Visual exploratory activity in elite women's soccer: An analysis of the UEFA Women's European Championship 2022

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Recent research has developed understanding of the technical and tactical determinants of success in elite women's soccer, however a lack of research exists on analysing how elite female players visually explore their environment to support skilled soccer performance. This study aimed to describe the visual exploratory activity (VEA) of elite female central midfield players and understand the relationships between VEA, performance with the ball and specific contextual and situational factors. Thirty female central midfield players (*M* age = 26.7 years, *SD* = 3.8) from the eight teams who competed in the knock-out stages of UEFA Women's European Championship 2022 were analysed. Television broadcast and UEFA tactical footage were combined to analyse players across the seven knock-out stage matches, totalling 1,038 individual ball possessions. The mean scan frequency before receiving the ball was 0.35 scans/second. Results showed pitch location when receiving the ball to be the main predictor of scan frequency, which in turn predicted action result (p = 0.003) and turn with the ball (p = 0.003). Scan frequencies were lower compared to men's elite and academy players. This study sets a platform for experimental research to further our understanding of VEA and performance with the ball in women's soccer.

Key Words: central midfielders, scan frequency, women's soccer (football), visual perception, exploratory activity.

Introduction

Soccer is a dynamic invasion game that requires players to have awareness of the movements of the ball, teammates, and opposition players (Pokolm, 2021). Skilled performance requires players to visually explore their surroundings to identify opportunities for action (McGuckian et al., 2018). Visual exploratory activity (VEA), or 'scanning' as typically referred to by coaches (Eldridge et al., 2023), when one's team is in possession of the ball can be defined as a head or body movement where a player's face is temporarily directed away from the ball to locate teammates, opposition players or empty space, before engaging with the ball (Jordet et al., 2020). In men's soccer, players who engage in more frequent VEA typically perform more successful actions with the ball (e.g., higher pass success rates; Aksum et al., 2021; Jordet et al., 2020). However, there is a lack of understanding of how elite female players engage in VEA to support skilled performance. Recent literature has identified differences between male and female soccer in both tactical elements such as pass accuracy, ball recovery time (Pappalardo et al., 2021) and the start and development of possession (Mitrotasios et al., 2022), as well as specific physiological characteristics (de Araújo et al., 2020). With research identifying tactical differences between men's and women's soccer, and VEA having previously been shown to be important for skilled performance in men's soccer, there is a need to analyse VEA and performance with the ball in elite women's soccer.

Women's soccer is currently experiencing a dramatic increase in popularity and professionalism (Griffin et al., 2020; Okholm Kryger et al., 2021), with the UEFA Women's European Championship 2022 (UEFA Women's Euro 2022) setting a record aggregate attendance of 574,875 and the Championship having been watched by over 365 million people globally (UEFA, 2022). To date, research into women's soccer has largely focused on the physical (Vescovi et al., 2021) and physiological demands of the game (Datson et al., 2014; Martínez-Lagunas et al., 2014). Current literature has also emphasised the importance of understanding technical and tactical characteristics of the game (de Jong et al., 2020; de Jong et al., 2022). When compared to elite men's soccer, elite women's soccer appears to adopt a more attacking style of play, possession is lost more frequently, and passes are performed with less accuracy (Bradley et al., 2014; Garnica-Caparros & Memmert, 2021). These differences could have potential links to how a player visually explores their environment to inform their subsequent action with the ball. Previous literature has also found the more successful teams in elite women's soccer are those who maintain longer spells of possession (Iván-Baragaño et al., 2022; Maneiro et al., 2020; Soroka & Bergier, 2010), make more passes resulting in goal scoring opportunities (Kubayi & Larkin, 2020), and have high interconnectivity with more successful ball transfers and effective ball movements (de Jong et al., 2022). It appears that successful women's teams are those which are highly interconnected and able to effectively transfer and move the ball quickly to create goal scoring opportunities, factors which are related to the ability to effectively pick up information from the environment. Also, with central midfield players being mainly located in central areas of the pitch, research has suggested central midfielders may play a crucial role in successful ball transfers in teams that achieve international or domestic success (de Jong et al., 2022). These findings demonstrate the importance of maintaining possession and highlight the potential significance of VEA in elite women's soccer.

Previous studies investigating VEA in elite men's soccer have focused on understanding the influence of contextual factors on performance with the ball (Aksum et al., 2021; Jordet et al., 2020; Pokolm et al., 2022). Notable findings have identified positive relationships between VEA and pass success (Aksum et al., 2021; Jordet et al., 2013), as well as VEA being constrained by pitch location, playing position, phase of play (McGuckian et al., 2020) and opponent pressure (Jordet et al., 2020). More specifically, research has found central midfield players have higher scan frequencies compared to wide players (Pocock et al., 2019), central defenders and strikers (Aksum et al., 2020; Jordet et al., 2020). Central midfielders are frequently required to pass the ball forwards and turn with the ball, highlighting the need for players to have a 360-degree visual input to pick up information (Phatak & Gruber, 2019). Despite comprehensive observational studies into VEA in soccer (see Jordet et al., 2020; Pokolm et al., 2022), there is limited evidence on the influence of game-related contextual and situational factors on a female soccer player's VEA and subsequent performance with the ball.

The importance of VEA in soccer and the influence of contextual factors can be conceptually explained through the cyclical relationship between perception and action (Gibson, 1979). Soccer players engage in eye, head, and body movements to pick-up the most relevant environmental information, therefore recognising affordances (Pokolm et al., 2022; McGuckian et al., 2018). Affordances can be defined as opportunities for action that the environment provides an individual in relation to an individual's action capabilities (Gibson, 1979; Fajen et al., 2009). For example, a central midfielder may receive a pass from a team-mate whilst facing the goal their team is defending. Prior to the ball arriving, the player may search their environment for affordances, dependent on the location of teammates, opposition players and empty spaces located behind them. Through exploring the environment and depending on their own action capabilities, the player can recognise relevant affordances (e.g. turn; pass; dribble) and prospectively control actions with the ball (Fajen et al., 2009). A higher frequency of VEA could therefore underpin the search for more information to act upon, which may be linked to more effective performance with the ball.

Despite increasing interest in elite women's soccer, a lack of empirical evidence exists to investigate VEA and its contribution to successful performance. Previous literature has highlighted the need further investigate the technical and tactical match-play characteristics in women's soccer to gain a more holistic insight into match performance

(Harkness-Armstrong et al., 2022). Taking this into account alongside the growing body of work into VEA in elite men's soccer (see Eldridge et al., 2023; Jordet et al., 2020), there is a need to understand the role VEA plays in elite women's soccer, particularly in central midfield players. Therefore, the aim of this study is to describe the visual exploratory activity of elite female central midfield players and understand the relationships between VEA, performance with the ball and specific contextual and situational factors in elite women's soccer.

