European Journal of Human Movement

OPEN ACCESS

Original Research

Gaze behaviour differentiates elite from non-elite female soccer players: a 2D video projections exploratory study

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Received: 28/09/2022; Accepted: 08/11/2022; Published: 31/12/2022

Abstract: The present study explored visual strategies employed by female soccer players of high, medium, and low levels of expertise. We used eye-tracking technology to examine how skill-based differences related to gaze behavior in 30 participants (10 in each group) who were required to respond physically to film images projected on a screen using soccer skills (penalty kick, dribbling, pass reception, and defensive cover). Data were collected from search rate (visual fixations duration and number, and number of fixated areas), percentage of viewing time, and variability of pupil diameter. Analyses revealed that female elite players engaged in more visual fixations, directed gaze toward more relevant areas of the scene, and showed less variability of pupil diameter, compared to their non-elite counterparts. Our findings seem to corroborate prior research which compared participants with different levels of expertise while performing soccer skills.

Keywords: visual search; visual perception; motor control; motor skill; football; women

1. Introduction

Team sports offer a unique dynamic context in which perception and action can be studied. There has been a recrudescent interest in measuring eye movements and assessing visual search behavior in skilled and non-skilled athletes (Dicks et al., 2010; Mann et al., 2019; Moran et al., 2019; Vater et al., 2020; Williams & Ericsson, 2005), especially in soccer (Cardoso et al. 2019; Paillard & Noe, 2006; Roca et al., 2011, 2013; Savelsbergh et al., 2002; 2005; Williams & Davids, 1998; Williams et al., 1994; Wood & Wilson, 2010; Woolley et al., 2015). As soccer players move in the field, they need to gather information from the ball, teammates, and opponents. Thus, where and when they look is crucial for performance. Skilled soccer players are known to adopt certain visual search behaviors that allow them to analyze the surrounding scene efficiently. However, in situ field studies are challenging to conduct (see Aksum et al., 2020). Constant dynamic changes during the game make it harder to compare how players with different levels of experience respond to specific situations. Film-based paradigms, on the other hand, due to their consistent scene repeatability, allow for direct comparisons between players with different skill levels and can offer an initial platform for exploratory studies, although film-based studies are limited in their external validity (Williams & Ericsson, 2005).

Skilled soccer players have consistently shown superior performance than non-skilled ones regarding the use of relevant information and predictive cues about the opponents to guide their motor responses (Abernethy et al., 2001; Casanova et al., 2009; Rodrigues et al., 1999; Williams & Burwitz, 1993; Williams & Davids, 1998; Williams et al., 1993; Vater et al., 2020; Williams & Ericsson, 2005). Particularly, research using eye-tracking technology has helped identifying direct implications with regard to skill-based differences between visual fixation and attention (i.e., in anticipating a pass) (Roca et al., 2013; Ward et al., 2002; Williams & Davids, 1998; Williams & Ericson, 2005). These findings demonstrated that soccer players are not only capable of "looking" but also "seeing", and therefore exhibiting more efficient behaviors by casting fewer, yet longer visual fixations at more informatively relevant areas of the scene (i.e., skilled players can deal with visual information loss). Acquiring quality information in a single fixation while picking up relevant information through foveal and peripheral vision might be critical to allow time to analyze the stimuli (e.g., a moving ball and/or opponents). Such skilled visual behavior contributes to perceiving and acting earlier (anticipation) via an efficient use of long-term knowledge. As a result, more accurate expectations can be established about upcoming movements of the opponent (pattern recognition) (Abernethy et al., 2001; Moran et al., 2002; Roca et al., 2013; Vater et al., 2020; Ward et al., 2007; Williams et al., 1993, 1994, 2004). Another relevant measure that has been pointed out as a valid and reliable index of attentional effort is pupil diameter variability (Moran & Toner, 2017; Moran et al., 2016, 2019). Specifically, more dilated pupils represent increased mental effort allocated by the individual as indicated by neurophysiological correlates (Alnæs et al., 2014). Sport performance has also been related to pupillometry as skill-based differences were identified in attentional effort (Campbell et al., 2019; Moran et al., 2016, 2019; O'Shea & Moran, 2016, 2018).

