds substantial strength to the research findings, as the observed outcomes are a direct reflection of the natural behaviours used by the football players included in the study, and therefore they can directly inform applied practice.

8.4 Research limitations

This thesis presents novel research with substantial theoretical, methodological and practical contributions, however, there are some limitations to the study methodology and design which should be considered when evaluating the findings. Many of these limitations are a product of such a novel research area. The limitations of this thesis, as outlined below, should be addressed with further development in this research area to provide an even stronger evidence base.

i. Due to the specificity of the research question, only research using technology to investigate the eye, head or body visual exploratory movements of football players were included in the systematic review of literature (Chapter 2). Therefore, research investigating these factors using notational or observational methods were excluded from the review, as were investigations which investigated these actions in other sport settings. To account for this and to give a full description of the behaviour, Chapter 1 discussed known research which investigated the head movements of football players without the use of technology.
ii. The experimental design used in Chapter 5 may not have provided the appropriate environmental information to participants that is required to maintain representative perception-action couplings found in live match-play. In particular, the constraints of the study did not require participants to control a real ball when completing the task. This is an important component of action in a live football situation, and the participants may have exhibited different exploratory head movements if they were also required to control a ball before making a passing action. However, given the findings supported the theoretical underpinnings of the study, and the novelty of the experimental task, Chapter 5 still provides a significant contribution to this area of research.
iii. The dataset used in the studies comprised of participants from a limited number of clubs from one geographical region of Australia. As a result, the findings are representative of the participants involved in the studies at the time of data collection. While the findings supported the theoretical underpinnings of the studies, it is possible that findings may differ in samples with different individual and team characteristics, such as training background, playing philosophies and strategies, or socio-cultural histories.

iv. Due to restrictions imposed by FIFA on the use of technology during competitive match-play, the use of head-mounted IMUs was not allowed during official matches. As a result, data were collected during intra-club practice matches. While it is possible that official matches would result in different player actions, the matches used for data collection were considered sufficiently competitive for these investigations.

v. Data for each study were collected at different times of the competitive season. Data for Chapter 6 were collected during preseason, while data for Chapter 7 were collected at the end of a season. It is possible that players would display different actions between these two times of the season.

vi. Consistent across Chapters 5, 6 and 7 is that participants were required to wear an IMU housed in a headband while participating in the data collection tasks. While participants were not explicitly told what the IMU was collecting, it is likely that participants had some understanding of the purpose of the device. Therefore, it is possible that their exploratory actions may have changed in response to the experimental nature of the data collection.

vii. Exploratory head movement is only one component of the visual exploratory chain. As a result, the current thesis is unable to provide evidence about the relative contribution of eye, body and/or locomotor movement on visual exploration and how this relates to visual perception in a football context. Despite this, the thesis makes a substantial contribution to the extant literature, which was dominated by eye- movement research in non-representative contexts, by providing an understanding of the exploratory actions which allow perception of an environment in 360-degrees.

8.5 Future research

This thesis has greatly developed research investigating visual exploratory action in football, however, visual exploration research in sport settings is still a developing area. In particular, research investigating visual exploratory action in representative environments is scarce. To further increase the practical applications of this research, and to extend this research to other areas, it is recommended that future research aims to build upon the work completed in this thesis in several ways. The following list is not exhaustive, but the ideas discussed are likely to result in substantial practical benefits in a range of settings.

8.5.1 Future football research

Given that coaches have differing perceptions of the optimal introduction and delivery of visual exploration training for players (Pulling et al., 2018), there is a need to provide an evidence-base for future player development. In doing so, an investigation of the influence of various training designs on visual exploratory action is needed. It is recommended that this investigation considers 1) the influence of the training design on visual exploratory outcomes such as head turn frequency and excursion, 2) the transfer of these actions to match-play, 3) any subsequent performance improvements resulting from changes in visual exploratory action, and 4) how visual exploratory action changes as players develop over time.

Chapter 7 introduced an analysis of visual exploration when the opposition team had ball possession, however, a deeper understanding of defensive visual exploration is needed (Nyland, 2010). Similar to the on-ball performance benefits seen as a result of extensive visual exploration (as shown in Chapters 5 and 6), it is likely that defensive actions would benefit from extensive exploratory action. Interceptive actions, defensive positioning, defensive pressure and team defensive structure are all likely to improve with a greater awareness of environmental information gained from extensive exploratory action.

Given the active nature of visual exploration, it is likely to be impacted by states of fatigue. Various performance decrements occur during periods of fatigue (Harper, West, Stevenson, & Russell, 2014; Rampinini et al., 2009), and it is likely that visual exploration would also be influenced by fatigued states. If reductions in visual exploration do occur during fatigued states, it may be that visual exploratory action acts as a moderator to associated performance decrements during fatigued states, as a reduction in visual exploration would result in players acting according to a limited range of afforded actions.

It is likely that psychological states will be closely related to the visual exploratory actions used by players. Anxiety states have been related to perception of action capabilities (Bootsma et al., 1992; Pijpers et al., 2006), which could influence performance due to limited affordance perception. Understanding the relationship between anxiety, action capabilities and exploration in a football context could have important outcomes for applied settings. Positive psychological states may be directly related to the visual exploratory actions used by football players. The broaden and build theory of positive emotions (Fredrickson, 2001, 2004, 2013) posits that positive emotional states (such as joy, interest, love etc.) broaden one's thought-action repertoires. One outcome of these states is widened visual attention (Wadlinger & Isaacowitz, 2006), which has clear parallels to extensive visual exploratory actions. A proposed future research endeavour is to investigate the influence of positive affective states on the visual exploratory actions of football players. If the broaden-and-build theory holds true, this work could have a beneficial practical application to pre-performance routines and performance interventions.

The current thesis has focussed on the visual exploratory actions of individual players within a football team, however, an important aspect of football performance lies in individual actions within the team coordination context (Araújo et al., 2006; Silva et al., 2013; Vilar et al., 2012). In order to coordinate interpersonal movement (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007b), players perceive shared affordances *of* others and shared affordances *for* others (Silva et al., 2013). This perception of other's action opportunities, and action opportunities for others, allows dynamic movement and synergy between players, which have been shown in studies of interpersonal movement in football (Folgado et al., 2014; Frencken, Poel, Visscher, & Lemmink, 2012). The success of these interpersonal movements is therefore reliant on the perception of these shared affordances through visual exploratory actions, however, these relationships are currently unknown. Future research should investigate the relations between visual exploratory actions and the perception of shared affordances.