Figure 1 presents the hypothesised relationships based on current research evidence. Each arrow represents a potential relationship between VEA (scan frequency), contextual ("on or around the ball"), situational ("off the ball") and performance with the ball factors. It is hypothesised that central pitch locations will elicit higher scan frequencies compared to wide locations on the pitch and players experiencing higher amounts of opponent pressure will result in lower scan frequencies compared to players experiencing lower amounts of opponent pressure. Higher scan frequencies will be observed when the score line is a draw compared to winning and losing and when the score line is losing compared to winning. These hypotheses are informed by findings in men's soccer from Jordet et al. (2020) who found game standing to be significantly related to scan frequency. Therefore, it is predicted in the current study that higher scan frequencies will be observed when the score line is a draw compared to winning and losing and when the score line is losing compared to winning. Higher scan frequencies will be observed in earlier stages of a game (between 0-15 minutes) compared to later stages of a game (>75 minutes) as well as in the final compared to the semi-finals and quarter final matches. Due to limited research that currently exists investigating the influence of contextual factors on scan frequency, these hypotheses are presented following tendencies and trends found in previous literature in elite men's soccer (see Fernandes et al., 2020; Jordet et al., 2020).For the factors that may be influenced by scan frequency, it is hypothesised that higher scan frequencies will result in more successful actions with the ball, more forward passes compared to sideways and backwards passes, more passes completed over greater distances (e.g., 15-34 m and 35 m +) compared to shorter passes (e.g., 0-14 m), more forwards and sideways orientated body positions compared to a backwards orientated body position and more turns with the ball.

Method

Insert Figure 1 near here

Participants

Participants were thirty female central midfield players (*M* age = 26.7 years, *SD* = 3.81) from the eight teams who competed in the knock-out stages of UEFA Women's Euro 2022. Knock-out stage matches were selected to include the top eight European teams in the championship, similar to the approach of Aksum et al. (2021). All players satisfied the following inclusion criteria: i) to have competed in a minimum of two out of three group-stage matches, ii) to have accumulated a minimum of 150 minutes playing time over the course of the UEFA Women's Euro 2022 and iii) to be classified as a central midfield player based upon UEFA tactical line-ups for each knock-out stage match. The current investigations inclusion criteria is similar to that reported in previous literature into VEA in men's soccer (Phatak & Gruber, 2019). Due to the observational nature of the study involving elite female soccer players in their natural sport setting (matches of an international tournament), no informed consent was gained due to data being analysed using broadcast footage which was publicly available. Ethical approval was granted from the lead author's institution.

Footage

Two types of match footage were obtained for the current study. Firstly, broadcast angle footage was obtained through screen-recording publicly available televised footage, as well as UEFA tactical camera (wide angle) footage. The video quality of the UEFA tactical camera footage was 1920x1080 ('Full HD'). All footage was then imported into Hudl Sportscode (Hudl, Nebraska, USA) with the broadcast footage synced and aligned with UEFA wide angle footage which resulted in split screen footage being generated to enable all players to be on screen at all times. All matches were analysed on a Dell Computer (Windows 10) at a resolution of 1920 x 1080 connected to an Apple MacBook Pro (Version 12.6.3). In instances where a player was visible on the broadcast footage and then left the televised picture, the remainder of the instance was analysed using the UEFA tactical camera footage. A total of 402 instances were analysed solely using broadcast footage and 636 instances analysed using the broadcast footage and tactical camera footage specifically provided by UEFA.

Procedures

Prior to data collection, pilot testing was conducted by analysing the Women's FA Cup Final 2022 to allow the researcher to identify any issues with the operational definitions and code window. As a result of the pilot test, minor changes were made to the operational definitions of action type, turn with the ball and line break. A ball possession in the current study was defined as a player receiving the ball from a teammate and performing an action with the ball (e.g., a pass). For an instance (individual ball possession) to be included in the final analysis all instances were required to meet specific inclusion criteria (see Table 1).

Insert Table 1 near here

Data Collection

Phase 1

All knockout matches were coded using a bespoke code window, which included the creation of a ‘contextual’ (including performance with the ball factors) and ‘situational’ window. All instances were labelled with situational factors (“off the ball”) which were then edited to capture the final 10 seconds prior to the analysed player receiving the ball from a teammate, or from the point when the analysed player’s team won possession of the ball during the 10 s interval. The 10 second cut-off point was chosen to allow comparison to be made with previous studies into VEA in elite male soccer (see Aksum et al., 2021; Jordet et al., 2020).

Phase 2

Contextual factors (“on or around the ball”) were labelled with the exception of pass distance and opponent pressure. To adequately analyse the players’ scans, the magnifying trackable zoom feature tool was utilised to track the analysed players’ scans throughout the 10 second interval. This magnifying zoom feature was placed over the individual player being analysed and then tracked the movements of the player through the 10 second interval. This feature was used in combination with reducing the speed of each instance by 50% in order to accurately capture all head and or body movements of the analysed players between the 5-10 second interval. The ruler feature was utilised to measure pass distance and opponent pressure which uses 3-D calibration technology where X and Y coordinates track the movements of the players and the ball. Similar methods have been previously used by OPTA statistics which has demonstrated high levels of reliability (Bradley et al., 2007; Liu et al., 2013). Known distances of goal-line to six yard box, goal-line to 18-yard box and goal-line to penalty spot were measured and checked for accuracy of the ruler. For all passes analysed, the ruler measuring feature in Hudl Studio which uses 3-D tracking and calibration technology measured the exact point from which the ball left the analysed player's foot and was then either received by a teammate, intercepted by an opposition player or the exact point in which the ball left the pitch. Instances were then cut to the exact point at which the analysed player received the ball from a teammate. Finally, instances from Sportscode timelines were exported as CSV files and transferred to Microsoft Excel (Microsoft Corporation, Washington, USA, Version 16.67) for data analysis purposes.

Measures and Variables

The following variables were analysed: scan frequency, body orientation and performance with the ball. Performance with the ball was split up into action type (with the final action of a pass also including pass distance, pass direction and lines broken), action result and turn with the ball. Pass distance categories were classified following previous research in elite women's soccer (Mara et al., 2012). We present scan timing across the final five seconds prior to ball contact as a result of all 1,038 instances analysed capturing the analysed players VEA across the final five seconds prior to ball contact because a number of instances were six, seven, eight and nine seconds in duration. To gain a more comprehensive insight into how elite female central midfield players visually explore their environment, the contextual variables of opponent pressure and pitch location were also investigated. All operational definitions were informed by previous research and validated by a UEFA A License Football Coach with 22 years soccer coaching experience (see supplementary material for list of operational definitions).

Data Analysis

Reliability

An independent observer with three years' experience as a soccer analyst performed additional coding on all variables to assess inter-rater reliability. A total of 156 individual ball possessions were re-analysed across two matches for both inter and intra-rater reliability totalling 15% of the entire sample, similar to samples presented in previous research in elite men's soccer of 10% and 8.2%, respectively (Aksum et al., 2021; Jordet et al., 2020). Intra-rater reliability was completed following a six-week gap to minimise the chances of any potential learning effects. Intra-class correlations (ICC) were utilised for the continuous variable of number of scans which formed the basis variable for scan frequency. ICC were assessed following Cicchetti (1994) criteria to understand the strength of agreement between two separate coders and repeated observations of the same coder (see Table 2). For all remaining categorical variables, Cohen's Kappa values (Cohen, 1960) were produced for both inter and intra-rater reliability with the strength of agreements classified following Landis and Koch (1977) criteria (see Table 3).

Insert Table 2 near here

Insert Table 3 near here

Statistical Analysis

All statistical analysis was conducted in RStudio (R Core Team. R, 2022). As a result of only achieving a moderate agreement for the variable of 'lines broken' for inter-rater reliability, the variable was not included in any statistical modelling. To achieve the first aim of the study, descriptive statistics were presented for VEA (scan frequency) against each variable of interest. To achieve the second aim, a linear mixed model (LMM) was built to understand the relationships between scan frequency and contextual and situational variables, with mixed effects logistic regression models developed to understand relationships between scan frequency and performance with the ball variables.

