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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 as well as 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 (mean age = 16.25 years) 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. Further, players explored most extensively when in the back third of the pitch, and least when they were in the middle third of the pitch. Playing role, pitch position and phase of play should be considered as constraints on visual exploratory actions when developing training situations aimed at improving the scanning actions of players.

Keywords: scanning; soccer; representative design; constraints; perception; situation awareness

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, Davids, Chow, Passos, &

Raab, 2009). Doing so requires that the athlete has an awareness of the particular situation, as making decisions without all relevant information results in a decision based on limited opportunities for action (i.e. 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 environmental information for decision-making have been an area of interest in the sport expertise domain for some time (Mann, Williams, Ward, & Janelle, 2007; McGuckian, Cole, & Pepping, 2018b). Visual exploratory actions, which entail eye, head and body movements, support the pick-up of visual information. In invasion sports such as football, where players are surrounded by opportunities for action, visual exploratory head movements are particularly important for players to gain information about their environment in 360-degrees (Gibson, 1979; McGuckian, Cole, Chalkley, Jordet, & Pepping, 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, Pulling, & Robins, 2013; Jordet, 2005; Jordet, Bloomfield, & Heijmerikx, 2013; McGuckian et al., 2017; Pocock, Dicks, Thelwell, Chapman, & Barker, 2019). By quantifying the frequency (Jordet et al., 2013; McGuckian et al., 2019) and excursion (McGuckian, Cole, Jordet, Chalkley, & Pepping, 2018a) 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., 2018a). 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., 2018b; van Andel, McGuckian, Chalkley, Cole, & Pepping, 2019), it is currently unclear to what extent the various constraints that surround players during their athletic behaviour influence the exploratory actions of players in an 11v11 match context. An important consideration for the development of situation awareness - defined as an adaptive, externally directed consciousness (Salmon et al., 2008; Smith & Hancock, 1995) - 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), and the location of attacking plays has been related to attacking success (Herold et al., 2019; Mara, Wheeler, & Lyons, 2012; Smith & Lyons, 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 game-relevant 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 game-relevant 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. Despite its apparent importance, the ways in which a player's on-pitch position 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, wide defenders, centre-midfielders, wide-midfielders, and strikers (Bush, Barnes, Archer, Hogg, & Bradley, 2015; Liu et al., 2016; Yi, Jia, Liu, & Ángel Gómez, 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; Dellal, Wong, Moalla, & Chamari, 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. Research by Pocock et al., (2019) provides some evidence for playing role differences in visual exploration, suggesting that centre-midfield players visually explore more frequently than wide-midfielders and strikers following a Physical, Environment, Task, Timing, Learning, Emotion and Perspective (PETTLEP) imagery intervention. Here, we aimed to investigate the visual exploratory actions of central players (i.e. central defenders, centre-midfielders and strikers) and wide players (i.e. wide defenders and wide-midfielders) (Pulling, Kearney, Eldridge, & Dicks, 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 fundamental importance to gain an understanding of a player'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). Importantly, McGuckian et al. (2018a) showed that players explore more extensively as they become closer to gaining ball possession. It is argued that the pick-up 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 investigated players' pick-up of action-relevant visual information - that is, visual information relevant to the football task - during off-ball periods, by presenting data on the exploratory actions of players across an entire game, irrespective of ball-possessions, and categorised the actions 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). For example, during a defensive phase of play, it has been shown that players position themselves in closer proximity to each other, resulting in a smaller surface area compared to when in an offensive phase of play (Clemente et al., 2013; Duarte et al., 2012). As a result, when a team is in a defensive phase of play, players are more likely to be surrounded by opposition players, which is likely to constrain their visual exploratory actions differently compared to when a team is in an offensive phase of play. Furthermore, during transition phases of play, it is unclear which team has control of the ball, and therefore the positional requirements may be unclear to players. During these uncertain transition phases, it is possible that players maintain their visual orientation towards the ball until ball possession is determined, resulting in a reduction in exploratory behaviour. Although these differing phases of play are likely to present constraints on exploratory action, how these constraints affect actual exploration 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. As players are typically surrounded by teammates and opposition players when in more central areas of the pitch, it was expected that players would display more extensive exploratory actions when they were located in these areas compared to when they were located in other areas. Similarly, as they are more likely to be surrounded by other players, it was expected that central players would display more extensive exploratory actions than wide players. Given the likely uncertainty of play, it was expected that players would explore less during transition phases than other phases.

