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The relationship between amount and timing of visual exploratory activity and performance of elite soccer players

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Objective: Visual exploratory activities (VEA) refer to head and body movements that soccer players make prior to receiving the ball to discover possibilities for action. The current study investigated the degree to which the amount and timing of VEA relates to performance and is influenced by player position.

Method: Using pre-recorded video-footage of matches, the VEA of elite soccer players (n = 72) playing in national professional leagues were analyzed with respect to amount (i.e., in number/s) and timing (i.e., during the penultimate and final pass prior to ball reception) for different player positions (i.e., lines and axes). ANOVAs were used to compare the amount of VEA as a function of its timing and player position, and hierarchical stepwise regression analyses were conducted to examine the degree to which VEA predicts subsequent performance (i.e., adequate ball contact, passes, dribbling actions and shooting).

Results: Elite players showed more VEA in the final pass than in the penultimate pass, and midfielders showed more VEA than players in other lines. In addition, the amount of VEA during the penultimate pass predicted the adequacy of the subsequent pass. The amount of VEA during the final pass did not significantly contribute to this.

Conclusion: In elite soccer players, the amount of VEA systematically varies according to the spatial and temporal unfolding of the play and is positively related to subsequent performance. VEA supports the early perception of the possibilities for action.

Key Words: Visual exploratory activity, soccer, anticipation, affordances, decision making.

Declarations of interest: none

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"Football is a sport that you play with your brain.
You have to be in the right place at the right moment, not too early, not too late."
Johan Cruijff

Introduction

Successful performance in soccer requires that players vary their actions according to the continuously changing affordances or possibilities for action of the game (Araújo, Davids, & Hristovski, 2006; Fajen, 2007*)*. Consequently, skilled performance is closely linked to visual perception. In this respect, ecological psychology (Gibson, 1966, 1979) holds that visual perception is an activity of a perceiver with the eyes in a moving head on a body that moves in the environment, rather than a passive reception of visual stimuli that are processed in increasingly higher brain centers. Put differently, for a player to take adequate action, it is critical to engage in active exploration or search of the on-goings in the immediate situation (Gibson, 1979; Fajen, Riley & Turvey, 2009). In this regard, in soccer, sport scientists have referred to visual exploratory activities (VEA) (Jordet, 2005; Jordet, Bloomfield, & Heijmerikx, 2013), a term that is known among practitioners as 'scanning' or 'checking your shoulder'. Jordet (2005) defined VEA as "a body and/or head movement in which the player's face is actively and temporally directed away from the ball, seemingly with the intention of looking for teammates, opponents and other environmental objects or events, relevant to the carrying out of a subsequent action with the ball" (p. 143).

Research has shown that VEA is associated with performance both within and across levels of play. Specifically, an increased amount of VEA prior to the player receiving the ball is associated with a better subsequent action, such as the direction and accuracy of a pass. These observations originate from notational analysis of professional matches (Aksum et al., 2021a; Jordet et al., 2013, 2020; Phatak & Gruber, 2019; Pokolm et al., 2022) as well as from observations in controlled experimental environments (Aksum, Brotangen, Bjørndal, Magnaguagno & Jordet, 2021; Eldridge, Pulling & Robins, 2013; McGuckian et al., 2017; McGuckian, Cole, Chalkley, Jordet & Pepping, 2018; McGuckian, Cole, Jordet, Chalkley & Pepping, 2020b). Jordet et al. (2013) analyzed video-footage of midfielders from 64 English Premier League (EPL) matches. Each player's VEA was studied for 15 minutes, but only for situations in which -according to the researchers - the pertinent information for selecting the subsequent action was behind the player's back. The researchers showed a significant positive correlation between the amount of VEA in the 10 seconds prior to ball reception and the percentage of successful passes. Similarly, Phatak and Gruber (2019) analyzed the VEA of 51 midfielders during UEFA Euro 2016 championship matches, focusing on the final pass prior to ball reception (i.e., instead of the final 10 seconds). They reported a positive correlation between the amount of VEA and the percentage of successful passes. Interestingly, the relationship only emerged when the teammate who was going to pass had the ball still in possession. Once they had passed and the ball was travelling to the receiver (i.e., the player showing the VEA), the relationship vanished.

Recently, Jordet et al. (2020) and Aksum et al. (2021b) investigated the role of a player's position within a team. It stands to reason that different playing positions within a team offer different affordances and thus induce different amounts of VEA. Jordet et al. (2020) studied 27 elite players in the English Premier League across 21 matches, while Aksum et al. (2021b) studied UEFA European U17 and U19 Championship semi-finals and finals. Both studies reported that the amount of VEA in the final 10 seconds prior to ball reception was positively associated with success in the subsequent pass. Further, both studies revealed that central defenders and midfielders displayed more VEA compared to the players positioned along the side of the field. Similarly, McGuckian et al. (2020a; see also Eldridge et al., 2013) reported more extensive VEA in a training match by youth players who were positioned at the central axis in comparison to players who were playing wide, along the sides. These effects of playing position underline that VEA is not merely an ability of the individual player, but also reflects an adaptation to the situational constraints (Newell, 1986). The central positions in defense and midfield likely offer a larger, more dynamic landscape of affordances than the more spatially constrained back or wing positions in the defense and attack.