A LMM was developed with the dependent variable of scan frequency and fixed effects of pitch location, opponent pressure, game state, stage of competition and time in the game. Repeated measurements in the data were accounted for within the random effects structure of subject (player) nested within fixture. The lme4 package (see Bates et al., 2014) in RStudio was used to fit the LMM. The emmeans package was used provide estimate means for each variable, and the results were reported as mean ± SE. Tukey's pairwise comparisons were conducted to identify differences between individual fixed effects, with statistical significance set at $p < 0.05$. The effsize package was used to calculate effect size (ES), which was classified as trivial (<0.2), small (0.2-0.59), moderate (0.6-1.19), large (1.2-1.99), or very large (>2.0) (Batterham & Hopkins, 2006). Effects were considered unclear if the 90% confidence intervals included both positive and negative values below 0.2 (Hopkins et al., 2009). The assumptions of linearity, normality of the distribution of the model and homogeneity of variance were verified visually.

Mixed effects logistic regression models with separately considered dependent variables (performance with the ball variables, see Figure 1) were developed with scan frequency as a fixed effect. Mixed effects ordinal logistic regression was performed for the variable pass distance using the Ordinal package (Christensen, 2018). Mixed effects binomial logistic regression was performed for the variables of action result and turn with the ball using the lme4 package (Bates et al., 2014). Mixed effects multinomial logistic regression was performed for the variables of pass direction, action type and body orientation using the

Mclogit package (Elff, 2021). The random effects structure of subject (player) nested within fixture was maintained. The *summary* and *anova* functions in RStudio were used to produce estimates, standard errors, *z*-values, and *p*-values for the separate models built. Through utilising mixed effect models, this enabled us to examine the condition/factor of interest while accounting for variability within and across participants and items (Brown, 2021). For all models developed the assumptions of the distribution of the model, linearity and homogeneity of variance were verified visually, with the assumption of proportional odds satisfied visually for the mixed effects ordinal logistic regression. Statistical significance was set at $p < 0.05$.

Results

Description of VEA behaviours

Central midfielders ($n = 30$) recorded a mean scan frequency of 0.35 ± 0.17 scans/second (scans/s) prior to receiving the ball in the knock-out stages of the UEFA Women's Euro 2022 (*n instances* = 1,038). An average of 34 instances per player were analysed across the knockout stages (SD = 21.75, min = 7, max = 93). Across the final five seconds prior to receiving the ball, the highest mean scan frequency was observed in the final 1-2 seconds before ball contact (see Figure 2). Table 4 presents mean scan frequencies and the number of instances per variable for all analysed variables except pitch location. Figure 3 presents mean scan frequencies, standard deviations and the number of instances analysed across twelve pitch locations.

Insert Figure 2 near here

Insert Table 4 near here

Insert Figure 3 near here

Pitch Location and Scan Frequency

Table 5 shows the estimated means ± SE for all individual pitch locations. Pairwise comparisons revealed players performed significantly more scans in DMCL compared to ACL pitch locations (0.39 ± 0.02 vs 0.26 ± 0.04 scans/s; p = 0.019; moderate ES: 0.83 ± 0.22) and in DMCR compared to ACL pitch locations (0.39 ± 0.02 vs 0.26 ± 0.04 scans/s; p = 0.013; moderate ES: 0.84 ± 0.22). Significant differences were also identified in DMR compared to ACL pitch locations (0.39 ± 0.02 vs 0.26 ± 0.04 scans/s; p = 0.044; moderate ES: 0.83 ± 0.24) and in DMCL compared to AMCL (0.39 ± 0.02 vs 0.39 ± 0.02 scans/s; p = 0.007; small ES: 0.48 ± 0.12) and in DMCR compared to AMCL (0.39 ± 0.02 vs 0.31 ± 0.02 scans/s; p = 0.004; small ES: 0.49 ± 0.12). Figure 4 presents all small and moderate effect sizes (90% Confidence intervals) within pitch location. All other pairwise comparisons revealed trivial or unclear effect sizes.

Opponent Pressure and Scan Frequency

There were no significant differences between different amounts of opponent pressure. Pairwise comparisons revealed players performed more scans when opponent pressure was at 7-9 m compared to 0-3 m (0.35 ± 0.03 vs 0.31 ± 0.02 scans/s; small ES: 0.22 ± 0.12), however the difference was not statistically significant ($p > 0.05$). Table 5 presents estimated means ± SE for all opponent pressure categories.

Game State and Scan Frequency

No statistical differences, nor substantial effect sizes were identified between winning, drawing and losing. Table 5 displays the estimated means ± SE for all game state categories.

Time in the Game and Scan Frequency

Table 5 presents the estimated means ± SE for all different time in the game categories. Pairwise comparisons revealed players performed more scans between 0-15 minutes compared to 90-105 minutes (0.34 ± 0.02 vs 0.30 ± 0.03 scans/s; small ES: 0.26 ± 0.15) and between 16-30 minutes compared to 90-105 minutes (0.35 ± 0.03 vs 0.30 ± 0.03 scans/s; small ES: 0.31 ± 0.16), however the differences was not statistically significant ($p > 0.05$). Players also performed more scans between 45-60 minutes compared to 90-105 minutes (0.35 ± 0.02 vs 0.30 ± 0.03 scans/s; small ES: 0.31 ± 0.16) and between 61-75 minutes compared to 90-105 minutes (0.34 ± 0.02 vs 0.30 ± 0.03 scans/s; small ES: 0.28 ± 0.16), however the differences were not statistically significant ($p > 0.05$). All other pairwise comparisons revealed trivial or unclear effect sizes.

Insert Figure 4 near here

Stage of competition and Scan Frequency

No statistical differences, nor substantial effect sizes were identified between the quarter-final, semi-final and final. Table 5 displays the estimated means ± SE for all the three stages of competition.

Insert Table 5 near here

Scan Frequency and Action Type

Results show scan frequency significantly predicted action type for dribble vs pass ($\beta = -3.68$, $z = -2.55$, $p = 0.011$), with a higher scan frequency associated with a decrease in the odds of choosing to dribble over pass. Higher scan frequencies were also associated with a significant decrease in the odds of choosing to shoot over pass, ($\beta = -2.36$, $z = -2.48$, $p = 0.013$). No relationship was observed for receiving vs pass ($\beta = -1.36$, $z = -1.81$, $p = 0.070$). The action type ‘pass’ was labelled as the reference category.

Scan Frequency and Action Result

A positive relationship was identified between scan frequency and action result indicating for every one-unit increase in scan frequency, the log odds of the result of the action with the ball being successful increase by 1.33, while keeping all other factors constant. Players demonstrated a higher scan frequency when possession was maintained ($M = 0.36 \pm 0.17$ scans/s) compared to when possession was lost after their action with the ball ($M = 0.32 \pm 0.18$ scans/s). The mixed effects binomial logistic regression model was statistically significant χ^2 (1) = 8.81, $p = 0.003$. An unsuccessful action ('0') was labelled as the reference category.

Scan Frequency and Pass Direction

Significant relationships were found between scan frequency and the direction of a pass. Results show scan frequency significantly predicted pass direction for forwards pass vs backwards pass, ($\beta = -0.85$, $z = -0.43$, $p = 0.049$), with a higher scan frequency associated with a decrease in the odds of performing a forward pass. No relationship was observed when comparing sideways vs backwards passes ($\beta = -1.07$, $z = -1.77$, $p = 0.077$). Higher scan frequencies were associated with a significant decrease in the likelihood of not performing a pass compared to performing a backwards pass, ($\beta = -2.59$, $z = -4.14$, $p < 0.001$). The pass direction 'backwards' was labelled as the reference category.