There seems to be no evidence showing that gaze behaviors of female athletes differ from males (Chen et al., 2021; Van Maarseveen et al., 2018), however, research on gaze behaviour in female soccer players is lacking. The purpose of this study is not to highlight gender differences; in fact, this paper does not include male participants to compare them to female ones. Rather, the goal of this study is to focus on female participants in soccer skills to explore how their skill-based levels relate to gaze behaviors. For this exploratory study, we used a more controlled laboratory film-based (2D video) paradigm similar to the ones used by Williams & Davids (1998) and Williams et al. (1994), and we focused on the number, duration and location of fixations, the percentage of time spent viewing each fixation area by locations, and the pupillary response which have been shown to change between professional, varsity, and novice players in a number of settings, such as performing a penalty kick against a stationary and a moving goalkeeper, dribbling, pass reception, and defensive cover. In line with previous soccer studies (Cardoso & Costa, 2013; Cardoso et al., 2019; Casanova et al., 2009; Roca et al., 2011; 2013; Savelsbergh et al., 2002, 2005; Van Maarseveen et al., 2018; Williams & Burwitz, 1993; Williams & Davids, 1998; Williams et al., 1993; 1994; Wood & Wilson, 2010), our expectation was that elite female soccer players (professionals) would demonstrate superior gaze behavior strategies (e.g. fewer but longer visual fixations at more informatively relevant areas of the scene and less dilated pupils) than their non-elite counterparts.

2. Materials and Methods

Participants

Our purposive sample comprised 30 Brazilian female volunteers (mean age = 21.16, SD = 3.03 years): 10 professional soccer players from a leading team of the Country's Major League (mean age = 24.8, SD = 4.13 years), who self-reported an average regular practice in soccer of 11.34 (SD = 2.73) years and 600 minutes of training time per week, 10 varsity soccer players (mean age = 20.7, SD = 1.63 years), who self-reported average regular practice in soccer of 6.09 (SD = 2.30) years a maximum of 180 minutes of training time per week, and 10 novices (mean age = 20.7, SD = 2.21 years) with average self-reported regular practice in soccer of 0.65 (SD = 0.39) years taken only sporadically in leisure time or in Physical Education classes. These criteria to classify participants with respect to level of expertise was used in several previous studies (Roca et al., 2013; Savelsbergh et al., 2002, 2005; Van Maarseveen et al., 2018; Williams & Davids, 1998; Williams et al., 1994; Wood & Wilson, 2010). Participants read and signed an informed consent form prior to taking part in the study, which was approved by the research ethics committee (School of Arts, Sciences, and Humanities, University of Sao Paulo, CAAE 48919015.9.0000.5390). All procedures of the study complied with the Helsinki Declaration.

Apparatus

Data were recorded with a head-mounted eye-tracker (Mobile Eye XG, Applied Science Laboratories®), which is a video-based monocular system that measures the eye line-of-gaze using a spectacle-mounted unit (eye and scene camera mounted to a safety glasses style assembly), a small display-transmit unit (see Figure 1), and a notebook for processing data. The system's software incorporates a circular cursor, ranging 0.5 to 1° of visual angle.

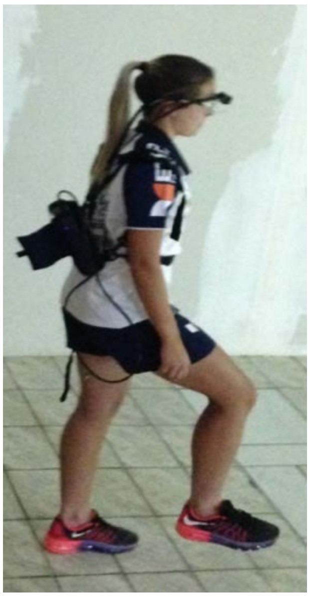

Figure 1. A participant performing one of the tasks wearing the equipment.

The eye camera records the pupil while the scene camera records the environment. The eye camera tracks the reflection of the pupil from a hot mirror, which is reflective in the near infrared spectrum, but transparent in the visible spectrum (the participant's view is not obscured). The system operates within a safe range of infrared illumination (Applied Science Laboratories, 2014). The scene camera is aimed directly forward and the eye/scene data are updated at 60 Hz.

Calibration and film clips

Before testing, the system is calibrated to verify point-of-gaze, adjusting to the participant's eye (position of the eye image, eye alignment, adjustment of the corneal reflection detection, adjustment of the pupil detection) and scene (position and calibration of the scene image). To compute visual point-of-gaze, the image in Figure 2 was projected (Sony® VPL-DX140 projector) onto a white screen (3m x 3.7m) positioned 4.6m from the participants (visual angle = 21.9°). Participants were instructed to look at five pre-calibrated points on the image: the ball, the goalkeeper's chest, the upper portion of the goalpost (above the goalkeeper's head), the right side of the goalpost (following the goalkeeper's left hand), and the left side of the goalpost (following the goalkeeper's right hand). The points of gaze where the participants were directing their visual attention appeared superimposed onto the scene in the form of a positional cursor such that direction of attention could be monitored. These calibration points were recorded and saved on file for subsequent analyses.