8.5.2 Other sport environments

Many invasion team sports, such as field hockey, Australian rules football, rugby, netball, basketball American football, ice hockey and handball, involve situations in which players are surrounded by environmental information that needs to be perceived to support optimal performance. Therefore, the visual exploratory actions used by football players will serve a similar functional role for athletes in various other sport settings. Presently, however, there is no research that has investigated the exploratory head movements of players in these sports. Recently, research has shown postural differences between playing zones and playing roles among field hockey players (Warman, Cole, Chalkley, Johnston, & Pepping, in press), which likely influences the athlete's ability to visually explore their environment. This finding indicates that future research needs to consider unique constraints of each sport when investigating the visual exploratory actions of athletes, as they may result in small but important differences in the actions used by athletes.

8.5.3 Novel immersive environments

The development of immersive environments, such as virtual reality (VR), augmented reality (AR) and 360-degree video, have gained interest for their possible application to sport performance (Bird, 2019; Correia et al., 2014; Cotterill, 2018; Craig, 2013; Düking, Holmberg, & Sperlich, 2018). VR has been applied to football settings in order to create reproducible situations (Dessing & Craig, 2010), and some early investigations have shown promise for improvements in decision-making and transfer of performance to real play in baseball (Gray, 2017) and darts (Tirp et al., 2015). With the ability to surround the user with visual information, these immersive environments offer the ability to investigate the visual exploratory head movements of users while maintaining experimental control over the information that is presented. Initially, investigations should establish the validity of immersive environments to produce similar visual exploratory actions as those used in competitive match-play (Düking et al., 2018). Once this is established, research may focus on the efficacy of using immersive environments to develop the exploratory actions of players and the transferability of these exploratory actions to open match-play.

8.5.4 Other enveloping environments

Visual exploratory action is a component of human perception, and therefore is relevant in settings other than football. Exploratory head movement is particularly important for any human interaction in environments with relevant information in 360-degrees. Some primary examples of these environments include emergency services, security and intelligence, and defence forces. For each of these, the tasks which people perform concern the safety of themselves and others, and perception of the surrounding environment is vital for successful performance. The different tasks performed for each of these examples, however, likely constrains the visual exploratory actions required to perform successfully. For example, a police officer arriving at an incident may need to quickly perceive the surrounding environment to prospectively control future actions, which may require head movements with a large excursion at a high frequency. Alternatively, a security officer surveying a large crowd may use head movements with a large excursion at a low frequency to slowly sweep the crowd without raising suspicion. The optimal exploratory strategies for each setting are currently unknown and require future investigation.

8.5.5 Development of additional visual exploratory action outcomes

This thesis and previous work (Eldridge et al., 2013; Jordet, 2005; Jordet et al., 2013) define visual exploratory actions according to head rotation about the longitudinal axis (i.e. turning the head left or right), as it is these movements that support perception of the environment in 360-degrees. In addition to these movements, there are other functional movements that support on organism's visual perception. For example, football players will look at the ball when receiving a pass and when they have the ball (Oppici et al., 2017), resulting in a change in head pitch. This change in head pitch could be used as an additional measure of visual exploration at these ball possession moments, and it is likely strongly related to a player's technical skill on the ball. That is, a more technically skilled player is likely to have the action capabilities to look at the ball less when receiving a pass and during ball possession, and this can be quantified through measurement of head pitch. The pitch variable, therefore, may be a viable measure of a player's technical ball control skill.

The measures of visual exploration used throughout this thesis (see Table 4.1, pg. 71) describe the number and size of head movements. With the use of inertial sensors to collect head movement data, the opportunity to analyse more complex aspects of head movement are possible. For example, analysis of head movements according to General Tau Theory (Lee, 1976, 2009; Lee, Lishman, & Thomson, 1982) may reveal interesting descriptive information related to the intensions of exploratory head movements.

8.6 Conclusions

This thesis, and the studies included within it, represent a substantial contribution to a field of research that is still young. While the findings contribute greatly to our understanding of visual exploratory action in a football setting, there are numerous unanswered questions that should be addressed in future investigations. The thesis has contributed greatly to the theoretical foundation of visual perception, developed and utilised technology to enhance reliability and efficiency of data collection, and uncovered interesting findings in relation to the visual exploratory actions of footballers. In particular, this thesis adds support to the theoretical proposal that active visual exploration is vital for human performance, in this case for a football setting. With more extensive visual exploratory head movement, players can perform on-ball actions more quickly and are more likely to make good use of their surrounding environment. Further, positional and phase of play constraints influence the visual exploratory actions utilised by football players. While the findings of this thesis do not provide an insight into *what* football players visually perceive, it does give an understanding of *how* football players visually perceive their environment. This is important, because how a player perceives their environment determines the *possibility* of perceiving afforded actions. These findings should be used to inform training design to attain maximal developmental value. Additionally, these findings provide an evidence base to inform future investigations of visual exploratory action in a range of enveloping environments.

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Chapter 10: Appendices

1. Statement of the Contribution of Authors

I hereby declare that my contribution to each of the published or under review manuscripts within this thesis, as outlined on the next page, to be accurate and true.

Primary Author: Thomas McGuckian

Signature: Date: 6/8/19

Co-Author: Gert-Jan Pepping

Signature: Date: 6/8/19

Co-Author: Michael Cole

Signature: Date: 6/8/19

Co-Author: Geir Jordet

Signature: Date: 6/8/19

Co-Author: Daniel Chalkley

Signature: Date: 6/8/19

The contribution of authors for each published or under review manuscript is represented as the combination of study development, data collection and analysis, and preparation and revision of the manuscript.

Study	Thomas McGuckian	Gert-Jan Pepping	Michael Cole	Geir Jordet	Daniel Chalkley	Total
Study 1. A systematic review of the technology-based assessment of visual perception and exploration behaviour in association football	75%	15%	10%	-	-	100%
Study 2. Visual exploration when surrounded by affordances: Frequency of head movements is predictive of response speed	65%	15%	9%	2%	9%	100%
Study 3. Don't turn blind! The relationship between exploration before ball possession and on-ball performance in association football	65%	15%	9%	2%	9%	100%
Study 4. Constraints on visual exploration of youth football players during 11v11 match-play: The influence of playing role, pitch position and phase of play	65%	15%	9%	2%	9%	100%

2. Evidence of Publication – Study 1

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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.