The affordances, however, are not only contingent on spatial position, they may also change temporally. They likely arise and dissolve during the final seconds before ball reception (McGuckian, Cole, Chalkley, Jordet & Pepping, 2020b). For example, McGuckian et al. (2018) compared passing performance in simulated soccer situations when players had either 1-, 2-, or 3-seconds exploration time before ball reception. They found that having only 1 second available adversely affected performance after ball reception. This suggests that in the fast-paced soccer environment also the time constraints on VEA are critical to performance (Araujo et al., 2006; Araujo, Davids, Chow, Passos & Raab, 2009). Indeed, anticipation, or looking ahead, is a defining characteristic of skilled perception and action (van der Kamp, Rivas, van Doorn & Savelsbergh, 2008; Savelsbergh, van der Kamp, Williams & Ward, 2005). Practitioners refer to this as 'reading the game'. In highly complex and dynamic environments, skilled players are typically found to pick up information longer before initiating an action than their less skilled counterparts. In an early study, Williams, Davids, Burwitz and Williams (1994) showed that when watching filmed open play situations, inexperienced, low skilled soccer players primarily focused gaze to the ball and the player in possession of the ball, while more experienced players, made more fixations to other players, who were further away in space and time (see also Savelsbergh, Onrust, Rouwenhorst & van der Kamp, 2006). These observations suggest that skilled perception not only entails an increased amount of VEA, but also an earlier start, that is, more passes before they anticipate receiving the ball.

In this respect, it is appropriate to link the timing of VEA to the unfolding play, rather than mere time in seconds. That is, the evolving affordances in elite soccer are likely nested in tactical patterns of play. For example, in Dutch soccer (including the teams examined in this study) most of the teams play according to the principle of offensive coverage (da Costa, da Silva, Greco & Mesquita, 2010). Essentially, this involves the forming of triangles, also known as the 'third man'-principle (see Fig. 1, players 3, 6 and 10). Play-

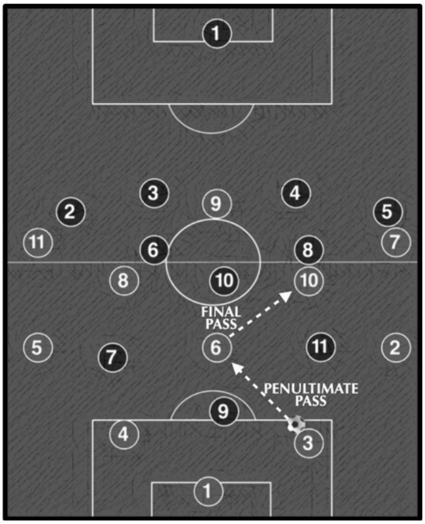

Fig. 1. - The 'third man'-principle. Players 3, 6 and 10 form a triangle. Once player 3 is in ball possession, player 10 'knows' to receive the ball via player 6. For player 10 receiving the ball, the passing from player 3 to player 6 is referred to as the penultimate pass, while the passing from player 6 to the receiving player 10 is denoted as the final pass.

ers take relative positions on the field to form triangle (or diamond) shapes to create opportunities of passing and/or creating passing chances for their teammates. Accordingly, the 'third man' (or receiving player, player 10 in Fig. 1) already knows they will receive the ball via a second, intermediate player (player 6 in Fig. 1) once the first player is in ball possession (player 3 in Fig. 1). This allows a skilled receiving player to start exploring during the penultimate pass, at the beginning of the triangle, instead of waiting until after the final pass is delivered.

To further the observations in previous studies, we investigated whether the amount of VEA (i.e., number/s) is differentiated within a group of elite soccer players who have been assigned specific positions in the team (i.e., they play at different lines, defense, midfield and attack, and axes, central and wide). We compared the amount and timing of VEA as a function of player position, and examined the degree to which the amount and timing of VEA predicts the adequacy of the receiving player's subsequent actions. We hypothesized that the amount of VEA is larger for players positioned in defense and midfield on the central axis, and during the penultimate compared to the final pass. We also anticipated that the amount of (early) VEA during the penultimate pass would predict most of the variance with respect the performance of the subsequent action.

Method

Participants

A priori power analyses showed that using an ANOVA with repeated measures required 60 participants, while for a hierarchical regression analysis with four predictors (see Data analysis) a minimum of 65 participants was required to identify effects of moderate size (i.e., $\alpha = 0.05$, $1\text{-}\beta = 0.80$, $f^2 = 0.20$). Consequently, we selected pre-recorded video-footage of 72 players from a Dutch elite soccer club. Choosing players of one club ensured that they would play within the same tactical system. The first team of the club competes (almost) every season in the European Champions/Europa League and in the first Dutch soccer league (Eredivisie), whereas the second U23 team competes in the second Dutch soccer league (Eerste Divisie). From the 72 players (mean age = 21.5 years, SD = 3.6 years), 29 first team players and 32 U23 players played or had played for their national (youth) team. For each team, the selected players were proportionately distributed across line (i.e., 12 defense, 12 midfield and 12 attack) and axis (i.e., 23 wide, 13 central). Goalkeepers were not included in this study. The study was carried out in accordance with the guidelines of the local university's ethics committee. At the start of each season, the players had provided a written informed consent for the video recordings and matches to be used for scientific research. No further consent for the present study was solicited.