A digital video camera (Sony® Full HD XR120) was used to generate video film clips of the test target actions from a female player's perspective (first person).

Figure 2. Penalty kick against a stationary goalkeeper.

Figure 3. Penalty kick against a moving goalkeeper.

Figure 4. Dribbling.

Figure 5. Pass reception.

Figure 6. Defensive cover.

Design and procedures

We used a cross-sectional design. The experiment was run in a room with the lights off; luminosity was measured with a digital luxmeter (Tecman® TM830M) and ranged from 17 to 22 luxes. After having read and signed the informed consent and the personal information forms, the participants wore the spectacles and the small backpack containing the display-transmit unit, which was wirelessly connected to the notebook. Then, calibration was performed, and verbal instructions were given to the participants about the scenes. The film clips were projected onto the same wide screen used for calibration, thereby closely simulating the real image size and distance between the players and opponent(s). Participants did not watch any scene before the beginning of the experiment and were instructed to perform naturally in response to the projected scenes as if they were in a real soccer game.

These test films were produced in an official soccer field with the same three varsity soccer players performing the five skills. The first scene was the penalty kick against a stationary goalkeeper located in the middle of the goal line (Figure 2). As shown in Figure 3, the second scene represented the penalty kick against a goalkeeper moving sideways on the goal line. To perform the penalty kicks against the projected goalkeeper, the participant ran towards the image and ceased the movement as soon as her foot touched the screen at the point of the penalty mark. The third scene depicted dribbling an opponent, as observed in Figure 4; the whole dribbling test film omitted (spatial occlusion paradigm) the upper regions of the opponent's body (from the hip upwards). In the fourth scene (Figure 5), responding to the video of a ball coming from a teammate pass, the player performed the movement of a pass reception, trying to cushion the projected ball with the dominant foot after receiving a low pass from a teammate. The scene illustrated in Figure 6 was the defensive cover, the participant had to respond to the projected video as a spare defender providing support to a teammate who was going over an attack player. We chose these skills on the basis of their technical and tactical importance, the underlying processes of attention, anticipation, and decision-making which are involved in their performance, and their significance for winning a match (Canal-Bruland, 2009; Furley et al., 2017; Natsuhara et al., 2020).

Two penalty kick film clips were included because the visual pattern of the kicker can vary depending on the activity of the goalkeeper; it is known that more penalties are saved on trials when the goalkeeper is moving (Wood & Wilson, 2010). The durations of the video clips were 5s, 7s, 3s, 7s, and 4s, from scene 1 to 5, respectively.

Once the participants stated that the instructions were clear and indicated that they were ready, they were positioned behind a starting line facing the projection screen, the eye-tracking record button was triggered, the playback of the video was run, and the participant responded physically to the film (as explained above).

Each of the video clips was presented in a sequence from 1 to 5, three consecutive times. During the video presentations, participants were allowed to move freely. Trials in which the participant made sudden jerks of the head were ignored and replaced by a new trial. Due to blinks or relevant head movements (missing data) during a trial, we chose from the three trials of each skill the one with less missing data for gaze analysis. Feedback was not provided in any of the trials.

Dependent variables

The eye and scene images were recorded with a resolution of 640 x 480 pixels. From the gaze overlaid on the video recordings, we extracted the following dependent variables:

1. Search rate: a) number of visual fixations – the amount of visual fixations per trial; b) number of areas fixated – the amount of areas of interest (AOIs) fixated per trial (AOIs were defined based on task relevance in each trial); c) fixation duration – the time spent making single fixations per trial.
2. Percentage viewing time – the amount of time participants spent fixating each of the areas of interest (AOIs) on the scene on each trial. If the fixation was not in one of these AOIs, it was classified as out of a defined area (OUT).
3. Pupillary response (pupil diameter variability) – single subtraction: the highest value of pupil diameter (in pixels) in relation to the smaller pupil diameter on the trial (baseline).

The number of visual fixations, the number of areas fixated, and the fixation duration were calculated with the assumption that a fixation is the period of time when the eye remained stationary within a 1.5° (visual angle) of movement tolerance for a period equal to, or greater than, 100 ms (Applied Science Laboratories, 2014). The following areas of interest were chosen for analysis: penalty kicks – ball, goalkeeper, goal, outer areas; dribbling – ball, opponent's feet, outer areas; pass reception – ball, teammate, outer areas; defensive cover – ball, opponent, outer areas. Fixations were analyzed before the kicks and pass reception were produced, during the movement for dribbling and defensive coverage, and before the pass reception.