ARTICLE HISTORY
Accepted 15 June 2017

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 abil- ity to perceive their surroundings and make the most bene- ficial 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 research- ers 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 under- stand the visual perception requirements of athletes in sport- ing 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.

3. Evidence of Publication – Study 2

ECOLOGICAL PSYCHOLOGY
2019, VOL. 31, NO. 1, 30–48
https://doi.org/10.1080/10407413.2018.1495548

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REPORT

Visual Exploration When Surrounded by Affordances: Frequency of Head Movements Is Predictive of Response Speed

Thomas B. McGuckian[a], Michael H. Cole[a], Daniel Chalkley[a], Geir Jordet[b], and Gert-Jan Pepping[a]*

[a]School of Exercise Science, Australian Catholic University; [b]Department of Coaching and Psychology, Norwegian School of Sport Sciences

ABSTRACT
Little is known about the actions supporting exploration and their relation to subsequent actions in situations when participants are surrounded by opportunities for action. Here, the movements that support visual exploration were related to performance in an enveloping football (soccer) passing task. Head movements of experienced football players were quantified with inertial measurement units. In a simulated football scenario, participants completed a receiving– passing task that required them to indicate pass direction to one of four surrounding targets, as quickly as they could after they gained simulated ball possession. The frequency of head movements before and after gaining ball possession and the pass response times were recorded. We controlled exploration time—the time before gaining simulated ball possession—to be 1, 2, or 3 seconds. Exploration time significantly influenced the frequency of head movements, and a higher frequency of head turns before gaining ball possession resulted in faster pass responses. Exploratory action influenced subsequent performatory action. That is, higher frequencies of head movements resulted in faster decisions. Implications for research and practice are discussed.

In chaotic and fast-paced environments, such as in team sport, navigation, driving, or combat, the speed with which individuals are able to make decisions is vital for successful performance. Having prospective knowledge of the action-relevant information (about space, obstacles, other individuals, etc.) enables people to make appropriate decisions in a timely manner. Relations between an individual's action capabilities and the environment provide action-relevant information about opportunities for action, that is, affordances (Gibson, 1979). The ability to make decisions quickly is reliant on an individual's ability to discover the multiple affordances in the environment. Early knowledge of available affordances may allow faster responses in situations where fast responses are essential. Although laboratory studies have typically made action-relevant information easily available to participants (by means of frontal visual projection), in real-world scenarios individuals are generally completely surrounded by affordances.

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

4. Evidence of Publication – Study 3

frontiers in Psychology

ORIGINAL RESEARCH
published: 10 December 2018
doi: 10.3389/fpsyg.2018.02520

Don't Turn Blind! The Relationship Between Exploration Before Ball Possession and On-Ball Performance in Association Football

*Thomas B. McGuckian[1], Michael H. Cole[1], Geir Jordet[2], Daniel Chalkley[1] and Gert-Jan Pepping[1]**

[1] School of Behavioural and Health Sciences, Australian Catholic University, Brisbane, QLD, Australia, [2] Department of Coaching and Psychology, Norwegian School of Sport Sciences, Oslo, Norway

Visual exploratory action – scanning movements expressed through left and right rotation of the head – allows perception of a surrounding environment and supports prospective actions. In the dynamically changing football environment, the extent to which exploratory action benefits a player's subsequent performance with the ball is likely influenced by how and when the exploratory action occurs. Although few studies have examined the relationship between visual exploration and on-pitch football performance, it has been reported that a higher frequency of exploratory head movement up to 10-s before receiving the ball increases the likelihood of successful performance with the ball. This study investigated the relationship between head turn frequency and head turn excursion, and how and when exploratory head movement – within 10-s before ball possession – is related to performance with the ball in 11v11 match-play. Thirty-two semi-elite football players competed in 11v11 match-play. Head turn frequency and head turn excursion before ball possession were quantified with wearable inertial measurement units, and actions with the ball were coded via notational analysis. Odds ratio calculations were conducted to determine the associations between exploration variables and on-ball performance outcomes. A total of 783 actions with the ball were analyzed. Results revealed a strong relationship between head turn frequency and head turn excursion. Further, a higher than average head turn frequency and head turn excursion before receiving the ball resulted in a higher likelihood of turning with the ball, playing a pass in the attacking direction, and playing a pass to an area that is opposite to which it was received from. The strength of these outcomes varied for different time periods before receiving the ball. When players explored their environment with higher than average head turn frequency and excursion, they used more complex action opportunities afforded by the surrounding environment. Considerations for future research and practical implications are discussed.

Keywords: soccer, performance analysis, affordance, decision making, vision, ecological psychology, spatial awareness, scanning

OPEN ACCESS

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Universidade de Lisboa, Portugal

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Bruno Travassos,
Universidade da Beira Interior, Portugal
Ruud J. R. Den Hartigh,
University of Groningen, Netherlands

**Correspondence:*
Gert-Jan Pepping
gert-jan.pepping@acu.edu.au

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doi: 10.3389/fpsyg.2018.02520

5. Evidence of Publication – Study 4

6. Conference Acceptance – Australasian Skill Acquisition Network Conference, November 2017

16/10/2017

Dear Thomas McGuckian,

Thank you for registering to attend the Australasian Skill Acquisition Network (ASAN) conference, incorporating the Australasian Skill Acquisition Research Group (ASARG) meeting. We look forward to having you join us for this exciting conference to be held at the Brisbane campus of the Australian Catholic University.

We are also very glad to inform you that your abstract for a short presentation titled **"Individual differences in visual exploration in a lab-based football passing task"** has been accepted for presentation at the conference.

The full conference schedule is currently being finalised but we will endeavour to have a full program to you this week. In the meantime, if you have any questions regarding the conference or would like any additional information, please feel free to contact us or visit the conference website at www.asanconference.com.