Selection of Video-Footage

The pre-recorded video-footage was taken from a total of 43 competition matches (i.e., 20 and 23 of the first and U23 team, respectively) across five seasons (i.e., 2015-2016, 2016-2017, 2017-2018, 2018-2019 and 2019-2020[1]). The video-footage was obtained through the online platform Wyscout (https://wyscout.com) and the club's digital video archive. Studies showed that VEA is affected by opponent pressure (Aksum et al., 2021a, 2021b; Eldridge et al., 2013; Pokolm et al., 2022). Thus, with respect to match selection, only matches against teams that finished in the first eight of the season's final ranking were included (i.e., the two teams always ended within the first eight). This was done to avoid very large performance differences between the two teams and because lower positioned teams tend to wait longer before putting pressure to regain ball possession (i.e., "catenaccio"). Additionally, to avoid a possible home advantage bias (Pollard & Gomez, 2014), half of the selected matches (i.e., 22 out of the 43) were home matches.

With respect to selection of individual players, the following inclusion and exclusion criteria were used: (1) the player played the full match of 90 minutes and did not change his starting playing position; (2) only ball receptions from passes by teammates were analyzed. Headers, passes that were unintentional (e.g., a ball bouncing to a teammate from a tackle), passes from 'dropped-balls', passes from set piece situations (e.g., free kick, throw in, goal kicks, kick offs), and passes where the opponent players interfered by touching the ball were excluded; (3) only receptions that resulted from at least two consecutive within-team passes (i.e., including a penultimate and final pass) were included. Receptions that followed from one pass only were not considered; (4) receptions after which the player was fouled (and thus could not perform a subsequent action) were excluded; and (5) the quality of video footage permitted reliable identification of head movements. This, for example, excluded receptions near the far end of the pitch, where the variety of colors from audience and advertising hampered identification of head and/or shoulder movements, and receptions recorded by a swiftly moving the camera. If for one of these reasons a reception could not be analyzed, then, if available, a reception of the same player in extra time (i.e., after the 90 minutes) was included. For each player, one full match (i.e., 90 minutes) was coded. If a match included multiple players that fulfilled the above criteria, then they were all included. Together this resulted in a total of 935 receptions that were analyzed for the present study. Table 1 shows how they were distributed across playing position.

Data Analysis

The matches were analyzed using SportsCode Elite software, which allowed, among others, to reduce viewing speed to ¼ of normal speed. For each ball reception the player made, it was first determined if the abovementioned criteria applied. If so, VEA was determined. This

[1] In the 2019-2020 season, the IFAB (International Football Association Board) changed the rules regarding the goal-kick (Law 16 in the Laws of the Game). Specifically, the ball must not leave the penalty area in the goal-kick situation, and consequently, the goalkeeper's teammates must be inside the penalty area to receive the goal-kick. This might have altered performance and VEA compared to earlier seasons, particularly for the defensive line.

Table I
The distribution of receptions across line and axis.

Group	Total
Central defenders	215
Wide defenders	148
Central midfielders	135
Wide midfielders	233
Central attackers	47
Wide attackers	157

was done separately for the penultimate and final pass (Fig. 1). Coding for the penultimate pass started the moment the first passing player received the ball and ended when the ball was received by the second passing or intermediate player (i.e., the pass from player 3 to player 6 in Fig. 1). This started coding for the final pass, until the ball was received by the receiving player or participant (i.e., the pass from player 6 to player 10 in Fig. 1). For each pass, the number of VEAs and the duration (in seconds) was coded.

Following Jordet et al. (2013, 2020), VEAs were defined as the receiving player's active isolated head turns by which the face (and hence, the eyes) was temporally directed away from the ball. Accordingly, each time the head of the player moved away from the ball, one VEA was counted (e.g., if the face moved away from the ball, turned toward the ball, and then again moved away from the ball, 2 VEAs were counted). Next, the actions after ball reception were coded. When the receiving player touched the ball, this was considered as ball control. If any action (i.e., pass, shot on goal or dribble) ensued from ball contact, then ball contact was considered adequate, otherwise (e.g., ball tackled by opponent, ball jumping from foot to opponent) ball contact was considered as inadequate. After contact, the subsequent action was categorized as a pass, a shot on goal or a dribble. A pass was defined as the ball being kicked in the direction of a teammate or (intentionally) into the (empty) space for a running teammate. If the pass reached the teammate, then it was coded as adequate; if the pass did not reach the teammate, it was coded as an inadequate. Passes that resulted in off-side were also considered inadequate. A shot on goal was defined as the ball being kicked within the goal mouth. If it reached the goal mouth it was considered adequate, irrespective of whether it entered the goal; other shots were coded as inadequate. Finally, since previous studies showed that professional players on average contact the ball 1.7 to 2.2 times before making an action (Dellal et al., 2010; 2011), we defined dribbling as a player making more than two touches. It was considered adequate if ball possession was maintained and inadequate if the ball was lost.