Statistical analysis

The data were analyzed through the ASL Results software® and then exported to electronic spreadsheets. Each dependent variable regarding search rate and pupillary response was analyzed separately, considering the five skills, by means of a multivariate analyses of variance (MANOVA) with "group" as the between-participants factor (professionals x varsity x novices). Box's Tests were run to check for violation of the equality of covariance matrices assumption. When appropriate, F-ratios were reported with the degrees of freedom adjustments. Partial eta-squared values (partial η^2) were also reported to indicate effect sizes for significant results. Follow-up testing was conducted using Sidak post hoc procedures. Percentage viewing time was submitted to descriptive and non-parametric analyses, a Kruskal-Wallis (ANOVA by Ranks) followed by the Chi-Square H test (because there were more than five subjects in each group), to identify whether group differences existed for time spent fixating each area of interest. The software of analysis (ASL Results) allows a frame-by-frame tracking of each AOI (ball, opponent, goal). For all analyses, alpha was set at .05.

3. Results

Means and standard deviations for the search rate variables (number of visual fixations, the number of AOIs fixated, and fixation durations) are shown in Table 1. Box's Test indicated the no violation of the Equality of Covariance Matrices assumption (MBox = 48.60, $p = 0.238$), hence we considered Roy's Largest Root, which detected a significant effect for "group", $F(5,24) = 3.08$, $p = 0.027$, partial $\eta^2 = 0.39$, regarding the number of fixations. Sidak post hoc procedure showed that the professional players engaged in more fixations than (a) the novices for the penalty kick with non-moving goalkeeper, and the defensive cover and (b) the varsity players for the pass reception. There were no significant differences between the professionals, varsity and novices for fixation durations, $F(10,44) = 0.19$, $p = 0.99$, partial $\eta^2 = 0.04$, and for the number of AOIs fixated per trial, $F(10,44) = 1.17$, $p = 0.34$, partial $\eta^2 = 0.21$.

While performing the kick with a stationary goalkeeper (Figure 7), the three groups spent almost the same amount of time looking at the goalkeeper [χ^2 (2) = 2.84, $p = 0.24$]. Rather, when the goalkeeper was moving (Figure 8), novices spent less time looking at the opponent [χ^2 (2) = 6.55, $p = 0.04$] and, despite the lack of statistical differences, the varsity and novices spent a larger time fixating the outer areas. Even though descriptive differences can be seen in Figure 9 in the dribbling, no significant effect was detected by the analyses [χ^2 (2) = 0.92, $p = 0.63$]. Regarding pass reception (Figure 10), all participants spent less time gazing at the teammate [χ^2 (2) = 18.42, $p < 0.001$] and about half of their time looking at the ball. All participants looked less at the opponent when performing the defensive cover, [χ^2 (2) = 5.89, $p = 0.05$], while novices and varsity players tended to pay more attention to the outer areas (more than half of the time), as demonstrated in Figure 11.

Means and standard deviations for the pupillary response are presented in Table 2. Box's Test indicated the violation of the Equality of Covariance Matrices assumption (MBox=102.11, $p = 0.0001$), hence Hotellings-Trace F-ratio was used. There were significant differences between groups, $F(10,44) = 3.48$, $p = 0.002$, partial $\eta^2 = 0.44$, with Sidak post hoc procedure showing for most conditions (a) lower pupil variability values for the professional players compared to novices (p = 0.04), except for pass reception, and (b) lower pupil variability for the varsity players in comparison to the novices when performing the kick against a moving goalkeeper (p = 0.003).

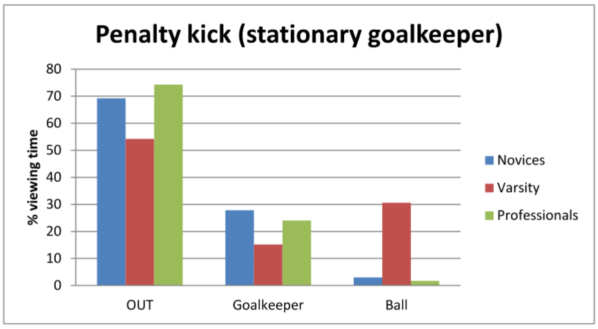

Figure 7. The percentage of time spent viewing each fixation location across groups to kick the penalty against a stationary goalkeeper as a function of locations.

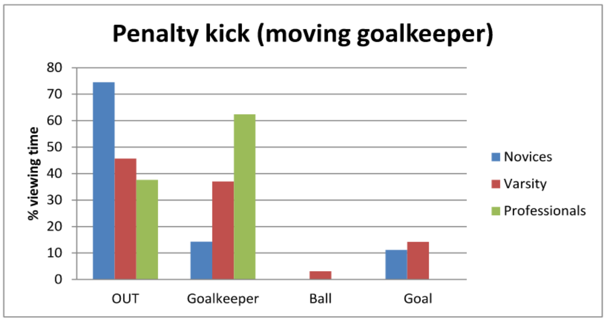

Figure 8. The percentage of time spent viewing each fixation location across groups to kick the penalty against a moving goalkeeper as a function of locations.