Yours sincerely,
On behalf of the ASAN organising committee

Dr. Gert-Jan Pepping
Deputy Head
School of Exercise Science
Australian Catholic University

School of Exercise Science
Faculty of Health Sciences

1100 Nudgee Road
Banyo, Queensland 4014
Australia

T: +61 7 3623 7679
E: adminqld@acu.edu.au
W: acu.edu.au

7. Conference Acceptance – 12th Conference of the International Sports Engineering Association, March 2018

Thursday, December 21, 2017 at 9:22:14 AM Australian Eastern Standard Time

Subject: Your full paper has been accepted for presenta2on
Date: Thursday, 21 December 2017 at 9:20:46 am Australian Eastern Standard Time
From: ISEA 2018 Secretariat
To: Thomas McGuckian

International Sports Engineering Association Conference 2018

Dear Mr Thomas McGuckian,

On behalf of **ISEA 2018** we are pleased to confirm that your paper, as detailed below, has been accepted for presentation.

Title	Giving Inertial Sensor Data Context for Communication in Applied Settings: An Example of Visual Exploration in Football
Paper Status	Full paper accepted for oral presentation

Please note, all presenting authors must register as Full Delegates by 31 January 2018 to be included in the program. The Early Bird rate will be available for accepted authors until 1 January. Please register via the Submission Portal.

The program will be finalised in February and you will be advised of presentation details as soon as they are available.

If you have any questions, please do not hesitate to contact us.

Kind regards,

ISEA 2018 Secretariat
admin@ccm.com.au

Page 1 of 1

8. Conference Acceptance – 23rd Annual Congress of the European College of Sport Science, July 2018

23rd annual Congress of the
EUROPEAN COLLEGE OF SPORT SCIENCE
SPORT SCIENCE AT THE CUTTING EDGE
4 - 7 July 2018, Dublin - Ireland
Hosted by University College Dublin & Ulster University

ECSS DUBLIN 2018

EUROPEAN COLLEGE OF SPORT SCIENCE

Feldblumenweg 26
50858 Cologne

GERMANY

VAT-ID: DE251715668 - St.Nr.: 223/5905/0216
register of associations: VR12508

Dublin, 19.03.2018 - 23:15:22

Letter of Acceptance

This is to certify that the following title has been accepted at the 23rd Annual Congress of the European College of Sport Science between 4 - 7 July 2018 in Dublin - Ireland:

Thomas McGuckian

Australian Catholic University
1100 Nudgee Road
4014 Banyo, Australia

Abstr.-ID: 1006
Title: How is scanning before ball possession related to performance with the ball? An investigation of football players' exploratory action
Authors: McGuckian, T.1, Cole, M.1, Chalkley, D.1, Shepherd, J.2, Jordet, G.3, Pepping, G.J.1
Institution: 1. Australian Catholic University, 2. Gri ! th University, 3. Norwegian School of Sport Sciences

University College Dublin & Ulster University

This document has been created digitally and is valid without a signature

9. Conference Acceptance – Australasian Skill Acquisition Network Conference, November 2018

UTS
UNIVERSITY OF TECHNOLOGY SYDNEY

15/10/2018

Dear Thomas McGuckian,

Thank you for registering to attend the Australasian Skill Acquisition Network (ASAN) conference at the University of Technology Sydney. We look forward to your presentation in Sydney on the 16th of November 2018.

The full conference schedule is available on https://www.uts.edu.au/research-and-teaching/our-research/human-performance-research-centre/events/australasian-skill

Yours sincerely,
On behalf of the ASAN organising committee

Dr Job Fransen
Human Performance Research Centre
Faculty of Health
University of Technology Sydney

Human Performance Research Centre
Faculty of Health, UTS

Cnr of Moore Park Rd and Driver Ave
Moore Park 2021, NSW

T: +61 2 9514 5203
E: hprc@uts.edu.au
W: https://www.uts.edu.au/research-and-teaching/our-research/human-performance-research-centre

10. Ethics Approval – Study 2

Tuesday, November 7, 2017 at 11:50:27 AM Australian Eastern Standard Time

Subject: 2016-230E Ethics applica1on approved!
Date: Tuesday, 8 November 2016 at 10:32:41 am Australian Eastern Standard Time
From: Res Ethics (sent by Pra1gya Pozniak <pra1gya.pozniak@acu.edu.au>)
To: Gert-Jan Pepping, Michael Cole
CC: Res Ethics, Thomas McGuckian

Dear Applicant,

Principal Inves1gator: Dr Gert-jan Pepping
Co-Inves1gator: Dr Michael Cole
Student Researcher: Thomas McGuckian (HDR Student)
Ethics Register Number: 2016-230E Project Title: Valida1on of Iner1al Sensors for Measurement of Explora1on Behaviour in Sport.
Risk Level: Low Risk
Date Approved: 08/11/2016
Ethics Clearance End Date: 31/12/2017

This email is to advise that your applica1on has been reviewed by the Australian Catholic University's Human Research Ethics Commibee and confirmed as mee1ng the requirements of the Na1onal Statement on Ethical Conduct in Human Research.

The data collec1on of your project has received ethical clearance but the decision and authority to commence may be dependent on factors beyond the remit of the ethics review process and approval is subject to ra1fica1on at the next available Commibee mee1ng. The Chief Inves1gator is responsible for ensuring that outstanding permission lebers are obtained, interview/survey ques1ons, if relevant, and a copy forwarded to ACU HREC before any data collec1on can occur. Failure to provide outstanding documents to the ACU HREC before data collec1on commences is in breach of the Na1onal Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research. Further, this approval is only valid as long as approved procedures are followed.

If your project is a Clinical Trial, you are required to register it in a publicly accessible trials registry prior to enrolment of the first par1cipant (e.g. Australian New Zealand Clinical Trials Registry hbp://www.anzctr.org.au/) as a condi1on of ethics approval.

If you require a formal approval cer1ficate, please respond via reply email and one will be issued.

Researchers who fail to submit a progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed a progress/final report form must be submibed. The informa1on researchers provide on the security of records, compliance with approval consent procedures and documenta1on and responses to special condi1ons is reported to the NHMRC on an annual basis. In accordance with NHMRC the ACU HREC may undertake annual audits of any projects considered to be of more than low risk.