Further, given that players explore less extensively when ball possession is temporally distant (McGuckian et al., 2018a), and when the need to find opportunities to act is paramount when in possession of the ball, it was expected that players would explore more extensively when in possession of the ball than when either their teammates or opponents had possession of the ball.

Materials and Methods

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). 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, Moran, & Piggott, 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).

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 two separate 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, Shepherd, McGuckian, & Pepping, 2018; McGuckian et al., 2019, 2018a; van Andel et al., 2019), 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, which was worn on the head such that the IMU was positioned at the back of the head, 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.).

Variables

The IMU, GPS and video data sources were synchronised (using known events in each data source) and processed in MATLAB (MathWorks, Natick, USA) to obtain variables relating to pitch position and visual exploratory head movement. Given that the three data sources were captured at differing sampling frequencies, the GPS and video sources were up-sampled to match the 250Hz sampling frequency of the IMU source. 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 for every player.

Playing role

Participants' primary playing role was manually noted in order to analyse differences in exploratory action between playing positions. Following the aims of the study, playing positions were categorised as either central or wide playing roles.

Pitch position

Based on common tactical principles and positional research in football (Brooks, Kerr, & Guttag, 2016; Coutinho et al., 2019; Horn, Williams, & Ensum, 2002; Mara et al., 2012; Smith & Lyons, 2017), the playing area was divided into three areas in both horizontal and vertical orientations (Figure 1). The horizontal zones were created by dividing the pitch along the width of the pitch, creating a back third, middle third and a front third. The vertical zones were created by dividing the pitch along the length of the pitch between the edges of the 18-yard boxes. This resulted in a left channel, middle channel and right channel. 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; Warman, Cole, Chalkley, Johnston, & Pepping, 2019). 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; Goncalves, Figueira, Macas, & Sampaio, 2014) and consequently categorised into the relevant pitch zone.

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.

Exploratory head movement

Head turn frequency (HTF; head turns per second) and head turn excursion (HTE; degrees per second) were calculated using a validated algorithm (Chalkley et al., 2018) applied in previous investigations to quantify head movements with IMUs (McGuckian et al., 2019, 2018a). The algorithm identifies a head turn when head movement about the longitudinal axis exceeds 125 deg/s. Excursion of head movements is calculated as the absolute angular distance between the beginning and end of identified head turns. 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 continuous exploration variables of HTF^{c} and HTE^{c} were calculated.