The notational analysis was performed by the first author (SC), who is also a professional soccer performance analyst. To determine interobserver reliability, a second experienced soccer performance analyst independently inspected a random sample of 10 % of the data, that is, 7 players. The resulting interobserver reliability was good for the amount of VEA in the penultimate pass (ICC = 0.86) and excellent for the final pass (Cohen's $\kappa = 0.92$). Reliability for the type of performance (i.e., passes, dribbling actions and shoots) (Cohen's k = 0.91) and the adequacy of actions (Cohen's k = 0.92) were both excellent (Koo & Li, 2016; McHugh, 2012).

Statistical analyses

First, for each participant the amount of VEA (in number/s) for the penultimate and final pass were determined separately by dividing the total number of VEAs by the total pass duration. Second, the performance of the subsequent actions of each player was measured with percentage adequate ball contacts (i.e., total number of adequate ball contacts divided by the total number of actions multiplied by 100), percentage of passes (i.e., the total number of passes divided by the total number of subsequent actions multiplied by 100), percentage of adequate passes (i.e., the total number of adequate passes divided by the total number of passes multiplied by 100) and the percentage of adequate other actions (i.e., the total number of adequate dribbles and shots on target by the total of dribbles and shots on target multiplied by 100).

Next, we compared the amount of VEA as function of player position and timing by submitting the amount of VEA to a 3(line: defense, midfield, attack) by 2(axis: central, wide) by 2 (timing: penultimate, final pass) ANOVA with repeated measures on the last factor. Performance was compared across player position by submitting the percentage adequate ball contacts, percentage of passes, percentage of adequate passes, and percentage of adequate other actions to separate 3(line: defense, midfield, attack) by 2(axis: central, wide) ANOVAs with repeated measures on the last factor. In case the sphericity assumption was violated, Greenhouse-Geisser corrections for the p-value were used. Post hoc tests were conducted using t-tests with Bonferroni correction. Effect sizes are reported using η_p^2 with η_p^2 smaller than 0.06 denoted as small, η_p^2 between 0.06 and 0.14 as moderate, and η_p^2 larger than .14 as large.

Finally, separate hierarchical stepwise regression analyses were conducted to examine the degree to which the amount of VEA and player position predicted each of the four performance measures. Each of these analyses consisted of three steps. In the first step, the amount of VEA during the penultimate pass was entered to assess the role of (relatively) early VEA. In the second step, the amount of VEA during the final pass was added to assess if late VEA augmented any contribution of VEA during the penultimate pass. In the third and final step potential contributions of player position were assessed by entering the interaction between line and axis. For this last step two dummy variables were created one comparing midfielders and defenders combined with axis, the other comparing midfielders and attackers combined with axis. For all regressions, outliers that disproportionally influenced the regression parameters (i.e., Cook's D > 1) were excluded (Cook & Weisberg, 1982) and the assumptions of homoscedasticity (i.e., by inspecting the standardized residuals by standardized predicted values plot), error-independence (Durbin-Watson = 1.568 > 1.624, the critical value of 80 students and five predictors), lack of multicollinearity, and normal distribution of errors (e.g., non-significant Kolmogorov-Smirnov) were verified. Because the latter did not unambiguously confirm a normal distribution, the regression analyses were performed with wild bootstrapping with 2000 resamples. Accordingly, we use the bootstrap CI to determine the regression coefficients as they make no assumptions about the shape of the distribution (Efron & Tibshirani, 1993). Analyses were performed using SPSS Statistics 26.0.0.0.

Results

The Amount of Vea

The ANOVA revealed a significant main effect of timing, $F(1, 66) = 7.73$, $p < 0.01$, $\eta_p^2 = 0.11$, indicating more VEA in the final pass in comparison to the penultimate pass (Fig. 2). In addition, VEA clearly varied as a function of player's position. Accordingly, there was a significant effect of line, $F(2,66) = 20.3$, $p < 0.001$, $\eta_p^2 = 0.38$. Post hoc indicated that midfielders had increased amount of VEA relative to defenders and attackers (Fig. 2). The other effects did not reach significance.