It is the Principal Inves1gators / Supervisors responsibility to ensure that:
1. All serious and unexpected adverse events should be reported to the HREC with 72 hours.
2. Any changes to the protocol must be reviewed by the HREC by submihng a Modifica1on/Change to Protocol Form prior to the research commencing or con1nuing. hbp://research.acu.edu.au/researcher-support/integrity-and-ethics/
3. Progress reports are to be submibed on an annual basis. hbp://research.acu.edu.au/researcher-support/integrity-and-ethics/
4. All research par1cipants are to be provided with a Par1cipant Informa1on Leber and consent form, unless otherwise agreed by the Commibee.
5. Protocols can be extended for a maximum of five (5) years ajer which a new applica1on must be submibed. (The five year limit on renewal of approvals allows the Commibee to fully re-review research in an environment where legisla1on, guidelines and requirements are con1nually changing, for example, new child protec1on and privacy laws).

Page 1 of 2

Researchers must immediately report to HREC any maber that might affect the ethical acceptability of the protocol eg: changes to protocols or unforeseen circumstances or adverse effects on par1cipants.

Please do not hesitate to contact the office if you have any queries.

Kind regards,

Kylie Pashley
on behalf of ACU HREC Chair, Dr Nadia Cribenden

Ethics Officer | Research Services
Office of the Deputy Vice Chancellor (Research) Australian Catholic University

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Page 2 of 2

11. Ethics Approval – Study 3 & 4

Tuesday, November 7, 2017 at 11:48:39 AM Australian Eastern Standard Time

Subject: 2017-154H Ethics applica3on approved!
Date: Wednesday, 30 August 2017 at 4:27:50 pm Australian Eastern Standard Time
From: Res Ethics (sent by Pra3gya Pozniak <pra3gya.pozniak@acu.edu.au>)
To: Gert-Jan Pepping, Thomas McGuckian, Michael Cole
CC: Res Ethics

Dear Applicant,

Principal Inves3gator: Dr Gert-jan Pepping
Co-Inves3gator: Dr Michael Cole, Prof Geir Jordet
Student Researcher: Thomas McGuckian (HDR Student)
Ethics Register Number: 2017-154H
Project Title: Visual Exploratory Behaviour in Representa3ve Team Sport Games
Date Approved: 30/08/2017
Ethics Clearance End Date: 30/06/2019

This is to cer3fy that the above applica3on has been reviewed by the Australian Catholic University Human Research Ethics Commicee (ACU HREC). The applica3on has been approved for the period given above.

Researchers are responsible for ensuring that all condi3ons of approval are adhered to, that they seek prior approval for any modifica3ons and that they no3fy the HREC of any incidents or unexpected issues impac3ng on par3cipants that arise in the course of their research. Researchers are also responsible for ensuring that they adhere to the requirements of the Na3onal Statement on Ethical Conduct in Human Research, the Australian Code for the Responsible Conduct of Research and the University¿s Code of Conduct.

Any queries rela3ng to this applica3on should be directed to the Ethics Secretariat (res.ethics@acu.edu.au). It is helpful if quote your ethics approval number in all communica3ons with us.

If you require a formal approval cer3ficate in addi3on to this email, please respond via reply email and one will be issued.

We wish you every success with your research.

Kind regards,

Kylie Pashley
on behalf of ACU HREC Chair, Dr Nadia Cricenden

Senior Research Ethics Officer | Research Services Office of the Deputy Vice Chancellor (Research) Australian Catholic University

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Page 1 of 1

12. Ethics Approval – Study 2 Amendment

Tuesday, November 7, 2017 at 11:50:04 AM Australian Eastern Standard Time

Subject: 2016-230E Modifica0on approved
Date: Friday, 2 June 2017 at 9:39:58 am Australian Eastern Standard Time
From: Ms Pra0gya Pozniak
To: Dr Gert Jan Pepping, Thomas McGuckian
CC: Ms Pra0gya Pozniak

Dear Gert-jan,

Ethics Register Number : 2016-230E
Project Title : Valida0on of Iner0al Sensors for Measurement of Explora0on Behaviour in Sport.
End Date : 31/12/2017

Thank you for submiYng the request to modify form for the above project.

The Chair of the Human Research Ethics Commi]ee has approved the following modifica0on(s):

- Additon of personnel: Prof Geir Jordet
- Expand the age range of par0cipants to include male football players aged 12 to 35 years.
- Carry-out proposed tes0ng procedures on an outdoor football pitch.

We wish you well in this ongoing research project.

Kind regards,
Ms Pra0gya Pozniak

Research Ethics Officer | Office of the Deputy Vice-Chancellor (Research)
Australian Catholic University
T: 02 9739 2646 E: res.ethics@acu.edu.au

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Page 1 of 1

13. Participant Information Letter – Study 2

AUSTRALIAN CATHOLIC UNIVERSITY

PARTICIPANT INFORMATION LETTER

PROJECT TITLE: Measurement of exploration behaviour in sport
PRINCIPAL INVESTIGATOR: Dr Gert-Jan Pepping
CO-INVESTIGATORS: Dr Michael Cole, Professor Geir Jordet
STUDENT RESEARCHER: Thomas McGuckian
STUDENT'S DEGREE: Doctor of Philosophy

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?
The research project investigates exploration behaviour used by athletes while playing team sport. Exploration is a term used to explain the way in which people visually look around their surroundings, and may include the movement of the eyes, head and/or body. Exploration is important for sport performance, as it enables athletes to perceive their surroundings, which helps inform future decisions. This research project aims to validate wearable technology to measure exploration behaviour used by athletes. Once this is achieved, researchers will be able to study exploration behaviour in more depth, and applied sports scientists may be able to use the technology to more easily record this behaviour to help monitor and develop their athletes.

Who is undertaking the project?
This project is being conducted by Thomas McGuckian and will form the basis for the degree of Doctor of Philosophy at Australian Catholic University under the supervision of Dr Gert-Jan Pepping, Dr Michael Cole and Professor Geir Jordet. Mr McGuckian has previously completed research in the sport science field, and has experience teaching at the tertiary level in areas relevant to this research project. Dr Pepping, Dr Cole and Professor Jordet have extensive research experience in exercise science and are overseeing the conduct of this research project.