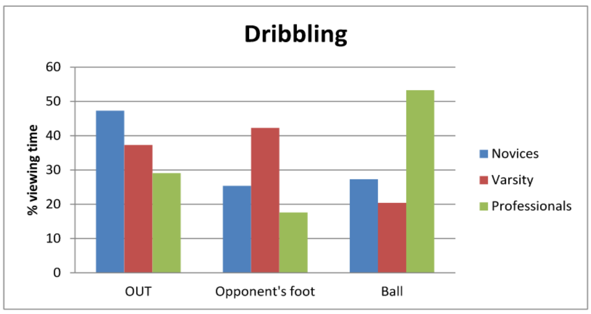

Figure 9. The percentage of time spent viewing each fixation location across groups while dribbling as a function of locations.

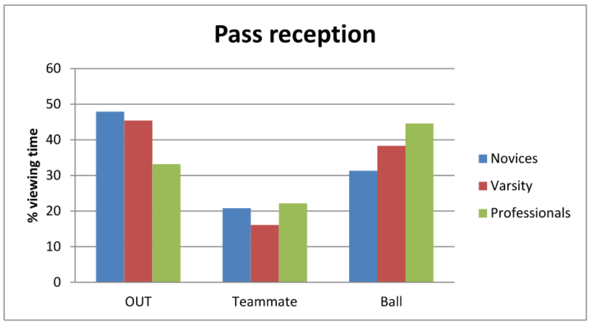

Figure 10. The percentage of time spent viewing each fixation location across groups to receive a low pass as a function of locations.

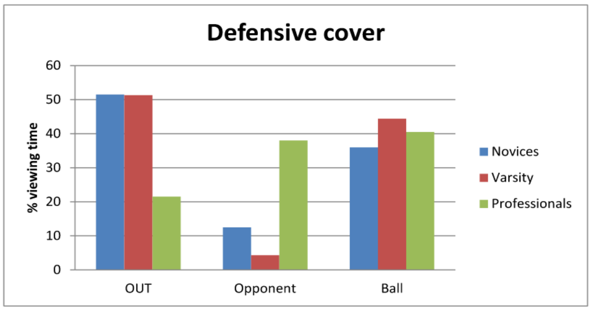

Figure 11. The percentage of time spent viewing each fixation.

4. Discussion

This study aimed to explore gaze behaviour strategies of female individuals with distinct skill levels in soccer skills. Specifically, we compared within a film-based (2D video) paradigm the number, the duration and the location of visual fixations, the percentage of time spent viewing each fixation area by locations, and the pupillary response in professional, varsity, and novice players in the penalty kick against a stationary and a moving goalkeeper, the dribbling, the pass reception, and the defensive cover. The findings partially corroborated the expectation according to which elite players would show more efficient gaze behaviour than their less experienced counterparts. The percentage of time spent viewing each fixation area by locations and the pupillary response showed that the elite players demonstrated more efficient visual strategies than the less skilled players, that is, professional soccer athletes tended to show less variability in pupil diameter and direct gaze toward relevant areas of the scene (despite non-defined areas between two relevant AOI can be used by football players as visual pivots from where they can obtain information from AOI through peripheral vision). In turn, non-elite soccer players tended to direct gaze toward irrelevant areas of the scene and show more variability in pupil diameter. With respect to the visual search rate, the experts engaged in more fixations than their less skilled counterparts, whereas no group-differences were detected in the duration of fixations. We will further address each group of variables below.

Table 1. Search rate variables across groups (mean - M and standard deviation - SD).

Variable	Novices		Varsity		Professional	
	M	*SD*	*M*	*SD*	*M*	*SD*
Penalty kick (stationary goalkeeper)						
Fixation durations (s)	0.236	0.096	0.213	0.096	0.237	0.119
Number of AOIs fixated	1.300	0.483	1.600	0.516	1.600	0.516
Number of fixations #	2.000	0.942	2.900	1.852	4.100	2.282
Penalty kick (moving goalkeeper)						
Fixation durations (s)	0.217	0.087	0.197	0.081	0.184	0.040
Number of AOIs fixated	1.300	0.483	1.500	0.527	1.800	0.421
Number of fixations	3.000	2.581	4.100	2.806	5.000	1.825
Dribbling						
Fixation durations (s)	0.315	0.109	0.332	0.152	0.327	0.145
Number of AOIs fixated	1.900	0.567	2.000	0.666	2.300	0.674
Number of fixations	4.800	2.936	5.100	2.766	6.500	2.549
Pass reception						
Fixation durations (s)	0.599	0.228	0.548	0.127	0.570	0.073
Number of AOIs fixated	2.700	0.674	2.800	0.421	3.000	0.226
Number of fixations ^	18.100	4.094	15.500	6.004	22.700	7.196
Defensive cover						
Fixation durations (s)	0.434	0.210	0.391	0.201	0.437	0.090
Number of AOIs fixated	2.000	0.816	2.100	0.875	2.700	0.483
Number of fixations #	5.600	3.098	7.100	2.469	10.300	4.137

Note. #$p<0.05$ Novices x Professionals; ^$p<0.05$ Varsity x Professionals.