Scan Frequency and Pass Distance

Scan frequency was not found to have a significant effect on pass distance ($\beta = -0.30$, SE = 0.36, $p = 0.403$).

Scan Frequency and Body Orientation

A relationship was identified between scan frequency and body orientation. Higher scan frequencies were associated with a significant decrease in the likelihood of having a forward body orientation compared to a backwards body orientation, ($\beta = -1.63$, $z = -3.16$, $p =$ 0.002). No relationship was observed when comparing sideways vs backwards body orientation ($\beta = -0.84$, $z = -1.79$, $p = 0.073$). A 'backwards' body orientation labelled as the reference category.

Scan Frequency and Turn with the ball

A positive relationship was found between scan frequency and the probability of turning with the ball indicating for every one-unit increase in scan frequency, the log odds of performing a turn with the ball increase by 1.58, while keeping all other factors constant. Players exhibited a higher scan frequency when performing a turn with the ball ($M = 0.39 \pm 0.18$ scans/s) compared to when no turn with the ball was performed ($M = 0.35 \pm 0.17$ scans/s). The mixed effects binomial logistic regression model was statistically significant χ^2 (1) = 9.02, $p = 0.003$. No turn with the ball ('0') was labelled as the reference category.

Discussion

The purpose of this study was to describe the visual exploratory activity (VEA) of elite female central midfield players and understand the relationships between VEA, performance with the ball and specific contextual ("on or around the ball") and situational ("away from the ball") factors. Results showed that pitch location was a significant predictor of scan frequency where players performed a higher number of scans in central defensive midfield pitch locations compared to defensive midfield wide and attacking central or wide pitch locations. Additionally, scan frequency was found to be a significant predictor for a number of performance with the ball variables. Higher scan frequencies resulted in an increased likelihood of performing a successful action with the ball and performing a turn with the ball. VEA appears linked to a player's performance with the ball and seems to vary depending on contextual demands (i.e. pitch location).

The first aim of this study was to describe VEA in elite central midfield players across the knock-out stages of the UEFA Women's EURO 2022. Players performed on average 3-4 scans in the final 10 seconds before receiving the ball (scan frequency = 0.35 ± 0.17 scans/s). This average is lower than that of similar studies investigating VEA in elite male youth (0.42 scans/s in U17 and U19's; Aksum et al., 2021) and professional male soccer

(0.44 scans/s; Jordet et al., 2020) players. These differences in findings could be linked to the higher passing tempo in elite men's soccer compared to elite women's soccer (Mitrotasios et al., 2022), which could in turn influence the frequency and timing of how a player needs to scan their environment. For example, we might expect a relationship between a higher passing tempo and an increase in scan frequency, as a result of players being required to have a greater understanding of their environment due to the ball arriving at their feet quicker. Similarly, with a slower passing tempo, we may expect lower scan frequencies due to players potentially having more time and space to scan their environment and so may perform scans of a longer duration that are less frequent. Aksum et al. (2021) found U19 male soccer players conducted their final scans significantly closer to ball contact compared to U17 players. It was suggested that the increase in tempo demands of the U19 game may provide an explanation for this finding (Aksum et al., 2021). Therefore, it could be suggested that a slower passing tempo may lead players to scan their environment less frequently.

In line with previous work (e.g., Aksum et al., 2021), we measured scan frequency up to ten seconds prior to receiving the ball. To understand the timing of a 'final scan' before completing an action, we also measured the timing of scans in the final five seconds relative to a player receiving the ball. Data showed that scan frequency was highest in the final 1-2 seconds prior to receiving the ball. A potential explanation for this finding is that players may direct their attention away from the ball in the final two seconds before ball contact to receive the most up to date information from the environment to subsequently inform their actions with the ball (Aksum et al., 2021; McGuckian et al., 2018). Previous research in men's soccer has found players that perform more scans in the one and two seconds prior to receiving the ball were more likely to turn with the ball (McGuckian et al., 2018). Therefore, in the context of the current study, by performing scans closer to receiving the ball, central midfield players may become more attuned to dynamically evolving game situations to enable them to make the most appropriate action with the ball using the most relevant information (Aksum et al., 2021). Rather than players simply increasing scan frequency, there appears a need to understand where and when players should scan to inform coaching interventions.

In line with our hypotheses, results showed pitch location when receiving the ball to be a significant predictor of scan frequency. The highest scan frequencies were observed in defensive midfield central left and right locations, with findings also showing higher scan frequencies observed in defensive midfield wide locations, compared to attacking wide locations. These findings align with current literature on VEA in elite men's youth (Aksum et al., 2021) and adult male soccer (Jordet et al., 2020) which has found players scan more frequently in central pitch locations compared to peripheral pitch locations. Central midfield players are often required to drop deeper to collect the ball and so are required to have a greater awareness of their surroundings due to also being surrounded by teammates (Aksum et al., 2021; Jordet et al., 2020). More specifically, central midfield players may also be more inclined to perform a greater number of scans in defensive midfield central pitch locations due to the potentially detrimental consequences of losing possession (Jordet et al., 2020). This current finding can be further explained by research that has found the more successful women's teams appear to be highly centralised and interconnected, with suggestions that midfielders play a crucial role in performing a high volume of passes through central areas of the pitch (de Jong et al., 2022). Taken together, it seems players when receiving the ball in defensive central midfield positions scan their environment more frequently to identify multiple passing options, with this pitch location being particularly important for progressing play and starting attacks. Therefore, pitch location appears an important variable when understanding VEA in elite women's soccer.

Contrary to our hypotheses, no relationship was observed between opponent pressure and scan frequency. Findings revealed players appeared to perform more scans when experiencing less defensive pressure (i.e. when the distance to the nearest opponent was 7-9 metres away compared to 0-3 metres away), however only a small and non-significant effect was identified (0.04; small ES: 0.22 ± 0.12). Research has found central locations of the pitch tend to be highly congested, with playing spaces in the centre of the pitch observed to be wider than they are deeper, with suggestions that successful possession may be more likely to be maintained in wide, shallow areas of the pitch compared to central areas (Zubillaga et al., 2013). Previous research investigating VEA in youth men's soccer found significant differences between scan frequency and opponent pressure, with higher amounts of opponent pressure resulting in lower scan frequencies compared to when experiencing low amounts of opponent pressure (Aksum et al., 2021; Pokolm et al., 2022). The disparities in findings could be attributed to differences across age groups and playing positions being investigated (e.g. elite youth male defenders, midfielders, and attackers vs elite women's soccer central midfield players). Future research should aim to further investigate the influence of opponent pressure across different playing positions, as well as investigate a potential relationship between pitch location and opponent pressure.

No relationships were found between situational variables (state of the game, time in the game and stage of competition) and scan frequency. A possible explanation for this could be attributed to all matches being played in a major senior international tournament with all games being highly pressurised knock-out matches. Our data further suggests VEA is highly individualised and unique to each player with regards to how a player visually explores their environment. Previous research into visual search behaviours in men's soccer has emphasised the importance understanding individuals strengths and weaknesses relative to their own action capabilities as this may constraint one's ability to pick up the most important information during visually guided behaviours (Button et al., 2011). Future research should therefore consider analysing these factors not in isolation, but in the context of other variables to understand the influence these factors have on how a player scans their environment.