Are there any risks associated with participating in this project?
The risks of participating in this project are very small. You will be asked to identify objects that surround you, so the only foreseeable risk comes from turning your head, neck and/or trunk quickly. If you have had any significant spine, head, neck or trunk injuries in the past, you should not participate in this project.

What will I be asked to do?
The project will be completed at Australian Catholic University, Banyo, Brisbane, at a mutually convenient time. You will be asked to complete two sets of trials, which will take approximately 45 minutes. Once all trials are finished, you will not be required for any follow up. Upon arriving to participate, you will have inertial sensors attached to the back of your head and on your back with elastic straps. Each trial will be recorded with a video camera and microphone. For the first set of trials, you will be asked to face the video camera and listen for two separate 'beeps'. The first 'beep' will signal

you to get ready. The second 'beep' will be your signal to start the trial. For each trial, you are required to look around the room and verbally identify, as quickly as possible, what is presented on four separate computer displays positioned behind you. You will be told how to identify each picture before the trial begins. After identifying what is on each of the displays, you will need to return your gaze back to the video camera. For the second set of trials, you will complete a similar task, however you will complete the task outside. Additionally, the computer screens will be replaced by real people, and you will be asked to receive a pass, control the ball, and then pass the ball to the appropriate person instead of verbally identifying anything.

What are the benefits of the research project?
Although there are no direct benefits to you by participating in this project, by participating in this project you will be contributing to a long term research project in an area that has not previously been investigated. It is anticipated that the findings from this research will be beneficial for sport development and performance, and will enable a rapid increase in research investigating exploration behaviour in sport. Additionally, the project may have applications in social psychology, rehabilitation and outdoor recreation.

Can I withdraw from the study?
Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences. If you are a student, withdrawing from the research will not adversely affect you, your results, or your relationship with staff members in any way. If you decide to withdraw at any point, any data that has already been collected will be excluded from the study. However, if the results have already been published, withdrawal of data will not be possible.

Will anyone else know the results of the project?
The results from this study will likely be published in a scientific journal in the broad areas of sport and exercise science. Only aggregated results will be published, so you will not be identifiable in any way. Data will be stored on a password protected computer, and your data will be de-identified with an ID number. Only the researchers will have access to the computer and data files.

Will I be able to find out the results of the project?
A summary of the results will be made available to you upon request. As the results will be aggregated, your individual data will not be available.

Who do I contact if I have questions about the project?
Do not hesitate to contact one of the researchers involved in this study with questions about the project. Questions in person are welcomed, otherwise use the contact details below.

Name: Thomas McGuckian
Email: thomas.mcguckian@acu.edu.au
Phone: 07 3623 7679

What if I have a complaint or any concerns?
The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (review number 2016-230E). If you have any complaints or concerns about the conduct of the project, you may write to the Manager of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph.: 02 9739 2519
Fax: 02 9739 2870
Email: resethics.manager@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?
After reading this information letter you can sign the attached consent form and return it to the researcher. The student researcher will subsequently contact you at a mutually convenient time to discuss your eligibility, answer any questions and/or schedule a suitable time for data collection. As stated previously, signing the included consent form indicates to the research team that you are willing to participate in this study, but this consent can be withdrawn at any time without adverse consequences. Thank you for taking the time to consider this project.

Yours sincerely,

Gert-Jan Pepping

Michael Cole

Geir Jordet

Thomas McGuckian

V.20140203 3

14. Participant Information Letter – Study 3 & 4

PARTICIPANT INFORMATION LETTER

PROJECT TITLE: Visual Exploratory Behaviour in Team Sport
PRINCIPAL INVESTIGATOR: Dr Gert-Jan Pepping
CO-INVESTIGATORS: Dr Michael Cole, Professor Geir Jordet
STUDENT RESEARCHER: Thomas McGuckian
STUDENT'S DEGREE: Doctor of Philosophy

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The research project investigates visual exploration behaviour used by athletes while playing team sport. Exploration is a term used to explain the way in which people visually look around their surroundings, and may include movement of the eyes, head and/or body. Exploration is important for sport performance, as it enables athletes to perceive their surroundings, which helps inform future decisions. This project aims to investigate the visual exploration behaviour of athletes using wearable technology while they play in real games. Once this is achieved, researchers will be able to understand visual exploration behaviour in more depth, allowing a greater understanding of how visual exploration behaviour influences decision making and performance in sport.

Who is undertaking the project?

This project is being conducted by Thomas McGuckian and will form the basis for the degree of Doctor of Philosophy at Australian Catholic University under the supervision of Dr Gert-Jan Pepping, Dr Michael Cole and Professor Geir Jordet. Mr McGuckian has previously completed research in the sport science field, and has experience teaching at the tertiary level in areas relevant to this research project. Dr Pepping, Dr Cole and Professor Jordet have extensive research experience in exercise science and are overseeing the conduct of this research project.

Are there any risks associated with participating in this project?

For the purposes of this study, you will be asked to play in games as you normally would. As such, the risks associated with participating in this project are no greater than those that you might face during a typical training session or while playing in a game. You will be asked to wear a small device on the back of your head and trunk, however the risk of injury as a result of this is considered to be minimal. If you have had any significant injuries in the past, you should talk to the investigators before participating in this project.

What will I be asked to do?

You will be asked to play in full-size and small-sided games while wearing small devices on the back of your head and trunk. One device will be attached to the back of an elastic headband, which you will be asked to wear on your head while playing. The second device will be housed in a pouch at the back of an elastic bib, which will be worn under your playing shirt, so that the device sits between your shoulder blades. These devices are used to monitor the movements of your head and body. The devices are small (55mm x 30mm x 13mm) and very lightweight (23grams), so they will not interfere with the way you play. The full-size games will be a full-length match, consisting of two halves that are separated by a 15 minute break. The small-sided games will consist of two shortened halves that are separated by a 10 minute rest period. You will be asked to play the same way you would play in a competitive match. As well as wearing the small devices, the games will be video recorded to allow analysis of match play.

What are the benefits of the research project?

Although participation is unlikely to directly benefit individuals immediately, participants in this project will be contributing to a long term research project in an area that has not previously been investigated. It is anticipated that the findings from this research will be beneficial for sport development, sport performance and injury management, and will enable a rapid increase in research investigating exploration behaviour in sport. Additionally, the project may have applications in social psychology, rehabilitation and outdoor recreation.