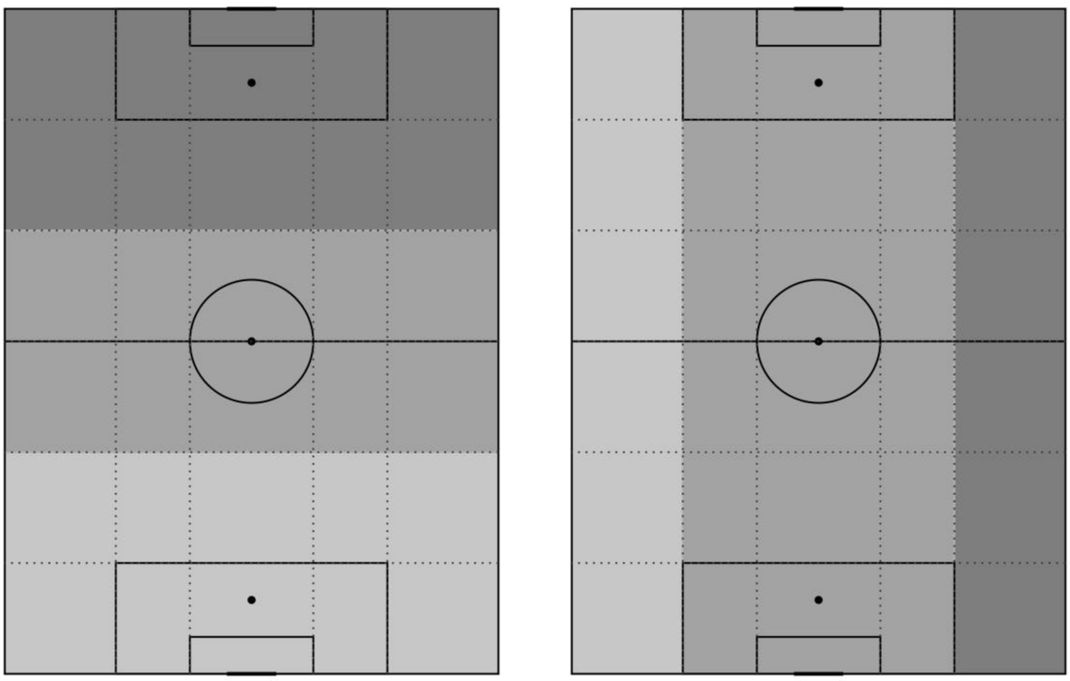

Figure 1. Defined pitch zones used for analyses. Left - horizontal pitch zones. Right - vertical pitch zones.

Statistical Analysis

Each player's average HTF^c and HTE^c were calculated for each ball-possession phase of play while they were in each of the pitch zones for both the horizontal and vertical pitch orientations. 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^c and HTE^c, separate LMM analyses with fixed factors of playing role (2 levels: central and wide), pitch position (3 levels) and ball-possession phase of play (4 levels: PBP, TBP, OBP, BT) were conducted for each exploration variable. These analyses were run separately for the horizontal and vertical pitch zone orientations. 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). 95% confidence intervals of the difference are also presented for post-hoc comparisons. Analyses were conducted using IBM SPSS version 22 (IBM Corp., Chicago, IL) with statistical significance set at $p < 0.05$.

Results

Horizontal pitch orientation - head turn frequency

The LMM analysis on HTF^c revealed significant fixed effects for pitch position ($F(2, 212.817) = 5.626$, $p = 0.004$, $\eta_p^2 = 0.050$) and ball-possession phase of play ($F(3, 211.076) = 168.116$, $p < 0.001$, $\eta_p^2 = 0.705$), but not for playing role ($F(1, 19.934) = 0.046$, $p = 0.833$, $\eta_p^2 = 0.002$). Significant interactions were not found for playing role by ball-possession phase of play (F(3, 211.049) = 1.481, p = 0.221, η_p^2 = 0.021), playing role by pitch position (F(2, 212.778) = 1.953, p = 0.144, η_p^2 = 0.018) or pitch position by ball-possession phase of play (F(6, 211.005) = 0.711, p = 0.641, η_p^2 = 0.020).

Pairwise comparisons for pitch position showed that players had a lower HTF^c when in the middle third compared to the back third (ES = 0.146, 95% CI = [-0.325, -0.024]) and front third (ES = 0.194, 95% CI = [-0.348, -0.034]). There was no significant difference in HTF^c between the front and back thirds.

Pairwise comparisons for ball-possession phase of play showed that players had a higher HTF^c during PBP than during TBP (ES = 2.170, 95% CI = [1.125, 1.527]), OBP (ES = 2.021, 95% CI = [1.050, 1.449]) and BT (ES = 2.571, 95% CI = [1.338, 1.736]) phases. Players also had a lower HTF^c during BT than both TBP (ES = 0.745, 95% CI = [-0.405, -0.017]) and OBP (ES = 0.828, 95% CI = [-0.480, -0.095]). There was no significant difference in HTF^c between TBT and OBP.

Horizontal pitch orientation - head turn excursion

The LMM analysis on HTE^c revealed significant fixed effects for pitch position (F(2, 212.362) = 3.448, p = 0.034, η_p^2 = 0.031) and ball-possession phase of play (F(3, 210.863) = 67.143, p < 0.001, η_p^2 = 0.489), but not for playing role (F(1, 19.750) = 1.779, p = 0.197, η_p^2 = 0.083). Further, significant interactions were found for playing role by ball-possession phase of play (F(3, 210.840) = 6.001, p = 0.001, η_p^2 = 0.079) and pitch position by ball-possession phase of play (F(6, 210.803) = 2.618, p = 0.018, η_p^2 = 0.069).