Table 2. Pupil diameter variability in pixels across groups (mean - M and standard deviation - SD).

Variable	Novices		Varsity		Professionals	
	M	*SD*	*M*	*SD*	*M*	*SD*
Penalty kick (stationary goalkeeper)*#	29.33	7.46	24.48	10.05	15.81	5.02
Penalty kick (moving goalkeeper)#	26.70	11.76	14.38	2.56	11.22	3.16
Dribbling#	27.71	11.67	19.38	6.36	15.65	3.56
Pass reception	19.84	9.72	21.12	9.79	12.40	3.65
Defensive cover#	28.18	15.39	23.17	6.56	16.74	3.50

Note. *$p<0.05$ Novices x Varsity; #$p<0.05$ Novices x Professionals.

Although the number of fixated areas and the fixation durations had been similar for all participants, the professional players engaged in more visual fixations when compared to novices and varsity players, particularly for the penalty kick with a non-moving goalkeeper, defensive cover, and pass reception. Thus, these findings did not corroborate our expectation that elite female soccer players (professionals) would demonstrate superior gaze behavior strategies than their non-elite counterparts. Research on the amount of visual information that soccer players gather in film-based studies (Cardoso & Costa, 2013; Cardoso et al., 2019; Roca et al., 2011; 2013; Savelsbergh et al., 2002, 2005; Van Maarseveen et al., 2018; Williams & Burwitz, 1993; Williams & Davids, 1998; Williams et al., 1993; 1994; Wood & Wilson, 2010) has shown disparities which has been attributed to the nature and type of the task presented to participants as well as the experimental instructions given prior to testing (Casanova et al., 2009; Williams et al., 2005). In spite of this discrepancy, we subscribe to the argument that higher search rates are more likely to occur when there are a number of stimuli on the display compared to scene contexts containing limited information (Vater et al., 2020; Williams & Davids, 1998; Williams et al., 2005). Our experimental tasks were more like the latter type. In such more limited contexts, perceptual skills involve "anchoring" the visual system on the areas of the scene that are the most informative (cue redundancy) and ignoring the areas of low information content. Our professional participants did cast more visual fixations to those relevant areas as a demonstration that they seemed to know where to look on the scenes displayed.

More than the amount of information attended, our results revealed between-group differences with regard to the nature of information, as indicated by the percentages of viewing time and variability of pupil diameter. When performing the penalty kick, elite players directed their gaze to the moving goalkeeper more than non-elite ones, who seemed to direct visual attention to irrelevant areas of the scene. The visual attention to kick a penalty against a moving goalkeeper is assumed to be stimulus-driven and, consequently, experienced players are more skilled to shift attention without losing input information in addition to "anchoring" the visual system to the relevant areas of the scene (Paillard & Noe, 2006; Van Maarseveen et al., 2018; Vater et al., 2020; Williams et al., 1994, 2005). This finding corroborates previous research conducted in goalkeepers (Savelsbergh et al., 2002, 2005; Wood & Wilson, 2010) and appears to allow subtle on-line adaptations within the scope of the available constraints (e.g., to make changes in the direction of the kick).

Regarding dribbling, despite the lack of significant statistical effects, the descriptive data allow us to establish hypotheses to be investigated in upcoming studies: non-elite soccer players looked proportionately more at the irrelevant areas of the scene compared to elite counterparts; professionals demonstrated a trend to fixate on the ball, whereas the varsity players preferred gazing at the opponent's feet. In one-to-one situations like dribbling, players need highly precise information from motion invariants from the opponent's hip and lower leg-ball regions joint angles to tune direction, speed and force, information that is poorly picked up by the peripheral visual system and is mainly obtained by foveal vision (Williams et al., 2005). As our dribbling test film spatially omitted these upper regions of the opponent's body (limitation to be addressed in future investigations), it can be argued that the professionals "anchored" their foveal vision onto the ball to pick up cues on the opponent's leg more quickly with their peripheral vision. Another speculative explanation to this finding is that experts direct their gaze to key areas of the scene perceived as many events as possible during one single eye fixation, whereas novices may gaze at single and successive events as they appear on the scene (Millner & Goodale, 1995; Ripoll, 1991). When receiving the ball after a low pass from a teammate, all players looked more at the ball than the teammate. Longer fixations on the ball might be explained by the fact that the low pass was given with no opponents trying to intercept it. This predictable goal-driven circumstance might have constrained the attention to the ball as no additional stimuli were presented on the display. All participants looked less at the opponent, while novices and varsity players tended to pay more attention to outer areas (more than half of the time).