Performance

Fig. 3a shows that the percentage of adequate ball contacts was high (i.e., for all positions above 90%). There were no significant differences as a function of line and axis (p's > 0.056). For the percentage of passes significant effects of line, $F(2, 65) = 6.40$, $p = 0.003$, $\eta_p^2 = 0.17$, and line by axis $F(2, 65) = 6.07$, $p = 0.004$, $\eta_p^2 = 0.16$, was found. Post hoc indicated that wide attackers had a lower percentage of passes than the defenders and midfield-

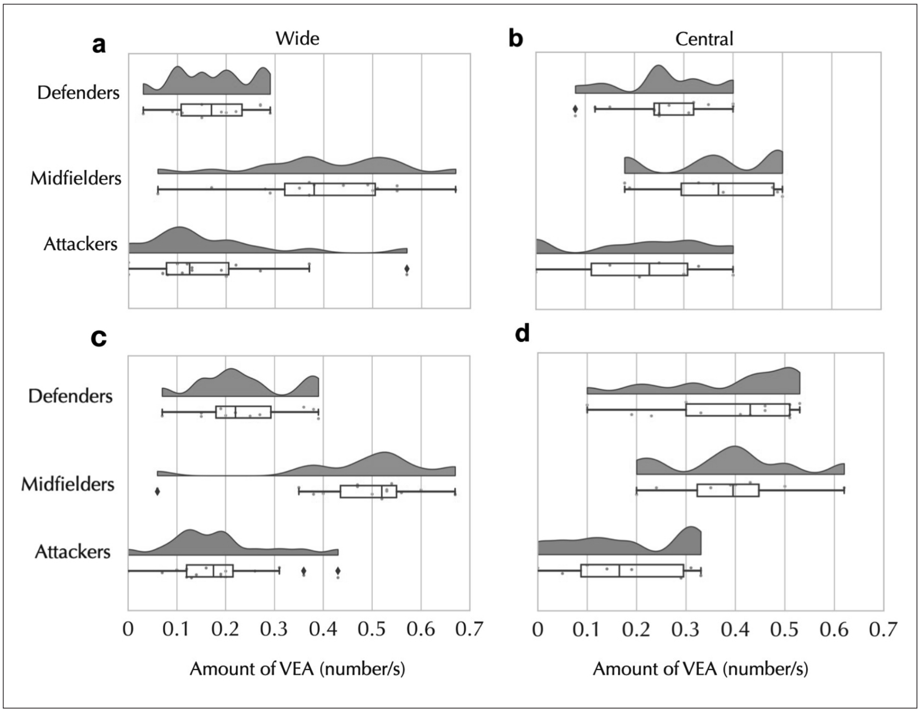

Fig. 2. - The amount of VEA (and SE) as a function of line and axis for the penultimate (a and b) and final pass (c and d).

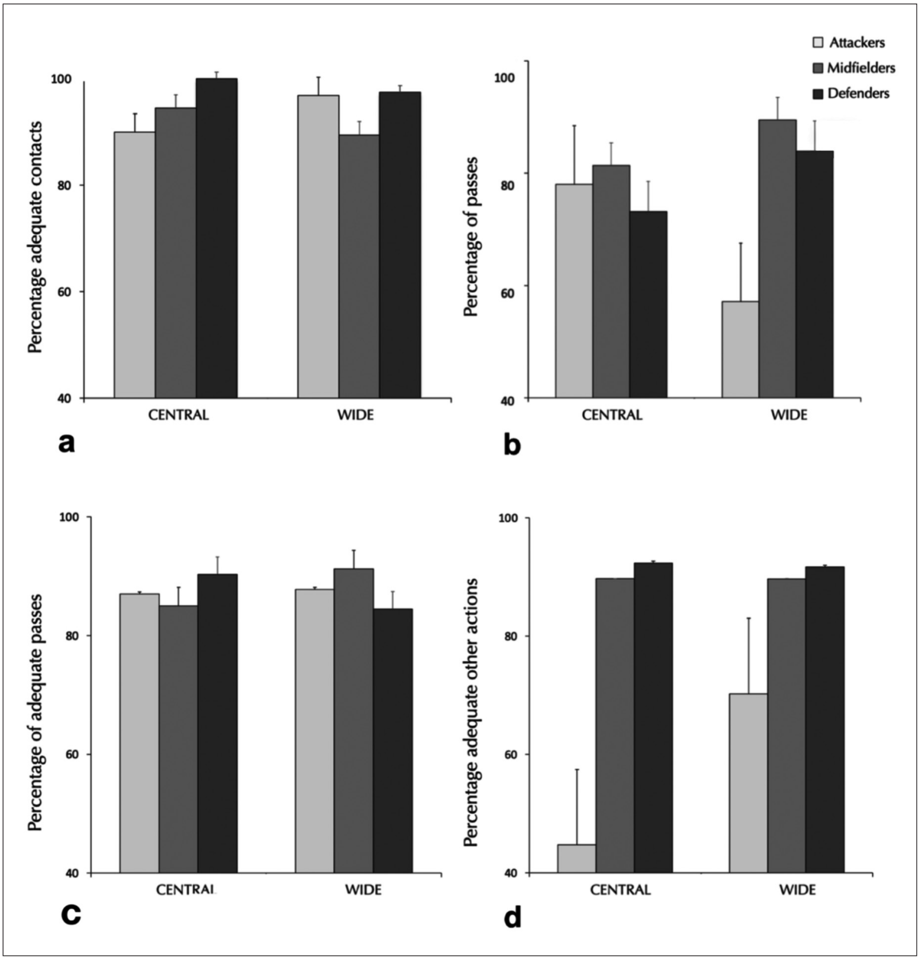

Fig. 3. - Percentage of adequate ball contacts (and SE) (a); percentage of passes (b); percentage of adequate passes (c); and percentage of adequate other actions (d) as a function of line and axis.