Pairwise comparisons for pitch position showed that players had a lower HTE^c when in the middle third compared to the back third (ES = 0.182, 95% CI = [-10.848, -0.327]), but there were no other significant differences in HTE^c between zones.

Pairwise comparisons for ball-possession phase of play showed that players had a higher HTE^c during PBP than during TBP (*ES* = 1.121, 95% CI = [16.247, 30.259]), OBP (*ES* = 1.192, 95% CI = [15.352, 29.257]) and BT (*ES* = 1.981, 95% CI = [29.801, 43.706]) phases. Players also had a lower HTE^c during BT than both TBP (*ES* = 1.117, 95% CI = [-20.276, -6.724]) and OBP (*ES* = 1.005, 95% CI = [-21.163, -7.734]). There was no significant difference in HTE^c between TBT and OBP.

Interaction effects between playing role and ball-possession phase of play are shown in Figure 2A. Interaction effects between horizontal pitch position and ball-possession phase of play are shown in Figure 2B.

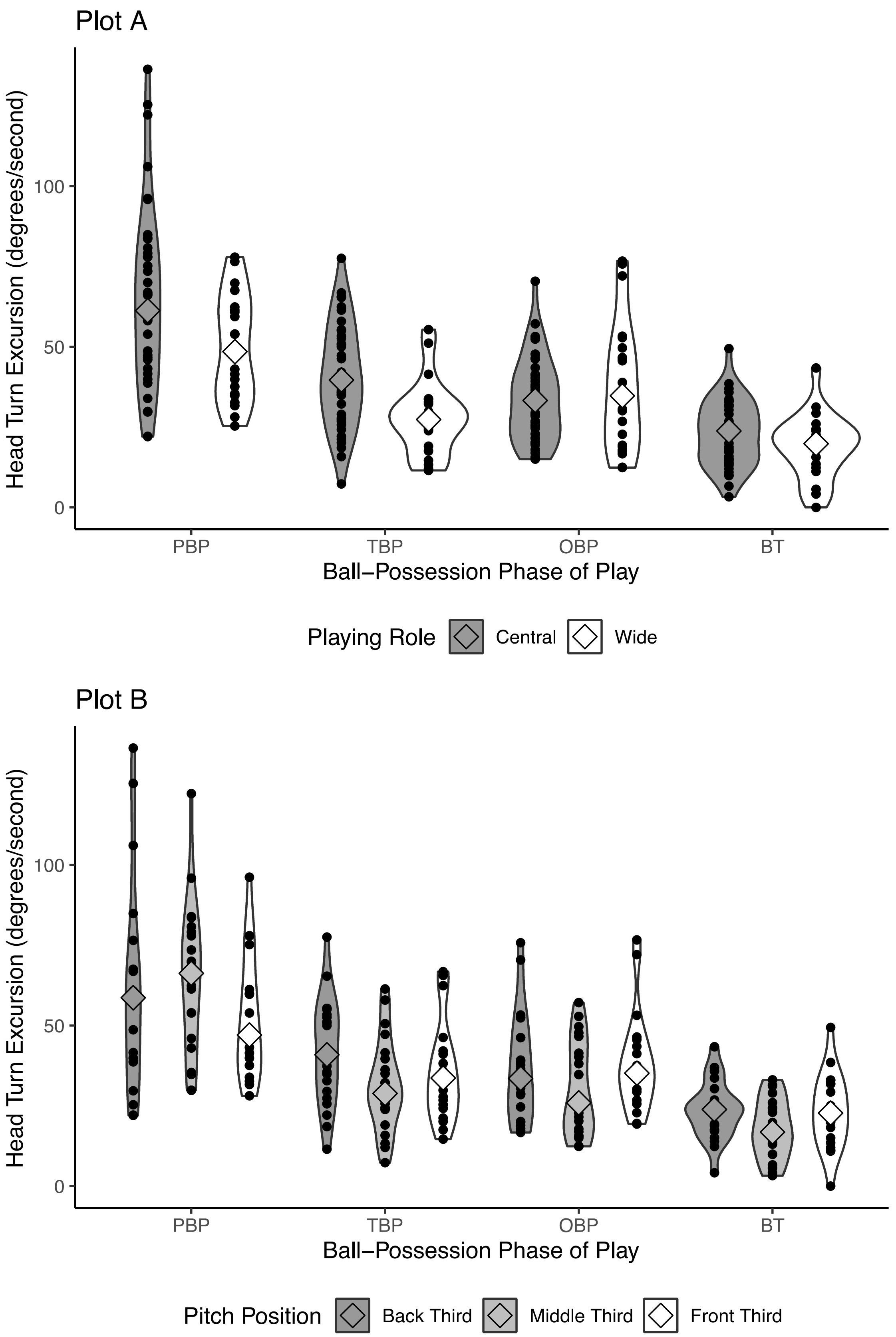
Plot A
Head Turn Excursion (degrees/second)
0
50
100
PBP
TBP
OBP
BT
Ball−Possession Phase of Play
Playing Role
Central
Wide
Plot B
Head Turn Excursion (degrees/second)
0
50
100
PBP
TBP
OBP
BT
Ball−Possession Phase of Play
Pitch Position
Back Third
Middle Third
Front Third