Scan frequency was a significant predictor of both action result and turn with the ball. Higher scan frequencies resulted in increased odds of performing a successful action with the ball and turning with the ball. Applied to the context of the current study, if a player has an enhanced understanding of their surroundings as a result of frequently exploring their environment, they may be more likely to perform a turn with the ball in order to identify potential empty space in an opposition's defensive structure. Research investigating possession tactics in UEFA Women's Euro 2022 (O'Donoghue & Beckley, 2023) found the most successful possessions were those of nine or more passes at a slower pass rate. These findings highlight the importance of well-constructed build-up play where possession is developed gradually resulting in more goal-scoring opportunities being created. In elite men's soccer, players scanned significantly more when possession was maintained (Jordet et al., 2020) and a higher likelihood of turning with the ball was identified with a higher exploration excursion and exploratory frequency (McGuckian et al., 2018). Therefore, with the current study finding a significant relationship between scan frequency and action result (i.e. higher scan frequencies resulting in players being more likely to maintain possession of the ball), this could have important implications for elite women's soccer.

Higher scan frequencies resulted in decreased odds of players choosing to dribble or shoot compared to pass. This aligns with research into elite men's soccer which has found a higher likelihood of players performing a pass compared to a shot, dribble or receiving (Jordet et al., 2020). Contradictory to our hypotheses, higher scan frequencies resulted in decreased odds of players performing a forward pass compared to a backwards pass and receiving the ball in a forward body orientation compared to a backwards orientation. This accumulation of evidence contradicts that of previous research into elite youth soccer which found higher scan frequencies have been associated with more forward passes compared to backwards passes (Eldridge et al., 2013) and research into elite youth soccer identifying higher scan frequencies resulted in more forwards and sideways body orientations compared to backwards (Aksum et al., 2021). A potential explanation for the differences in findings could be reflected by differences in developmental activities where literature has found elite women's soccer players may have spent less time in formalised training during early adolescence (e.g. academies) and so may have a lower 'training age' compared to elite male players (Ford et al., 2020). As a result, less time may have been spent developing specific technical and perceptual-cognitive skills, such as decision making and visual search (Pappalardo et al., 2021). Moreover, these contradictory findings can be further explained by research into the technical and tactical demands of elite male and women's soccer, which has found possession is lost more frequently, and passes are performed with less accuracy in elite women's soccer compared to elite men's soccer (Bradley et al., 2014; Garnica-Caparros & Memmert, 2021). Therefore, these differences in the technical and tactical demands of the game provide additional explanations for the differences in findings between the current study and that found in previous research in elite men's soccer. No relationship was identified between scan frequency and pass distance, with a potential reason for this being the combination of the study's random effects structure nesting players within fixtures as well as a considerably greater number of ball possessions analysed falling in the '0-14m' category compared to the '35m+' category (565 v 52) resulting in this analysis potentially being underpowered. Consolidating the above-mentioned findings, higher scan frequencies were associated with a high likelihood of players performing a pass over a shot, dribble or receiving as well as receiving the ball with a backwards body orientation and performing a backwards pass. This collection of evidence provides an initial insight into the relationships between VEA and a players performance with the ball.

Current findings can be interpreted through the lens of ecological psychology and Gibson's (1979) concept of affordances. Gibson's (1979) ecological approach to visual perception places an emphasis on the reciprocal nature of perception and action suggesting how the pickup of information from the environment is as an active process which involves the mobile body (see Fajen et al., 2009). Applied to the findings of the current study, if a player scans their environment more frequently, they may be more likely to see a greater number of opportunities for action (affordances), whilst having a better understanding of the positions of teammates and opposition players. Research has suggested that a player can turn their head frequently to perceive affordances in the playing environment, but their ability to act upon this information remains grounded in their own action capabilities (Fajen et al., 2009; Pocock et al., 2019). Therefore, from a theoretical perspective, our study reinforces the coupling of perception and action, with players appearing to support performance by visually exploring their environment immediately prior to engaging with the ball.

Based upon the study's findings we propose some practical implications. Our results revealed differences in VEA across pitch locations as well as VEA being related to a player's performance with the ball. It is recommended that coaches design practice activities where central midfield players are exposed to a high volume of passes being received in central defensive pitch locations with an emphasis on linking their visual exploratory activity to their subsequent actions with the ball. Coaches should further strive to provide players with active decision-making practices (e.g. small-sided or full sided game related practices) that involve modifications placed upon the game (Eldridge et al., 2023). This may allow for players to be exposed to frequently occurring in-game situations with sufficient contextual variation, for example receiving the ball under varying amounts of opponent pressure with different body orientations (Pokolm et al., 2022). Therefore, is strongly encouraged that practices are designed to promote the coupling of perception and action whilst taking into consideration the context and environment in which players visually explore their environment to support skilled performance. It is also worth highlighting how current findings have been compared and contrasted to that of VEA in elite and youth and men's soccer. Research has highlighted how professional women's soccer has been required to adapt to the rules and regulations of men's soccer, with evidence suggesting soccer may be more demanding for female players (Pedersen et al., 2019). Current findings shine a light on the challenges and difficulties of comparing men's and women's soccer and so it is imperative to design practice environments that are tailored specifically to women's soccer. For example, based upon the current study's findings, coaches should aim to design practice activities that encourage central midfield players to develop not just scan frequency, but also the timing of their scans relative to ball contact. When receiving the ball in central locations of the pitch coaches are encouraged to develop a player's ability to scan their environment in the final seconds prior to ball contact in order for players to identify the most up to date information from the environment.

The findings presented here should be considered in the context of some limitations. Firstly, the data presented is from one international tournament investigating central midfield players in isolation and so the results may not necessarily be representative of other populations and leagues. Secondly, the number of individual ball possessions analysed is relatively low (n = 1,038) in comparison to studies in men's soccer which were conducted in a similar vein (Pokolm et al., 2022; n = 5,338) and so findings must be interpreted and applied with caution. Also, as a result of achieving a moderate agreement for the variable 'lines broken', this variable was not included in any statistical modelling. In future research, one approach to improving the inter-rater reliability of the variable 'lines broken', is to conduct further video familiarisation. For example, to achieve greater consistency, both coders could be presented with numerous video examples of passes that broke and did not break an oppositions line of defence, and the coders would then justify their decisions whilst referring back to the operational definition. Whilst important to recognise these limitations, we provide a number of recommendations for how future research can address these limitations. Future investigations should aspire to further understand how both contextual and situational factors influence a player's VEA with a potentially fruitful avenue to explore VEA in the context of positional differences whilst coupling this to performance with the ball. Additionally, future work should investigate VEA in more in-situ and immersive environments which may provide an insight into understanding the type of practice activities that develop VEA. Recent advancements in technology have opened the door on participants being able to be surrounded with representative match scenarios in a 360-degree setting (see Honer et al., 2023; Musculus et al., 2021; Vater et al., 2019). Therefore, a logical next step appears to be to apply the study's findings in a more controlled setting by manipulating variables of interest (e.g., pitch location, opponent pressure, action type). By manipulating these variables in an immersive environment players could be presented with real life footage from an 11v11 match and are required to visually explore their environment and make decisions about their subsequent performance with the ball.