ers, while such differences were absent for the central axis (Fig. 3b). Fig. 3c shows that the percentage adequate passes did not vary as a function of a player's position. Accordingly, there were no significant effects for line and axis (p's > 0.32). Finally, Fig. 3d suggests that attackers had a lower percentage of adequate other actions compared to midfielders and defenders. This was confirmed by a significant main effect of line, $F(2,50) = 6.34$, $p = 0.004$, $R^2 = 0.20$. Post hoc indeed indicated that attackers had the lowest percentage adequate other actions. No further significant effects were found.

The Relationship Between VEA and Performance

In Model 1, we addressed the percentage of adequate contacts (Table 2). In the first step, the amount of VEA in the penultimate pass was entered. This did not result in a significant model, $F(1, 70) = 0.003$ $p = 0.96$. The addition of the amount of VEA in the final pass was added in the second step, $F(2, 69) = 0.40$ $p = 0.67$, and the line by axis interactions in the third step did not result in significant models, $F(4, 67) = 0.22$, $p = 0.93$.

For the percentage of passes (Model 2, Table 3), entering VEA for the penultimate pass in the first step resulted in a significant model, $F(1, 69)= 5.33$ $p =0.024$, $R^2 = 0.07$, seemingly suggesting that more VEA in the penultimate pass led to an increased percentage of passes, but this was not significant, $B = 30.9$, $p = 0.24$. In the second step, the addition of VEA in the final pass just failed to significantly improve the model fit, $\Delta R^2 = 0.05$, $p = 0.06$. However, the addition of the two line by axis interactions in the third step did improve the model fit, significantly $\Delta R^2 = 0.19$, $p < 0.001$, resulting in a significant model, $F(4, 66) = 7.33$, $p < 0.001$. This could be attributed to the increase in percentage of passes on the central axis relative to the wide axis being higher in defenders compared to midfielders, $B = -18.2$, $p < 0.001$. Neither the VEA for the penultimate nor for the final pass did significantly contribute to this model.

A clear relationship between the amount of VEA and performance was revealed for the percentage of adequate passes (Table 4). In Model 3, en-

Table II

Hierarchical Regression Model for the Percentage of Adequate Contacts (Model 1)

Model 1					
Dependent variable:	**Percentage of Adequate Contacts**				
	B	[BCa 95% CI]	p	R^2	ΔR^2
Step 1				0.00 (p=0.96)	
Constant	96.6				
VEA penultimate	0.30	[-8.2, 9.2]	0.95		
Step 2				0.01 (p=0.67)	0.01 (p=0.37)
Constant	97.4				
VEA penultimate	4.3	[-7.1, 15.9]	0.51		
VEA final	-6.0	[-16.8, 5.6]	.24		
Step 3				0.01 (p=0.93)	0.00 (p=0.94)
Constant	97.1				
VEA penultimate	4.7	[-7.4, 17.8]	0.51		
VEA final	-5.8	[-16.4. 6.0]	0.27		
Midfield vs Attack x Axis	0.9	[-14.1, 14.3]	0.90		
Midfield vs Defence x Axis	0.1	[-4.2, 4.6]	0.76		

Table III
Hierarchical Regression Model for the Percentage of Passes (Model 2)

Model 2					
Dependent variable:	**Percentage of Passes**				
	B	[BCa 95% CI]	p	R^2	ΔR^2
Step 1				0.07 (p=0.02)	
Constant	68.7				
VEA penultimate	30.9	[4.2, 57.7]	0.24		
Step 2				0.12 (p=0.01)	0.05 (p=0.06)
Constant	64.7				
VEA penultimate	11.2	[-22.3, 44.6]	0.51		
VEA final	29.2	[-1.4, 59.8]	0.06		
Step 3				0.31 (p=0.00)	0.19 (p=0.00)
Constant	73.0				
VEA penultimate	7.6	[-23.1, 38.4]	0.62		
VEA final	15.8	[-13.2, 44.9]	0.28		
Midfield vs Attack x Axis	5.8	[-5.5, 17.0]	0.31		
Midfield vs Defense x Axis	-18.2	[-28.6, -7.7]	0.001		

Table IV
Hierarchical Regression Model for the Percentage of Adequate Passes (Model 3)

