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REPORT

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

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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.

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That is, individuals need to discover affordances through exploratory action, in which the movements 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 that person is able to make decisions and guide his or her 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 is the focus of this article, 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 behavior in football (Jordet, Bloomfield, & Heijmerikx, 2013; McGuckian, Cole, & Pepping, 2018).

The eye movements involved with visual perception have been studied extensively in the sport expertise domain. Mann, Williams, Ward, and Janelle (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, Davids, & Button, 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., 2018), but added support to previous research suggesting that the representativeness of the experimental task influences the visual perception behaviors of footballers (Dicks et al., 2009). Importantly, McGuckian et al. (2018) found that the research utilizing 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, Riley, & Turvey, 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 that surround an individual.

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, Eppler, Marin, Weise, & Wechsler Clearfield, 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 his or her 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, and so on, 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 utilized 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.

Exploratory action in support of performatory action

With an understanding that exploratory and performatory actions occur simultaneously, we can also say that exploratory behavior 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 behaviors are important for prospective regulation and coordination (i.e., performance) in elite adult (Jordet et al., 2013) and youth (Eldridge, Pulling, & Robins, 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.

Current study

This 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 (a) the location of a teammate to pass the ball to and (b) the amount of available time before ball possession, changed the frequency of head movements and the time taken to respond. Second, 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.

Method

Participants

Participants were 12[1] male football players aged 16 to 18 years ($M = 17.25$, $SD = 0.75$) with 9–14 years of 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 semiprofessional 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).

[1]Data were 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.

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.

Experimental setup

Visual stimuli were presented via a custom-made PsychoPy (Peirce, 2007) script running on a 15-inch laptop (Apple, Inc., Cupertino, CA) connected to four 22-inch computer monitors (Dell 2209WA, Round Rock, TX) with a screen resolution of 1680×1050 pixels. The surrounding screens were set to a portrait position and placed atop 75-cm-tall tables, 3 m away from the participant, at 100 degrees and 150 degrees to the left and right of the participant's forward-facing position (see Figure 1). The participant's forward-facing position was toward the control computer (screen 0), which was positioned 1 m away on another 75-cm-tall table. Four 22-cm-tall sports cones were aligned with each surrounding screen and placed 1 m from the participant. From 3 m away, the vertical size (47 cm) of each surrounding screen equated to a visual angle of 8.96 degrees, the same visual angle produced by a 180-cm-tall player standing 11.49 m away on a football pitch.

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 250 Hz and stored locally on each IMU's memory card, and were downloaded at the end of each testing session. Each IMU was controlled remotely with a master device connected to a laptop (Dell, Round Rock, TX).

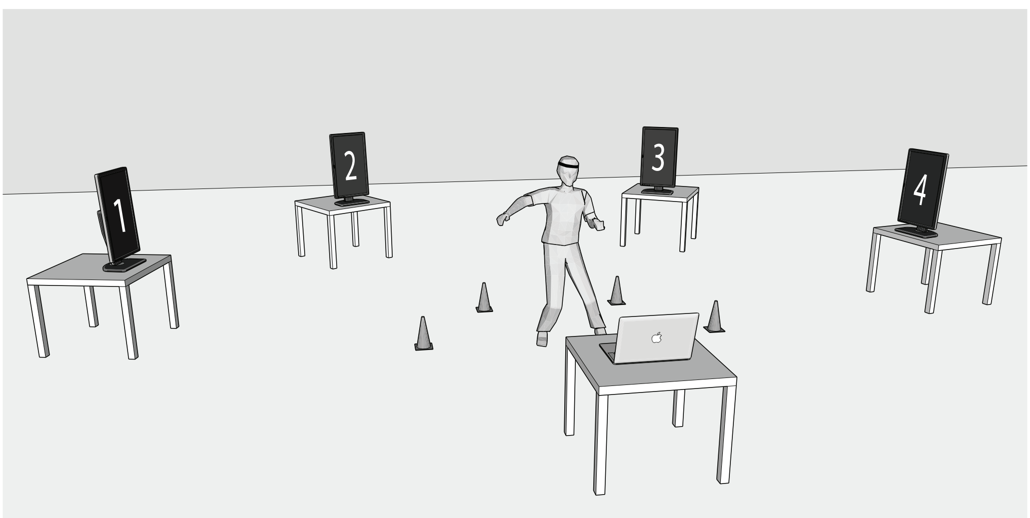

Figure 1. A schematic illustrating the experimental design used throughout data collection. Numbers indicate the screen numbers referred to in the analyses.