Conclusion

The primary objective of the study was to describe VEA in elite women's soccer as well as gain insight into the potential relationships that may exist between scan frequency and contextual, situational, and performance with the ball factors. The study found a significant relationship between pitch location and scan frequency as well as scan frequency being a significant predictor of both action result and turn with the ball. More specifically, higher scan frequencies were observed in central defensive midfield pitch locations, with players also more likely to perform a turn with the ball and perform a successful action with the ball (maintain possession) compared to an unsuccessful action (losing possession). When designing representative practice environments, pitch location seems an important variable to help further understand the contextual demands associated with how a player visually explores their environment to guide subsequent actions with the ball. Therefore, the study has established VEA is influenced by pitch location and related to performance with the ball in elite women's soccer. Future research is therefore required to extend and develop upon these findings across different age groups (e.g. women's youth soccer), playing positions (e.g. defenders, wide players, and forwards) and skill levels (e.g. semi-professional) as well as adopting more experimental research designs to further understand the influence of VEA on performance with the ball.

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Disclosure statement

Author ND is a current consultant for UEFA which enabled us access UEFA tactical footage. UEFA had no involvement in the production of the manuscript.

Data availability statement

All relevant data is available online from:

https://osf.io/2cnh7/?view_only=613db7aaada144e1abfefb648a0b272f

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Ethical approval

Ethical approval was obtained from the lead authors institution. Ethical approval number code: 2122_71

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Figure 1. *Hypothesised relationships between contextual ("on or around the ball"), situational ("off the ball"), performance with the ball factors and scan frequency. Each arrow represents a hypothesised relationship. Numbers denote references for each example: (1) Aksum et al. (2021); (2) Jordet et al. (2020); (3) Fernandes et al. (2020); (4) Eldridge et al. (2013); (5) Pokolm et al. (2022); (6) McGuckian et al. (2018).*

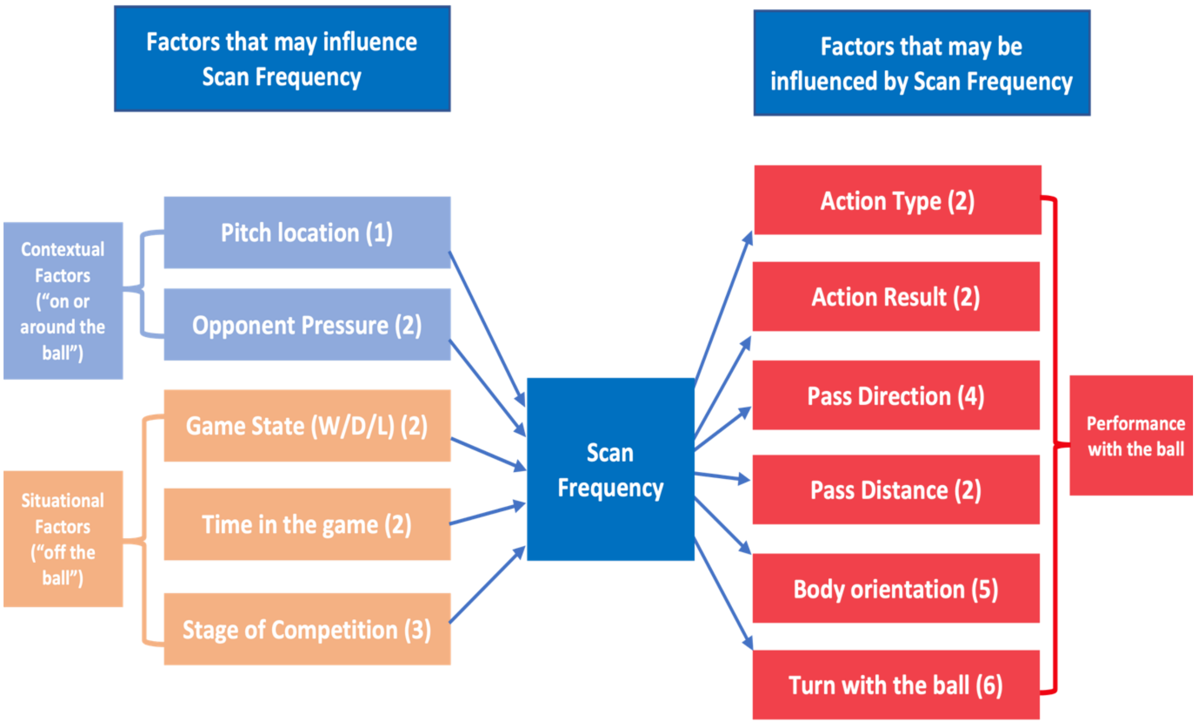

Table 1. *Instance Inclusion Criteria*

	Explanation
1	Visual explorations (scans) were measured in possession with all head movements that occurred in the final 10 seconds prior to receiving the ball from a teammate
2	If there was a turnover of possession in the final 10 seconds prior to analysed player receiving the ball from a teammate, analysis began the moment the analysed players team received control of the ball. For example, if the opposition team had control of the ball for 4 seconds and lost possession to the analysed players team, the analysis started at 6 seconds (the moment possession was won) and finished on the analysed players first touch of the ball.
3	In situations where the opposition team made contact with the ball, however, did not have the ball under control (e.g., duelling for the ball, clearing the ball or a deflected pass), it was deemed that the analysed players team had not lost possession in our analysis.
4	For set pieces (e.g., corner kicks, throw-ins, and free kicks) the 10 second interval for analysing visual explorations was kept consistent to enable the successful registering of scans. The minimum of 5 seconds and maximum of 10 seconds interval was maintained to ensure that there was consistency across all of instances analysed. As a result of pilot testing, central midfield players prior to the ball entering play from a set play (e.g., throw-in) were scanning their environment for information prior to receiving the ball. Therefore, by maintaining the 10 second interval the aim was to minimise the chance of excluding potentially important scans that may have informed the analysed players subsequent action with the ball.
5	In instances where the analysed player received a pass from a teammate, performed a pass to a teammate and then received the ball again within the 10 second interval (e.g., combination play), without the opposition gaining control of the ball, visual explorations were analysed throughout the entire 10 second interval and ended on the analysed players first touch of the ball.
6	The analysed players team were required to be in possession of the ball for a minimum of 5 seconds prior to the analysed player receiving the ball from a teammate (to provide sufficient time to analyse a player’s VEA and ensure all analysed players are performing VEA in attacking situations). Therefore, all instances were a minimum of 5 seconds and a maximum of 10 seconds in duration due to the analysed players team often gaining possession

	of the ball and the analysed player then receiving a pass from a teammate between 5-10 seconds of possession being won.

Table 2. *Intra-class corelations for number of scans (continuous variable)*.

	Inter-rater			Intra-rater		
Variable	ICC (95% CI)	*p*	Strength of Agreement	ICC (95% CI)	*p*	Strength of Agreement
Number of scans	0.899 (0.861-0.926)	<0.001	Excellent	0.912 (0.801-0.953)	<0.001	Excellent

Table 3. *Cohen's k for all categorical variables*.