Can I withdraw from the study?

Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences. If you decide to withdraw at any point, any data that has already been collected will be excluded from the study. However, if the results have already been published, withdrawal of data will not be possible.

Will anyone else know the results of the project?

The results from this study will likely be published in a scientific journal in the broad areas of sport and exercise science. Only aggregated results will be published, so you will not be identifiable in any way. Data will be stored on a password protected computer, and your data will be de-identified with an ID number. Only the researchers will have access to the computer and data files.

Will I be able to find out the results of the project?

A summary of the results will be made available to you upon request. Additionally, your individual results will be provided upon request.

Who do I contact if I have questions about the project?

Do not hesitate to contact one of the researchers involved in this study with questions about the project. Questions in person are welcomed, otherwise use the contact details below.

Name: Thomas McGuckian
Email: thomas.mcguckian@acu.edu.au
Phone: 07 3623 7679

What if I have a complaint or any concerns?

The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (review number 2017-154H). If you have any complaints or concerns about the conduct of the project, you may write to the Manager of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph.: 02 9739 2519
Fax: 02 9739 2870
Email: resethics.manager@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

After reading this information letter you can sign the attached consent form and return it to the researcher. If you are under 18 years of age, your parent/guardian will need to sign the consent form, and you will need to sign the assent form. The student researcher will subsequently contact you at a mutually convenient time to discuss your eligibility, answer any questions and/or schedule a suitable time for data collection. As stated previously, signing the included consent form indicates to the research team that you are willing to participate in this study, but this consent can be withdrawn at any time without adverse consequences. Thank you for taking the time to consider this project.

Yours sincerely,

Gert-Jan Pepping

Michael Cole

Geir Jordet

Thomas McGuckian

V.20140203 3

15. Minor Participant Information Letter – Study 3 & 4

PARTICIPANT INFORMATION LETTER

PROJECT TITLE: Visual Exploratory Behaviour in Team Sport
PRINCIPAL INVESTIGATOR: Dr Gert-Jan Pepping
CO-INVESTIGATORS: Dr Michael Cole, Professor Geir Jordet
STUDENT RESEARCHER: Thomas McGuckian
STUDENT'S DEGREE: Doctor of Philosophy

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?
The research project is interested in how players know what is happening around them while playing team sport. In sport, players move their eyes, head and/or body to see what is happening around them. This behaviour is important for sport performance, as it helps players make decisions. This project will help researchers understand what players do to see what is happening around them, which will help to understand decision making and performance in sport.

Who is undertaking the project?
This project is being completed by Thomas McGuckian as part of the degree of Doctor of Philosophy at Australian Catholic University under the supervision of Dr Gert-Jan Pepping, Dr Michael Cole and Professor Geir Jordet. Mr McGuckian has previously completed research in the sport science field, and has experience teaching at the tertiary level in areas relevant to this research project. Dr Pepping, Dr Cole and Professor Jordet have extensive research experience in exercise science and are overseeing the conduct of this research project.

Are there any risks associated with participating in this project?
For this study, you will be asked to play in games as you normally would. The risks associated with participating in this project are the same as those that you might face during a typical training session or while playing in a game. You will be asked to wear a small device on the back of your head and trunk, however the risk of injury as a result of this is considered to be small. If you have had any significant injuries in the past, you should talk to the coaches or researchers before participating in this project. Your coaches will be present at all times while you participate in this research.

What will I be asked to do?
You will be asked to play in full-size and small-sided games while wearing small devices on the back of your head and trunk. One device will be attached to the back of an elastic headband, which you will be asked to wear on your head while playing. The second device will be housed in a pouch at the back of an elastic bib, which will be worn under your playing shirt, so that the device sits between your shoulder blades. These devices are used to monitor the movements of your head and body. The devices are small (55mm x 30mm x 13mm) and very lightweight (23grams), so they will not interfere with the way you play. A researcher will attach the devices to the headband and bib, then give them to you to put on

yourself. The full-size games will be a full-length match, consisting of two halves that are separated by a 15 minute break. The small-sided games will consist of two shortened halves that are separated by a 10 minute rest period. You will be asked to play the same way you would play in a competitive match. As well as wearing the small devices, the games will be video recorded to allow analysis of match play.

What are the benefits of the research project?
Although participation is unlikely to directly benefit individuals immediately, participants in this project will be contributing to a long term research project in an area that has not previously been investigated. The research will be helpful for sport development, sport performance and injury management, and will enable a rapid increase in research investigating decision making in sport. Additionally, the project may have applications in social psychology, rehabilitation and outdoor recreation.

Can I withdraw from the study?
Yes. Participation in this study is completely voluntary. You do not have to participate. If you agree to participate, you can withdraw from the study at any time without any negative consequences. If you decide to withdraw at any point, any data that has already been collected will be excluded from the study. However, if the results have already been published, withdrawal of data will not be possible.

Will anyone else know the results of the project?
The results from this study will likely be published in a scientific journal in the broad areas of sport and exercise science. You will not be identifiable in any way. Data will be stored on a password protected computer, and your data will be de-identified with an ID number. Only the researchers will have access to the computer and data files.

Will I be able to find out the results of the project?
A summary of the results will be made available to you upon request. Additionally, your individual results will be provided upon request.

Who do I contact if I have questions about the project?
Do not hesitate to contact one of the researchers involved in this study with questions about the project. Questions in person are welcomed, otherwise use the contact details below.

Name: Thomas McGuckian
Email: thomas.mcguckian@acu.edu.au
Phone: 07 3623 7679

What if I have a complaint or any concerns?
The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (review number 2017-154H). If you have any complaints or concerns about the conduct of the project, you may write to the Manager of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph.: 02 9739 2519
Fax: 02 9739 2870
Email: resethics.manager@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?
After reading this information letter you can sign the attached consent form and return it to the researcher. If you are under 18 years of age, your parent/guardian will need to sign the consent form, and you will need to sign the assent form. The student researcher will subsequently contact you at a mutually convenient time to discuss your eligibility, answer any questions and/or schedule a suitable time for data collection. As stated previously, signing the included consent form indicates to the research team that you are willing to participate in this study, but this consent can be withdrawn at any time without negative consequences. Thank you for taking the time to consider this project.