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 who 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, that person's task was to indicate pass direction of the ball to the free teammate as quickly as possible by kicking the corresponding cone.

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 familiarize themselves with the experimental task. Following this, participants completed the first of four testing blocks of 24 trials, with each block separated by a 5-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 space bar 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 of between 1 and 4 seconds, each of the four surrounding screens and screen 0 simultaneously began playing different videos (TS, Figure 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 1, 2, or 3 seconds). As soon as the videos began playing, the participant was allowed to begin exploring his 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 2),

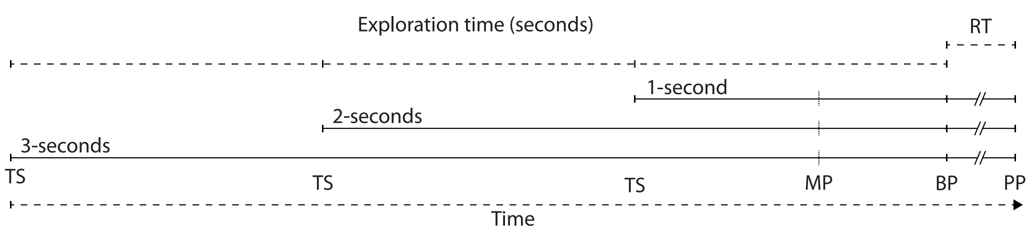

Figure 2. A schematic illustrating the timing of events in trials with 1, 2, and 3 seconds of exploration time. RT = response time, TS = trial start, MP = model pass, BP = ball possession, PP = participant pass. Time between MP and BP = 410 ms.

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 that 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 2). The response was noted and the participant was asked to press the spacebar when 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 50 Hz.

Visual information

A series of ball-passing videos was created to be presented on screen 0. These videos involved a model receiving a pass, and then passing the ball toward 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 1, 2, or 3 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 410 ms. The design of these videos enabled the participants either 1, 2, or 3 seconds to freely explore their environment before "receiving" the ball (Figure 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 2 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 1.75 m from the ground. All videos were edited to a total length of 6 seconds.

Independent (IV) and dependent (DV) variables

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

IV: Correct screen

The location of the free teammate was recorded for each trial. Screens 2 and 3 were located at 150 degrees from the participants' forward-facing position (towards screen 0), and screens 1 and 4 were located at 100 degrees from the participants' forward-facing position (Figure 1).

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 1, 2, or 3 seconds (Figure 2).

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 2).

DV: Number and frequency of head turns

A head turn[2] was defined as a distinct movement of the head about the longitudinal axis that resulted in an angular velocity that exceeded 125°/s. The time at which each head turn occurred was extracted from the head-mounted IMU data using a custom-made algorithm (Chalkley, Shepherd, McGuckian, & Pepping, 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.

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 his pass—defined as the moment in time that the participant made first contact with the cone

[2]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.

(Figure 2). Frame-by-frame video inspection was used to identify when foot-to-cone contact was made.

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, $p = .05$). As such, the recruited sample of 12 participants was considered appropriate not only to 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). Alpha was set at $p < .05$ 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 nonsignificant, indicating the data were normally distributed. To test for any learning or fatigue effects, one-way repeated-measures analyses of variance (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.

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

A $(4 \times 3 \times 2)$ factorial repeated-measures ANOVA was conducted on the frequency of head turns, with repeated measures on correct screen (four levels), exploration time (three levels: 1 second, 2 seconds, 3 seconds), and possession (two levels: before ball possession, in ball possession). A (4×3) factorial repeated-measures ANOVA was conducted for response time, with repeated measures on correct screen (four levels) and exploration time (three levels: 1 second, 2 seconds, 3 seconds). 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).