	Inter-rater			Intra-rater		
Variable	Kappa (κ)	*p*	Strength of Agreement	Kappa (κ)	*p*	Strength of Agreement
Action Type	0.871	<0.001	Almost Perfect	0.939	<0.001	Almost Perfect
Pitch Location	0.935	<0.001	Almost Perfect	0.897	<0.001	Almost Perfect
Lines Broken	0.594	<0.001	Moderate	0.842	<0.001	Almost Perfect
Action Result	0.925	<0.001	Almost Perfect	0.980	<0.001	Almost Perfect
Pass Distance	0.855	<0.001	Almost Perfect	0.928	<0.001	Almost Perfect
Pass Direction	0.906	<0.001	Almost Perfect	0.933	<0.001	Almost Perfect
Turn with the ball	0.810	<0.001	Almost Perfect	0.846	<0.001	Almost Perfect
Opponent Pressure	0.818	<0.001	Almost Perfect	0.826	<0.001	Almost Perfect
Body Orientation	0.870	<0.001	Almost Perfect	0.900	<0.001	Almost Perfect

Figure 2. *Mean (± SE) scan frequency (scans/s) during the final five seconds prior to ball contact.*

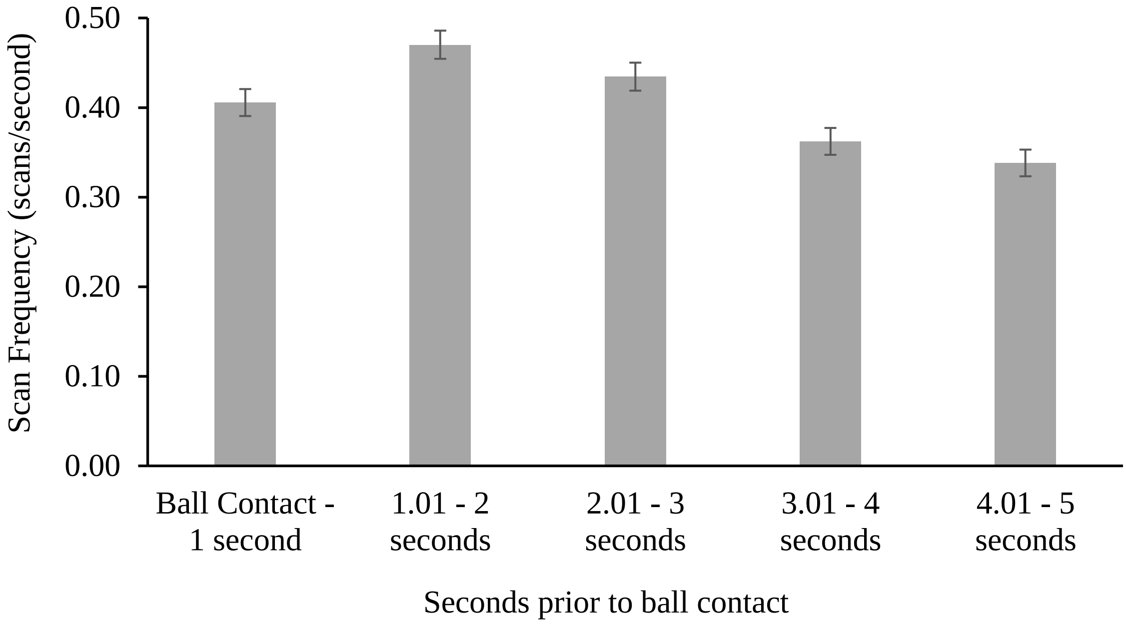

Table 4. *Mean Scan frequency and number of instances for all analysed variables.*

Variable (s)	Scan Frequency (scans/s) M (*SD*)	Number of Instances *n*
Contextual Factors		
Opponent Pressure		
0-3 m	0.34 (*0.17*)	645
4-6 m	0.37 (*0.18*)	295
7-9 m	0.40 (*0.18*)	82
10-32 m	0.39 (*0.27*)	16
Situational Factors		
Game State		
Winning	0.35 (*0.15*)	159
Drawing	0.36 (*0.17*)	693
Losing	0.31 (*0.17*)	186
Time in the game		
0-15 min	0.37 (*0.15*)	184
16-30 min	0.37 (*0.17*)	138
31-45 min	0.35 (*0.17*)	142
45-60 min	0.37 (*0.18*)	162
61-75 min	0.35 (*0.17*)	154
76-90 min	0.33 (*0.20*)	141
90-105 min	0.31 (*0.16*)	68
105-120 min	0.29 (*0.15*)	49
Stage of competition		
Quarter Final	0.36 (*0.17*)	616
Semi Final	0.35 (*0.17*)	277
Final	0.34 (*0.18*)	145
Performance with the ball		
Action Type		
Pass	0.36 (*0.17*)	904
Shot	0.29 (*0.16*)	44
Dribble	0.26 (*0.18*)	20
Receiving	0.32 (*0.18*)	70
Action Result		
Successful	0.36 (*0.17*)	776
Unsuccessful	0.32 (*0.18*)	262
Pass Direction		
Backwards	0.38 (*0.16*)	326
Sideways	0.35 (*0.18*)	135
Forwards	0.35 (*0.17*)	443
No Pass	0.30 (*0.17*)	134
Pass Distance		
0-14 m	0.35 (*0.17*)	565
15-34 m	0.37 (*0.17*)	287
35 m +	0.38 (*0.19*)	52

No Pass	0.30 (*0.17*)	134
Body Orientation		
Backwards	0.38 (*0.17*)	243
Sideways	0.33 (*0.17*)	477
Forwards	0.35 (*0.18*)	318
Turn with the ball		
Turn with the ball	0.39 (*0.18*)	148
No turn with the ball	0.35 (*0.17*)	890

Figure 3. *Mean scan frequency (scans/second) presented in 12 pitch locations (attacking direction from left to right) with standard deviation values and the number of instances (n). Note. Only pitch location zones with a minimum of 5 instances included in the figure. In all defensive zones* $n < 5$.