Figure 2. Violin plot showing head turn excursion according to ball-possession phase of play and playing role (plot A) and horizontal pitch position (plot B). Diamonds indicate mean HTE.

Vertical pitch orientation - head turn frequency

The LMM analysis on HTF^c revealed significant fixed effects for pitch position ($F(2, 210.530) = 6.937$, $p = 0.001$, $\eta_p^2 = 0.062$) and ball-possession phase of play ($F(3, 204.565) = 100.729$, $p < 0.001$, $\eta_p^2 = 0.596$), but not for playing role ($F(1, 20.477) = 3.461$, $p = 0.077$, $\eta_p^2 = 0.145$). Further, significant interactions were found for playing role by ball-possession phase of play ($F(3, 204.588) = 2.794$, $p = 0.041$, $\eta_p^2 = 0.039$) and pitch position by ball-possession phase of play ($F(6, 204.557) = 4.010$, $p = 0.001$, $\eta_p^2 = 0.105$).

Pairwise comparisons for pitch position showed that players had a higher HTF^c when in the right channel compared to the left channel (*ES* = 0.2.4, 95% CI = [0.033, 0.468]) and central channel (*ES* = 0.244, 95% CI = [0.096, 0.504]). There was no significant difference in HTF^c between the left and central channels.

Pairwise comparisons for ball-possession phase of play showed that players had a higher HTF^c during PBP than during TBP (*ES* = 1.729, 95% CI = [1.140, 1.675]), OBP (*ES* = 1.701, 95% CI = [1.066, 1.600]) and BT (*ES* = 1.932, 95% CI = [1.290, 1.824]) phases.

Interaction effects between playing role and ball-possession phase of play are shown in Figure 3A. Interaction effects between vertical pitch position and ball-possession phase of play are shown in Figure 3B.