Yours sincerely,

Gert-Jan Pepping

Michael Cole

Geir Jordet

Thomas McGuckian

V.20140203 3

16. Participant Consent Form – Study 2

CONSENT FORM

Copy for Researcher to Keep

TITLE OF PROJECT: Measurement of exploration behaviour in sport

PRINCIPAL INVESTIGATOR: Dr Gert-Jan Pepping

CO-INVESTIGATORS: Dr Michael Cole, Professor Geir Jordet

STUDENT RESEARCHER: Thomas McGuckian

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this project investigating the measurement of exploration behaviour, which will take approximately 45 minutes and will be digitally video recorded, realising that I can withdraw my consent at any time without any adverse consequences. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: ....

SIGNATURE: .... DATE: ....

SIGNATURE OF PRINCIPAL INVESTIGATOR: ....

DATE: ……………………………….

SIGNATURE OF STUDENT RESEARCHER: ....

DATE: ……………………………….

School of Exercise Science

Australian Catholic University
1100 Nudgee Road
Banyo, QLD 4014

T: (07) 3623 7100

Australian Catholic University Limited
ABN 15 050 192 660
CRICOS registered provider:
00004G, 00112C, 00873F, 00885B

17. Participant Consent-Assent Form – Study 2

AUSTRALIAN CATHOLIC UNIVERSITY

PAREN/GUARDIAN CONSENT FORM
Copy for Researcher to Keep

TITLE OF PROJECT: Measurement of exploration behaviour in sport

PRINCIPAL INVESTIGATOR: Dr Gert-Jan Pepping

CO-INVESTIGATORS: Dr Michael Cole, Professor Geir Jordet

STUDENT RESEARCHER: Thomas McGuckian

I .... *(the parent/guardian)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree that my child, nominated below, may participate in this project investigating the measurement of exploration behaviour, which will take approximately 45 minutes and will be digitally video recorded, realising that I can withdraw my consent at any time without any adverse consequences. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARENT/GUARDIAN: ....

SIGNATURE: ……. DATE: ....

NAMEOF CHILD: …….

SIGNATURE OF PRINCIPAL INVESTIGATOR:... DATE: ……………………………..

SIGNATURE OF STUDENT RESEARCHER: .... DATE: ....

ASSENT OF PARTICIPANTS AGED UNDER 18 YEARS

I ……………………… (*the participant aged under 18 years*) understand what this research project is designed to explore. What I will be asked to do has been explained to me. I agree to take part in this project investigating the measurement of exploration behaviour, which will take approximately 45 minutes and will be digitally video recorded, realising that I can withdraw at any time without having to give a reason for my decision.

NAME OF PARTICIPANT AGED UNDER 18: ....

SIGNATURE: ……. DATE: ....

SIGNATURE OF PRINCIPAL INVESTIGATOR:... DATE: ……………………………..

SIGNATURE OF STUDENT RESEARCHER: .... DATE: ....…….

School of Exercise Science

Australian Catholic University
1100 Nudgee Road
Banyo, QLD 4014

T: (07) 3623 7100

Australian Catholic University Limited
ABN 15 050 192 660
CRICOS registered provider:
00004G, 00112C, 00873F, 00885B

18. Participant Consent Form – Study 3 & 4

AUSTRALIAN CATHOLIC UNIVERSITY

CONSENT FORM
Copy for <u>Researcher</u> to Keep

TITLE OF PROJECT: Visual Exploratory Behaviour in Team Sport

PRINCIPAL INVESTIGATOR: Dr Gert-Jan Pepping

CO-INVESTIGATORS: Dr Michael Cole, Professor Geir Jordet

STUDENT RESEARCHER: Thomas McGuckian

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this project investigating visual exploration behaviour, which will be digitally video recorded, realising that I can withdraw my consent at any time without any adverse consequences, and that any data that has not already been published will be excluded from the study. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: ....

SIGNATURE .... DATE ....

SIGNATURE OF PRINCIPAL INVESTIGATOR:..

DATE: ………………………………….

SIGNATURE OF STUDENT RESEARCHER: ....

DATE: ……………………………….

School of Exercise Science

Australian Catholic University
1100 Nudgee Road
Banyo, QLD 4014

T: (07) 3623 7100

Australian Catholic University Limited
ABN 15 050 192 660
CRICOS registered provider:
00004G, 00112C, 00873F, 00885B

19. Participant Consent-Assent Form – Study 3 & 4

PAREN/GUARDIAN CONSENT FORM
Copy for Researcher to Keep

TITLE OF PROJECT: Visual Exploratory Behaviour in Team Sport

PRINCIPAL INVESTIGATOR: Dr Gert-Jan Pepping

CO-INVESTIGATORS: Dr Michael Cole, Professor Geir Jordet

STUDENT RESEARCHER: Thomas McGuckian

I .... *(the parent/guardian)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree that my child, nominated below, may participate in this project investigating visual exploration behaviour, which will be digitally video recorded, realising that I can withdraw my consent at any time without any adverse consequences, and that any data that has not already been published will be excluded from the study. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify my child in any way.

NAME OF PARENT/GUARDIAN: ....

SIGNATURE: ………………………………………………………………………………………………………. DATE: ....

NAMEOF CHILD: ……….

SIGNATURE OF PRINCIPAL INVESTIGATOR:... DATE: ……………………………..

SIGNATURE OF STUDENT RESEARCHER: .... DATE: ....……………….

ASSENT OF PARTICIPANTS AGED UNDER 18 YEARS

I ……………………… (*the participant aged under 18 years*) understand what this research project is designed to explore. What I will be asked to do has been explained to me. I agree to take part in this project investigating visual exploration behaviour, which will be digitally video recorded, realising that I can withdraw at any time without having to give a reason for my decision, and that any data that has not already been published will be excluded from the study.

NAME OF PARTICIPANT AGED UNDER 18: ....

SIGNATURE: ………………………………………………………………………………………………………. DATE: ....

SIGNATURE OF PRINCIPAL INVESTIGATOR:... DATE: ……………………………..

SIGNATURE OF STUDENT RESEARCHER: .... DATE: ....……………….

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Australian Catholic University
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Banyo, QLD 4014

T: (07) 3623 7100

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End of thesis.