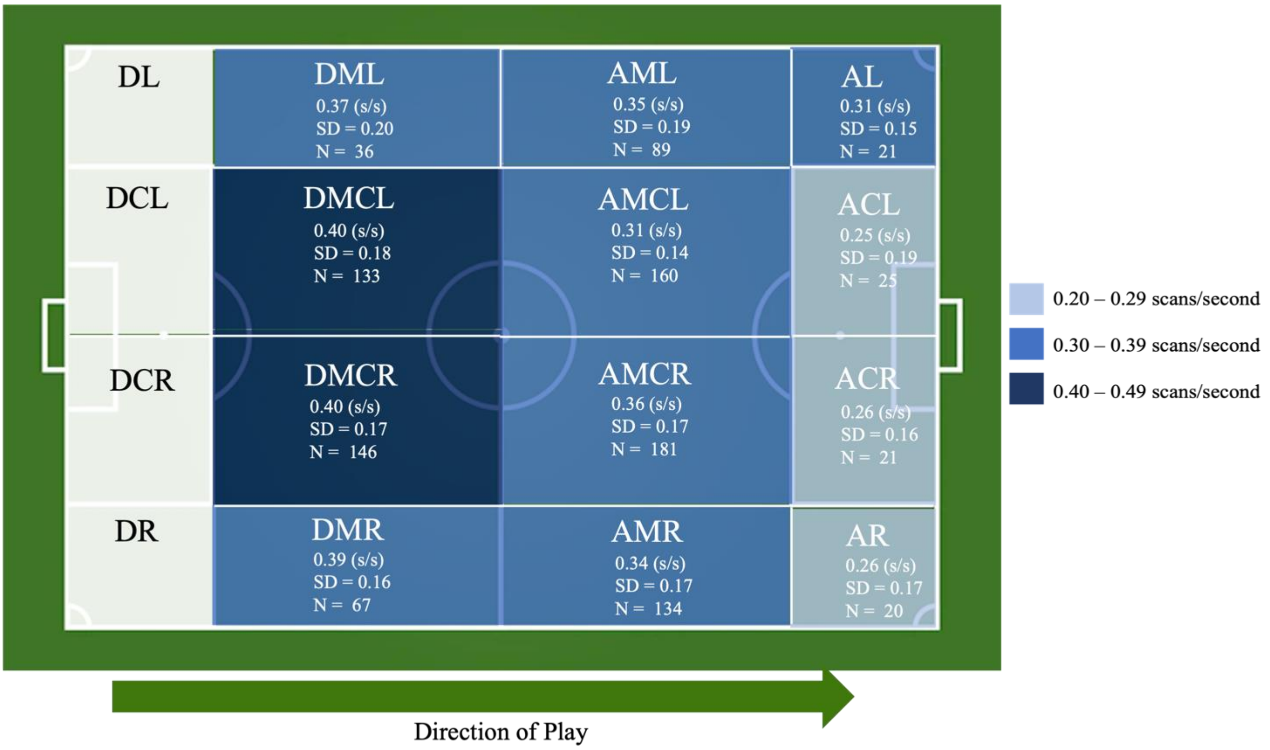

Figure 4. *Effect Sizes for differences in estimated mean and statistical significance for pitch location. Statistical difference (p < 0.05*, p < 0.001**).*

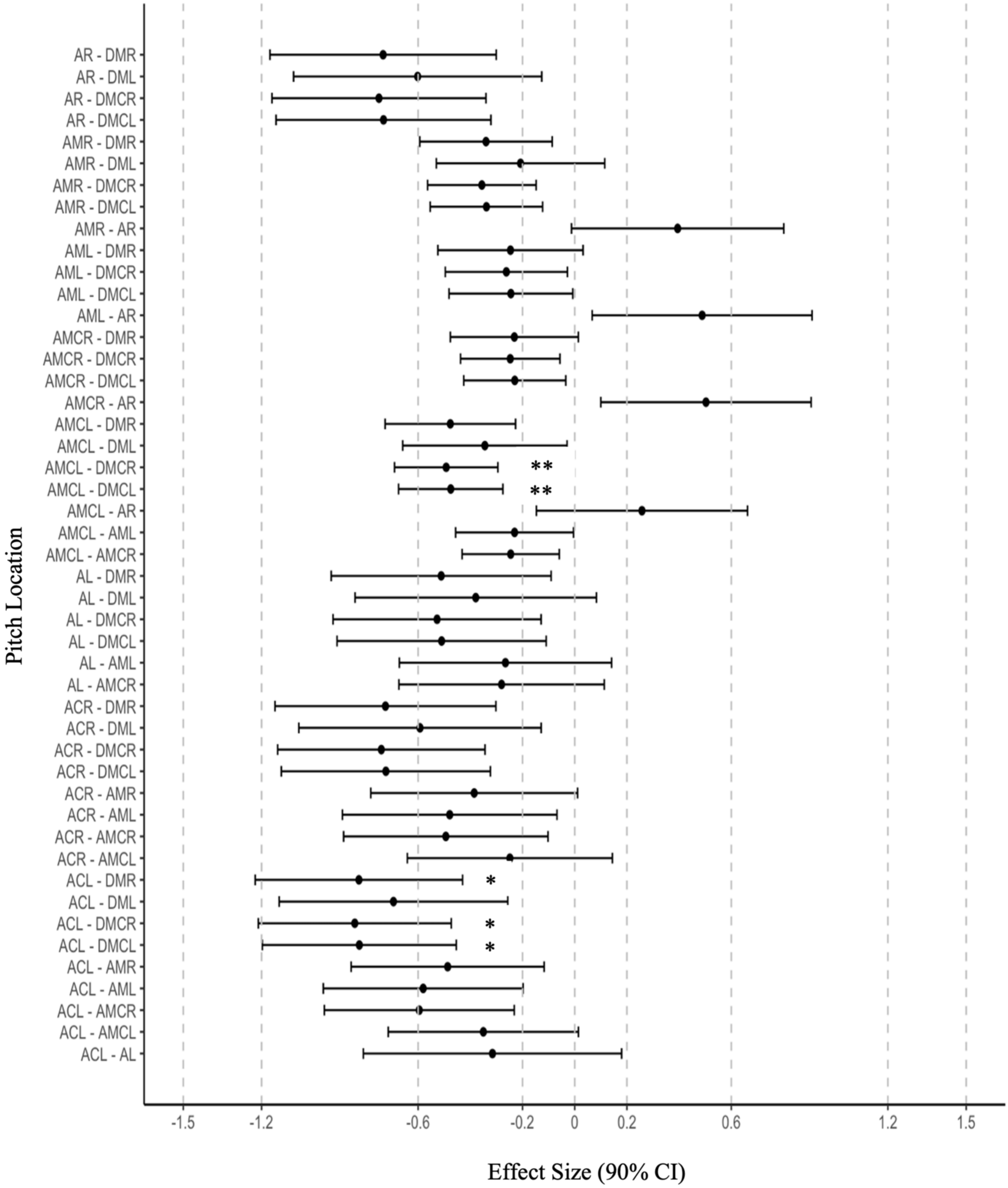

Table 5. *Estimated means ± SE for Scan Frequency for all contextual ("on or around the ball") and situational ("off the ball") factors.*

Variable (s)	Scan Frequency (scans/s) Estimated Means (*SE*)
Contextual Factors	
Pitch Location	
Defensive Right (DR)	0.26 (*0.17*)
Defensive Centre Left (DCL)	0.41 (*0.12*)
Defensive Left (DL)	0.26 (0.12)
Defensive Midfield Right (DMR)	0.39 (*0.02*)
Defensive Midfield Centre Right (DMCR)	0.39 (*0.02*)
Defensive Midfield Centre Left (DMCL)	0.39 (*0.02*)
Defensive Midfield Left (DML)	0.37 (*0.03*)
Attacking Midfield Right (AMR)	0.34 (*0.02*)
Attacking Midfield Centre Right (AMCR)	0.35 (*0.02*)
Attacking Midfield Centre Left (AMCL)	0.31 (*0.02*)
Attacking Midfield Left (AML)	0.35 (*0.02*)
Attacking Right (AR)	0.27 (*0.04*)
Attacking Centre Right (ACR)	0.27 (*0.04*)
Attacking Centre Left (ACL)	0.26 (*0.04*)
Attacking Left (AL)	0.31 (*0.04*)
Opponent Pressure	
0-3 m	0.31 (*0.02*)
4-6 m	0.33 (*0.02*)
7-9 m	0.35 *(0.03*)
10-32 m	0.34 (*0.04*)
Situational Factors	
Game State	
Winning	0.33 (*0.03*)
Drawing	0.34 (*0.02*)
Losing	0.31 (*0.02*)
Time in the game	
0-15 min	0.34 (*0.02*)
16-30 min	0.35 (*0.03*)
31-45 min	0.33 (*0.02*)
45-60 min	0.35 (*0.02*)
61-75 min	0.34 (*0.02*)
76-90 min	0.32 (*0.02*)
90-105 min	0.30 (*0.03*)
105-120 min	0.32 (*0.03*)
Stage of Competition	
Quarter Final	0.34 (*0.02*)
Semi Final	0.33 (*0.02*)
Final	0.32 (*0.03*)