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[3]; 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

[3]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.

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

Results

In total, 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 he 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 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 2 (*Mean* = 4.80) than in block 3 (*Mean* = 3.83) and block 4 (*Mean* = 3.70), but no difference in the frequency of head turns before ball possession between any of the blocks. Block 3 and 4, however, had a much higher proportion of trials with only 1 second of exploration time (11/24 trials and 12/24 trials, respectively) than block 2 (3/24 trials). Given that players completed less head turns before ball possession when they only had 1 second of exploration time (Table 1), the differences just described 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.

Table 1. Mean (SD) number of head turns according to exploration time and possession.

Exploration time (seconds)	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)

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

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 3a). When players were in possession of the ball, they had a significantly higher frequency of head turns when there was 1 second before receiving the ball than when there were 2 or 3 seconds before receiving the ball (Figure 3a). Finally, when there was 1 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 were 2 or 3 seconds of exploration time before receiving the ball (Figure 3a).

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 more quickly when

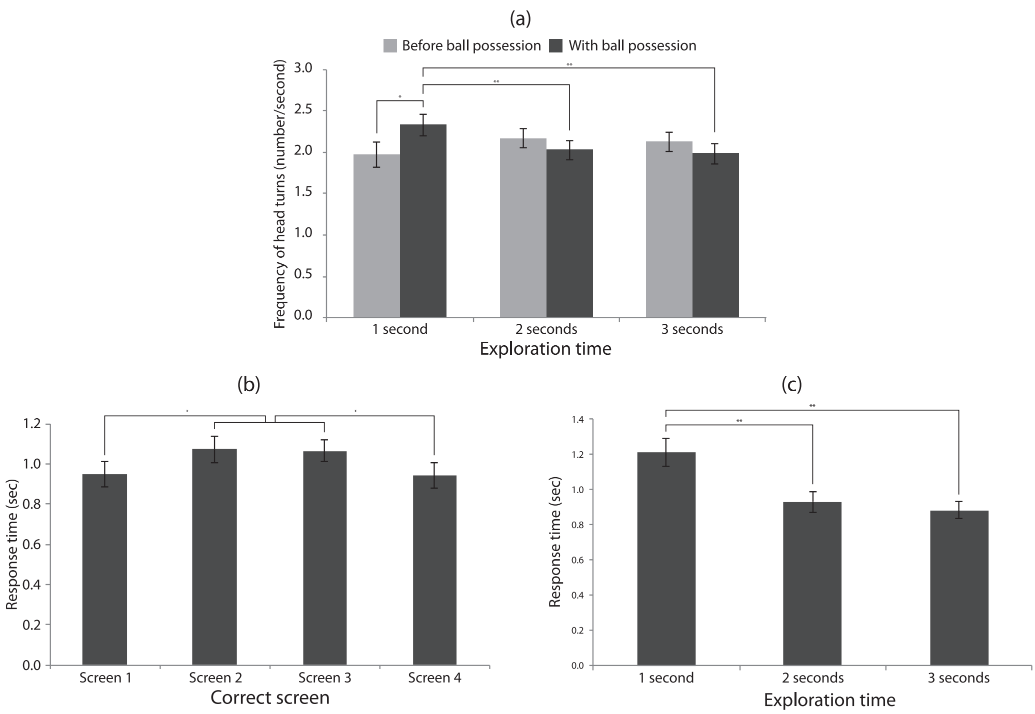

Figure 3. The mean (*SE*) for (a) frequency of head turns according to exploration time before ball possession and in ball possession; (b) response time according to correct screen; and (c) response time according to exploration time. Significance: $^{*}p < .05$; $^{**}p < .01$.

Table 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/second)	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.

screen 1 or 4 was correct compared to when screen 2 or 3 was correct (Figure 3b). Pairwise comparisons for the main effect of exploration time indicated that when there were 2 or 3 seconds before being in possession of the ball, players responded significantly more quickly than when there was 1 second before being in possession of the ball (Figure 3c).