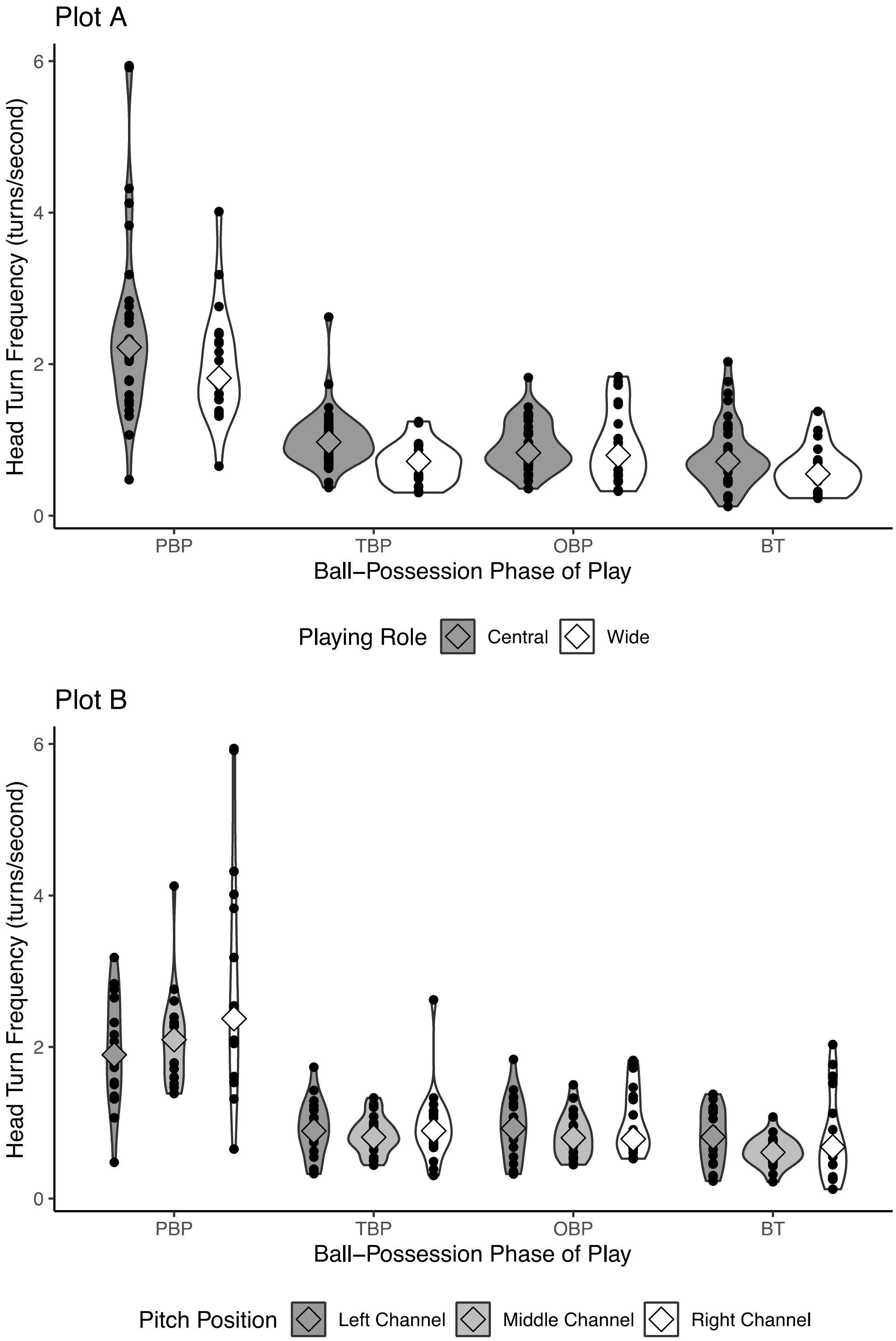
Plot A
Head Turn Frequency (turns/second)
0
2
4
6
PBP
TBP
OBP
BT
Ball–Possession Phase of Play
Playing Role
Central
Wide
Plot B
Head Turn Frequency (turns/second)
0
2
4
6
PBP
TBP
OBP
BT
Ball–Possession Phase of Play
Pitch Position
Left Channel
Middle Channel
Right Channel

Figure 3. Violin plot showing head turn frequency according to ball-possession phase of play and playing role (plot A) and vertical pitch position (plot B). Diamonds indicate mean HTF.

Vertical pitch orientation - head turn excursion

The LMM analysis on HTE^c revealed significant fixed effects for ball-possession phase of play ($F(3, 204.702) = 54.29$, $p < 0.001$, $\eta_p^2 = 0.443$), but not for pitch position ($F(2, 210.092) = 0.821$, $p = 0.441$, $\eta_p^2 = 0.008$) or playing role ($F(1, 20.654) = 3.238$, $p = 0.087$, $\eta_p^2 = 0.136$). Further, significant interactions were found for playing role by ball-possession phase of play ($F(3, 204.694) = 4.817$, $p = 0.047$, $\eta_p^2 = 0.066$) and pitch position by ball-possession phase of play ($F(6, 204.694) = 2.173$, $p = 0.003$, $\eta_p^2 = 0.060$).

Pairwise comparisons for ball-possession phase of play showed that players had a higher HTE^c during PBP than during TBP (*ES* = 1.187, 95% CI = [20.562, 37.871]), OBP (*ES* = 1.196, 95% CI = [18.534, 35.813]) and BT (*ES* = 1.744, 95% CI = [31.487, 48.766]) phases. Players also had a lower HTE^c during BT than both TBP (*ES* = 0.920, 95% CI = [-19.297, -2.523]) and OBP (*ES* = 0.848, 95% CI = [-21.322, -4.585]). There was no significant difference in HTE^c between TBT and OBP.