Participants drew less visual attention to the opponent while performing the defensive cover and the non-elite players tended to fixate their gaze at irrelevant areas of the scene. Thus, professionals appeared to engage in more complex visual strategies (i.e., fewer foveal fixations to facilitate shifting visual attention), particularly when the task required knowledge about where to move after the ball was controlled by the opponent's attack. This "off the ball" strategy was described by Williams et al. (1994) in a simulation of a formal soccer game (11 x 11), when skilled defenders did not look at the ball but to the player in possession of it while simultaneously monitoring positional changes of play in the periphery.

The variability of pupil diameter also showed visual skill-based differences. The analysis revealed that the non-elite players demonstrated higher values of pupil dilation than elite ones in all tasks, except the pass reception. Novices also showed greater pupil dilation than the varsity players in the penalty kick against a moving goalkeeper. This pattern corroborates previous findings (Cardoso & Costa, 2013) with adolescent soccer players. Pupil diameter variability appears to increase as a function of the cognitive effort imposed by motor tasks (Cardoso & Costa, 2013; Cardoso et al., 2019; Moran et al., 2016, 2019; Wilson et al., 2006), a typical feature of early motor learning (Magill & Anderson, 2021; Schmidt et al., 2019). Between-group comparisons in the pass reception and in the penalty kick against a moving goalkeeper suggest that fluctuations in the pupil diameter might differentiate decision-making in contexts with different levels of information processing. Future studies may help confirm this interpretation.

5. Conclusions, limitations, future studies, and practical applications

Overall, the current findings showed that the nature of visual information appeared to differentiate elite from non-elite female soccer players when responding to videos of penalty kick, pass reception, and defensive cover. Moreover, in these soccer skills, it was possible to establish two direct relationships between the experience level and (1) the gaze to relevant areas of the display and (2) the smaller variability of pupil diameter. One can speculate that due to their more refined structure of task-specific knowledge and improved strategic processing of information, elite female players can employ efficient gaze behaviour to perceive and act. The present study distinguishes itself from others due to a variety of soccer technical skills employed and the use of a cognitive effort measure (pupillary response). These conclusions reflect gaze behaviours that have been explored through 2D video projections, hence the results cannot be generalized to measurement situations in natural contexts.

As limitations, we highlight an order effect bias due to the fixed sequence of film clips, head movements during the execution of the skills, omitted regions of the opponent's body in the dribbling test film, and the absence of outcome measures for the skills. In upcoming studies, we call for the use of performance measures and cue usage (errors, verbal reports and event occlusion) in conjunction with eye-tracking techniques. Also, video recorded scenes provide a useful way to control visual contexts across participants, but they reduce visual access to the broader playfield, hence limiting the measurement of other critical factors and dynamic events that may be as important during the game (soccer players are not used to responding to displayed 2D video stimuli and we did not provide familiarization with the protocol using neutral stimuli to adapt to the procedures). In this sense, it is important to make use of real, live contexts as opposed to video scenarios – in fact, in situ x video differences in information pickup for perception and action have already been reported in baseball (Dicks et al., 2010) and soccer (Van Maarseveen et al., 2018) studies.

Bearing in mind the limitations cited above, we would like to outline some practical applications of the findings: (1) directing the gaze to the moving goalkeeper when performing the penalty kick is recommended, (2) when receiving the ball after a low pass from a teammate with no opponent trying to intercept, the ball should be the locus of visual attention, (3) while performing the defensive coverage, the opponent is only one source of information to be visually picked up, (4) moving opponents increase pupil diameter variability in inexperienced players. The three last implications should be carefully considered to be directly extrapolated to real world contexts because the videos of the pass reception and defensive coverage lack ecological validity (much visual information usually available in the game was not present, such as teammates and opponents).

Conflicts of Interest: The authors declare no conflict of interest.

References

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. Perception, 30(2), 233–252. Doi: 10.1068/p2872

Aksum, K. M., Magnaguagno, L., Bjørndal, C. T., & Jordet, G. (2020). What do football players look at? An eye-tracking analysis of the visual fixations of players in 11 v 11 elite football match play. Frontiers in Psychology. 11:562995. Doi 10.3389/fpsyg.2020.562995

Alnæs, D., Sneve, M. H., Espeseth, T., & Endestad, T. (2014). Pupil size signals mental effort deployed during multiple object tracking and predicts brain activity in the dorsal attention network and the locus coeruleus. Journal of Vision, 14, 1-20. Doi: 10.1167/14.4.1.