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% bias-corrected and accelerated [BCa] confidence interval [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

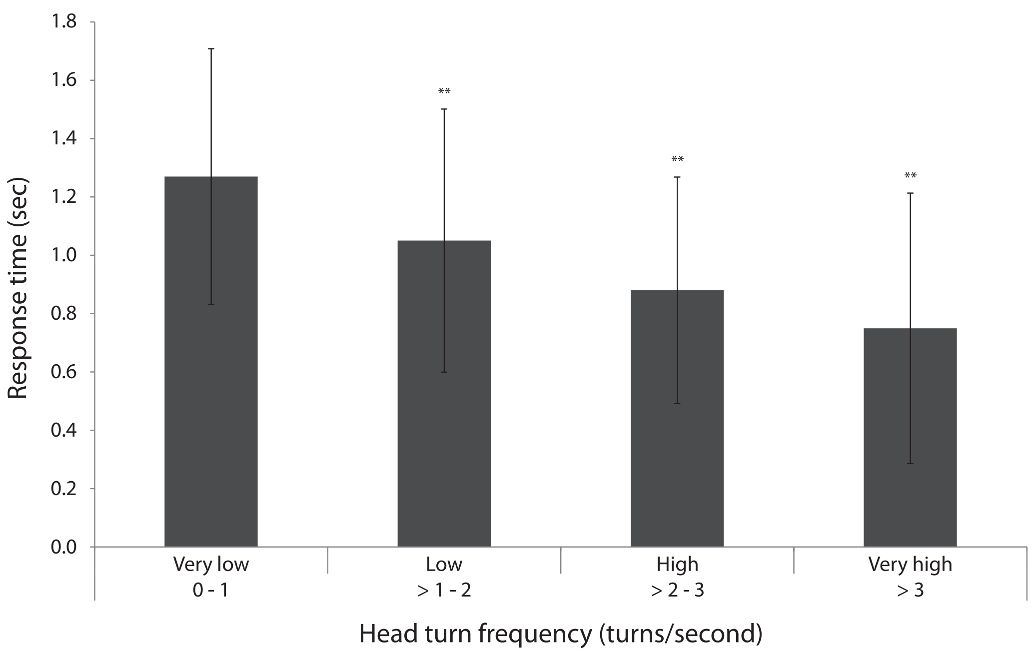

Figure 4. Mean (*SD*) response time according to head turn frequency. Significance: **$p < .01$ for difference compared to very low group.

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 that of the very low head turn frequency group. Results of this analysis are presented in Table 2 and Figure 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.

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—that is, 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: (a) the occurrence of head movements while the players had possession of the ball, and (b) the time taken to complete the requisite pass. There was no difference in the frequency of head turns during the 1, 2, and 3 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 1 second to explore prior to receiving the ball, compared to the conditions in which they were able to explore 2 or 3 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 1 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 (2 and 3 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 have 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 endeavor 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 behaviors 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, 2017) 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, Hertwig, & Hoffrage, 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 his intentions by restricting his 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., 2018), but vitally important behavior: the head movements that support visual perception.

Future research should take the preceding 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 behavior occurs (Dhami et al., 2004; Dicks et al., 2009). This endeavor 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 behavior, and to develop methodologies capable of investigating this behavior, in future perceptual research endeavors.

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, Gómez, Gonçalves, & Sampaio, 2016; Mackenzie & Cushion, 2013; Rein, Raabe, & Memmert, 2017). However, investigations of exploratory head movements reveal that the actions that 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 (Araujo, Davids, & Hristovski, 2006; Dicks et al., 2009; Krause, Farrow, Reid, Buszard, & Pinder, 2017; Pinder, Davids, Renshaw, & Araújo, 2011). That is, coaches should endeavor 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 that 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 (Araujo et al., 2006; Carling, 2011; Torrents et al., 2016).

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, this study showed that utilizing 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 defense 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 behavior 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 who are able to make use of their teammates more effectively through quick and accurate ball movement.

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