Model 3					
Dependent variable:	**Percentage of Adequate Passes**				
	B	[BCa 95% CI]	p	R^2	ΔR^2
Step 1				0.06 (p=0.04)	
Constant	82.9				
VEA penultimate	20.2	[4.1, 36.4]	0.02		
Step 2				0.06 (p=0.13)	0.00 (p=0.79)
Constant	83.4				
VEA penultimate	22.9	[-.4, 46.5]	0.04		
VEA final	-3.1	[-21.6, 13.1]	0.75		
Step 3				0.07 (p=0.34)	0.01 (p=0.80)
Constant	83.3				
VEA penultimate	21.1	[-1.8, 45.3]	0.06		
VEA final	-2.5	[-20.4, 12.7]	0.81		
Midfield vs Attack x Axis	-2.2	[-10.6, 3.5]	0.72		
Midfield vs Defense x Axis	-1.3	[-7.6, 10.0]	0.78		

tering VEA in the penultimate pass in the first step resulted in a significant model, $F(1, 69)= 4.24$ $p = 0.043$. It indicated that a higher amount of VEA during the penultimate pass was associated with a higher percentage of adequate passes, $B = 82.9$, $p = 0.043$. In the second step, the addition of VEA in the final pass, did not improve the model fit, $\Delta R^2 = 0.00$, $p = 0.79$, and also the addition of the two line by axis interactions in the third step did not further improve model fit, $\Delta R^2 = 0.01$, $p = 0.80$).

Finally, in Model 4 we addressed the percentage of adequate other actions (Table 5). In the first step, no significant model resulted based on VEA in the penultimate pass, $F(1, 54)= 0.31$ $p = 0.58$, ,$R^2 = 0.00$. Also the addition of VEA in the final pass, $F(2, 53) = 0.28$ $p = 0.76$, and the two line dummy variables, $F(4, 51) = 0.85$, $p = 0.50$, did not result in significant models.

TABLE V
Hierarchical Regression Model for the Percentage of Adequate Other Actions (Model 4)

Model 4					
Dependent variable:	**Percentage of Adequate Other Actions**				
	B	[BCa 95%CI]	p	R^2	ΔR^2
Step 1				0.00 (p=0.58)	
Constant	77.4				
VEA penultimate	15.7	[-43.4, 73.7]	0.64		
Step 2				0.01 (p=0.76)	0.00 (p=0.62)
Constant	75.3				
VEA penultimate	6.6	[-59.4, 70.8]	0.87		
VEA final	14.7	[-19.9, 49.9]	0.47		
Step 3				0.06 (p=.50)	0.05 (p=0.25)
Constant	83.6				
VEA penultimate	-0.7	[-76.9, 74.8]	0.99		
VEA final	4.0	[-40.1, 48.4]	0.87		
Midfield vs Attack x Axis	7.4	[-15.8, 31.7]	0.55		
Midfield vs Defense x Axis	-14.0	[-41.0, 14.0]	0.40		

Discussion

To take adequate action within the complex and dynamic environment of a soccer match, players must continuously monitor the play's changing affordances, particularly when they anticipate receiving the ball. Accordingly, previous studies have suggested that the elite soccer players engage in visual exploratory activity (VEA), and the more they do so, the more successful the ensuing actions tend to be (Aksum et al., 2021a; Eldridge, Pulling & Robins, 2013; Jordet et al., 2013, 2020; McGuckian et al., 2017; McGuckian, et al., 2018; McGuckian, et al., 2020b; Phatak & Gruber, 2019; Pokolm et al., 2022). This is especially true for players who are positioned at central positions in defense and midfield that offer a multitude of action possibilities (Aksum et al. 2021a, 2021b; Jordet et al., 2020; Pokolm et al., 2022). We expected to further substantiate these observations, but additionally aimed to explore the timing of VEA. In this respect, we hypothesized that among elite soccer players, early VEA (i.e., during the penultimate pass) would be the strongest predictor of the adequacy of subsequent actions. The current observations largely confirmed these hypotheses. They demonstrate that compared to players positioned in the defense and attack, midfielders showed the highest engagement in VEA. Additionally, it was found that the amount of VEA during the penultimate pass predicted the success of subsequent passing actions. The amount of late VEA, during the final pass, did not significantly add to this prediction.

The current findings indicate that the amount of VEA not merely reflects a (superior) ability of individual players, but that it systematically varies according to the spatial and temporal unfolding of the play. This underlines the adaptive character of VEA. Yet, our findings are not identical to previous reports. We found increased VEA for midfielders relative to both attackers and defenders, and irrespective of the axis (i.e., central or wide) in which they played, while previously researchers found increased VEA for midfielders and defenders positioned on the central axis (Aksum et al. 2021a, 2021b; Jordet et al., 2020; McGuckian et al., 2020a). Midfielders are surrounded by teammates and opponents in all directions, and thus obviously forced to extensively explore their very dynamic environment. Indeed, research has shown that individuals are not only attuned to their own affordances but also accurately perceive the action possibilities of other individuals, such as the teammates and opponents (Fajen et al., 2009; Marsh & Meagher, 2016). Therefore, by exploring more, players discover more opportunities for action for themselves but also increase awareness of the affordances of their teammates and opponents, allowing them maintain ball possession and build-up the play. This may be less for attackers, whose main task is to create scoring opportunities, forcing them to take more risks. Indeed, attackers made less VEA and showed less successful performance than the defenders and midfielders. However, it is not immediately clear why we find this increased VEA also for wide midfielders and not for central defenders. Probably, the most likely explanation is a difference in team tactics. In the current study, the teams always played in a 4-3-3 formation, while the previous studies also included teams playing in a 4-4-2 formation (and perhaps mostly so). In a 4-3-3 formation, following the principle of offensive coverage, during ball possession the midfielders (i.e., players 6, 8 and 10, Fig. 1) are typically positioned in a 'V'-shape to create opportunities for passing to build-up the play. Consequently, in a 4-3-3 format, wide midfielders tend play more centrally than in 4-4-2 formats, which may invoke more VEA. Alternatively, also the pressure from the opposing team trying to regain ball possession may influence how the amount of VEA is distributed across player positions. For example, Aksum et al. (2021b) show that variations in the distance between defenders in ball possession and the nearest opponent affects the amount of VEA. Indeed, an interesting avenue for future research is to address how team tactics differentiates patterns of VEA.