Interaction effects between playing role and ball-possession phase of play are shown in Figure 4A. Interaction effects between vertical pitch position and ball-possession phase of play are shown in Figure 4B.

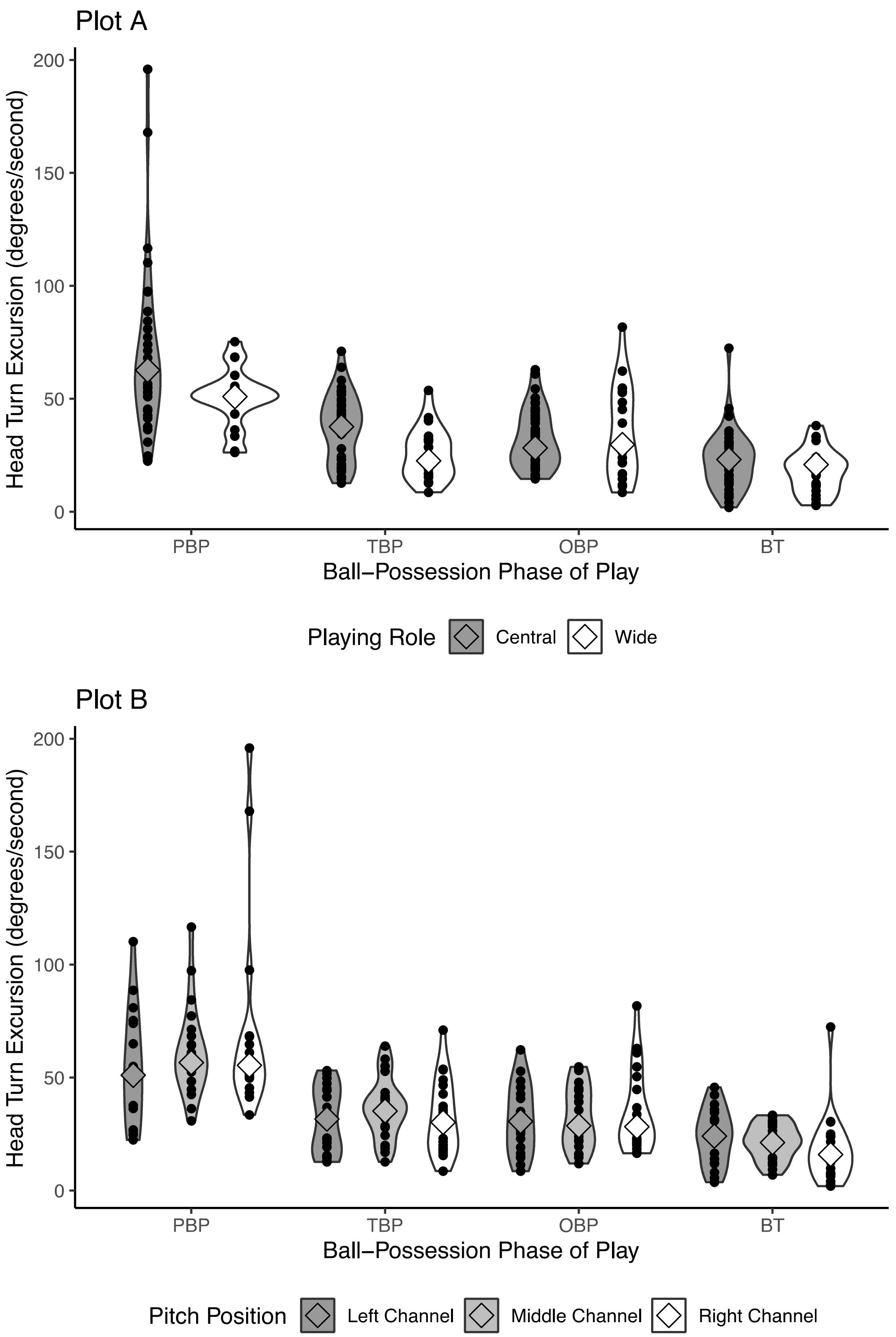
Plot A
Head Turn Excursion (degrees/second)
0
50
100
150
200
PBP
TBP
OBP
BT
Ball−Possession Phase of Play
Playing Role
Central
Wide
Plot B
Head Turn Excursion (degrees/second)
0
50
100
150
200
PBP
TBP
OBP
BT
Ball−Possession Phase of Play
Pitch Position
Left Channel
Middle Channel
Right Channel

Figure 4. Violin plot showing head turn excursion according to ball-possession phase of play and playing role (plot A) and vertical pitch position (plot B). Diamonds indicate mean HTE.

Discussion

With the aim of understanding how pitch position, playing role 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 role 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 defensive or attacking areas of the pitch compared to central areas of the pitch.

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 the players in the current sample may not be exploring adequately before they gain possession of the ball, and therefore required high amounts of visual exploration when in possession in order to discover opportunities for future action. A possible explanation for this may come from the playing level of the participants within this study, who represented a lower level compared to previous investigations of visual exploratory action in professional/elite academy football (Jordet et al., 2013; Pocock et al., 2019). If this was 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., 2018a). Further, given that players were only in possession of the ball for a very small percentage of playing time (~2%), development of exploratory actions off the ball should be prioritised, as they constitute a vast majority of playing time.

Compared to transition phases of play, the athletes explored more extensively when either team had 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 ball-possession or when defending against opposition possession, players have clear intentions as governed by the team's style of play (Hewitt, Greenham, & Norton, 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). 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, when ball possession is in contention, players are unsure if they should attack or defend, and therefore may watch the ball (likely resulting in less exploratory actions) until a team gains possession and the task constraints become clear. Furthermore, the times when task constraints and ball movement are likely most certain (i.e. during PBP) is when visual exploratory actions were highest, further supporting the hypothesis that task certainty may be related to visual exploratory actions. While we cannot confirm from this study that players revert to watching the ball during transition phases, it presents as a logical hypothesis for future investigations. In particular, it is suggested that future research investigate this question in relation to skill level, as it may be that a relationship between visual exploratory actions and task certainty is mediated by skill level. That is, it may be possible that the more stable game dynamics of higher-level players assists them in their capacity to visually explore their environment.

In general, central players explored more extensively than wide players when they had possession themselves or their team had possession; however, this was not the case during opposition possession or transition phases of play. 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, wide players 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 extensively 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 players had less extensive exploration when they were in central areas of the pitch compared to other areas of the pitch. 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; Pocock et al., 2019). The findings of this analysis may indicate that a focus only on central areas of the pitch may be misinformed, as it is other areas of the pitch that players engage in more extensive exploration. Further, given that these wide areas are potentially important from a goal scoring and goal defending perspective (Gómez, Gómez-Lopez, Lago, & Sampaio, 2012), it is important that future investigations take the entire pitch into consideration when investigating visual exploration.

The above findings have important practical implications for coaches. Given that the exploratory demands are position- and possession-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, Hertwig, & Hoffrage, 2004; Dicks, Davids, & Button, 2009; Pinder, Davids, Renshaw, & Araújo, 2011) that completely surround players with functional environmental information are 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).

The differences in exploration according to ball-possession phase of play present as clear areas for potential improvement of a players' situation awareness. 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, 2018a). Further, if players can 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., 2018). 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.

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. 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. 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 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 and other players, for example, will further contribute to our understanding of the behaviour. 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. Finally, to aid interpretation of the analyses, the pitch zones created in this study were relatively large. With the accuracy of GPS data, it is possible to obtain accurate pitch location, enabling analyses according to specific areas (e.g. exact player location) or broader areas (e.g. four quarters, see Warman et al., 2019). Therefore, future analyses with larger datasets may benefit from analysing data in a more wholistic way, as this is likely to give a more detailed understanding of the complex relationships between the many constraints of football match-play.

Conclusions

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. 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.

Acknowledgements

While completing this research, TM was supported by an Australian Government Research Training Program Scholarship. The funding body had no influence in the planning, execution or decision to publish this paper. The authors thank the clubs and players for their participation in this study, and the students that assisted with data collection for this study.

Declaration of interest

The authors report no conflict of interest.

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