Importantly, we also found that VEA is systematically affected by the temporal unfolding of play. Researchers have typically determined players' VEA in the final 10 seconds before they receive the ball in its entirety (cf. McGuckian et al., 2018). But clearly, depending on the unfolding play, possibilities for subsequent actions may rapidly change. In many time-constraint sports situations, skilled athletes are found to distinguish themselves, among others, by their ability to pick up early information -when reading the game, they look further ahead. Indeed, the current elite soccer players engaged in VEA before the ball was actually passed to them, during the penultimate pass. Yet, unlike what we had expected the amount of VEA was larger during the final compared to the penultimate pass, although the difference was not very pronounced. We suspect that initial perception regarding the subsequent action follow from (relatively) early VEA, but dynamics of the game require players to continuously monitor the ongoings of the situation. It is critical for further research to establish if timing of VEA is different among less skilled players, presumably by being more strongly concentrated during the final pass. Importantly, however, our findings do underline the importance of early VEA, during the penultimate pass, in elite players. That is, in agreement with previous observations, an increased amount of VEA was associated with better performance, especially with the adequacy or successfulness of the subsequent pass (Aksum et al. 2021a, 2021b; Jordet et al., 2021; McGuckian et al., 2020b; Pokolm et al., 2022). The current findings extend the previous observations by indicating that the information is already picked up during the penultimate pass, since the amount of VEA during the final pass did not result in a stronger relation with subsequent performance. This underlines that affordances are perceived based on relatively early VEA.

Our findings include observations of elite soccer matches, rather than re-created test situations which have an increased risk of response bias, among others. Yet, naturalistic observations typically come at the expense of experimental control. The current study is no exception. Most importantly, we know that head and body movements away from the ball systematically varies with spatial and temporal unfolding of the play, but these visual exploratory activities are only a proxy for the pick-up of optical[2] information that underpins the perception of affordances. In this respect, using gaze tracking techniques

[2] Notice that teammates also talk (or shout) with each other. Consequently, the affordances are specified by both optical and auditory information.

would potentially further our understanding, although gaze fixations do not necessarily correspond to information pick-up (see McGuckian, Cole and Pepping [2017], who discuss limitations of gaze tracking techniques). Also, soccer regulations do not allow to wear equipment such as gaze trackers during official matches. However, using gaze tracking during training matches, possibly combined with inertial measurements units (IMU) to measure head movements (McGuckian & Pepping, 2016; see also Chalkley, Shepherd, McGuckian, & Pepping, 2017), can help to further validate the use of video-observations.

With the increasing attention and understanding from research, VEA or scanning is also becoming of interest among practitioners, especially professional coaches (Pulling, Kearney, Eldridge, & Dicks, 2018; Eldridge, Pocock, Pulling, Kearney, & Dicks, 2022). Research observations (including the current study) have systematically confirmed the relationship between VEA and soccer performance. Consequently, coaches may want to explore if and how they can train VEA to improve individual and team performance. Typically, coaches organize their training sessions also based on the players' needs (Walker & Hawkins, 2018), in particularly considering the different playing positions. Based on the current findings, group training for midfielders may also include VEA, for example in exercises that re-enact offensive coverage in match situations. Beyond team training sessions, some have proposed to train VEA individually via the Footbonaut (McGuckian, Beavan, Mayer, Chalkley, & Pepping, 2020), but possibly virtual reality, in which matches can be 're-played' may be another interesting setting to explore (Ferrer, Shishido, Kitahara, & Kameda, 2020).

To conclude, we show that in elite soccer players VEA systematically varies according to the spatial and temporal unfolding of the play. Specifically, we observed that players positioned on the midfield showed more VEA than players playing in defense and attack. Importantly, we also found that the amount of VEA is positively associated with performance, in particular the adequacy of the pass. In fact, this positive relationship with performance seem to emerge early, during the penultimate pass before receiving the ball, attesting that the elite players were looking ahead while reading the game. Accordingly, to improve tactical performances, we recommend reproducing position specific match situations during training that encourage visual exploration and thus support the perception of affordances.

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