Applied Science Laboratories. (2014). Eye tracker systems manual: Mobile eye XG - Manual version 1.6. Bedford: Applied Science Laboratories.

Cardoso, F. S. L., & Costa, I. T. (2013). O comportamento pupilar como indicativo de conhecimento. [The pupillary behavior as indicative of knowledge] Revista Mineira de Educação Física, 9, 1087–1094.

Cardoso, F. S. L., Gonzalez-Villora, S., Guilherme, J., & Teoldo, I. (2019). Young soccer players with higher tactical knowledge display lower cognitive effort. Perceptual and Motor Skills, 126(3), 499-514. Doi: 10.1177/0031512519826437

Casanova, F., Oliveira, J., Williams, M., & Garganta, J. (2009). Expertise and perceptual-cognitive performance in football: A review. Revista Portuguesa de Ciências Do Desporto, 9(1), 115–122. Doi: 10.5628/RPCD.09.01.115

Campbell, M. J., Moran, A. P., Bargary, N., Surmon, S., & Kenny, I.C. (2019). Pupillometry during golf putting: a new window on the cognitive mechanisms underlying quiet eye. Sport and Exercise Performance Psychology, 8(1), 53-62. Doi: 10.1037/spy0000148.

Canal-Bruland, R. (2009). Guiding visual attention in decision making-verbal instructions versus flicker cueing. Research Quarterly for Exercise and Sport, 80(2), 369-374. Doi: 10.1080/02701367.2009.10599572

Chen, R., Stone, L. S., & Li, L. (2021). Visuomotor predictors of batting performance in baseball players. Journal of Vision, 21, 3. Doi: 10.1167/jov.21.3.3

Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. Attention, Perception, & Psychophysics, 72(3), 706-720. Doi: 10.3758/app.72.3.706

Furley, P., Noel, B., & Memmert, D. (2017). Attention towards the goalkeeper and distraction during penalty shootouts in association football: a retrospective analysis of penalty shootouts from 1984 to 2012. Journal of Sports Sciences, 35(9), 873-879. Doi: 10.1080/02640414.2016.1195912

Mann, D.L., Causer, J., Nakamoto, H., & Runswick, O. R. (2019). Visual search behaviours in expert perceptual judgements. In Williams, A.M. and Jackson, R.C., (Eds). Anticipation and decision making in sport. London: Routledge, Pp.59-78.

Magill, R. A., & Anderson, D. (2021). Motor learning and control: Concepts and applications (11th ed.). New York: McGraw Hill.

Millner, A. D., & Goodale, M. A. (1995). The visual brain in action. Oxford: Oxford University Press.

Moran, A., Byrne, A., & McgLade, N. (2002). The effects of anxiety and strategic planning on visual search behaviour. Journal of Sports Sciences, 20(3), 225–236. Doi: 10.1080/026404102317284781

Moran, A., Campbell, M., & Toner, J. (2019). Exploring the cognitive mechanisms of expertise in sport: progress and prospects. Psychology of Sport and Exercise, 42, 8-15. Doi: 10.1016/j.psychsport.2018.12.019.

Moran, A., Quinn, A., Campbell, M., Rooney, B., Brady, N., & Burke, C. (2016). Using pupillometry to evaluate attentional effort in quiet eye: A preliminary investigation. Sport, Exercise and Performance Psychology, 5, 365–376. Doi: 10.1037/spy0000066.

Moran, A., & Toner, J. (2017). A critical introduction to sport psychology. London: Routledge.

Natsuhara, T., Kato, T., Nakayama, M., Yoshida, T., Sasaki, R., Matsutake, T., & Asai, T. (2020). Decision-making while passing and visual search strategy during ball receiving in team sport play. Perceptual and Motor Skills, 127(2), 468-489. Doi: 10.1177/0031512519900057

O'Shea, H., & Moran, A. (2016). Chronometric and pupil-size measurements illuminate the relationship between motor execution and motor imagery in expert pianists. Psychology of Music, 44, 1289–1303. Doi: 10.1177/0305735615616286.

O'Shea, H., & Moran, A. (2018). To go or not to go? Pupillometry elucidates inhibitory mechanisms in motor imagery. Journal of Cognitive Psychology, 30, 466–483. Doi: 10.1080/20445911.2018.1461104.

Paillard, T., & Noe, F. (2006). Effect of expertise and visual contribution on postural control in football. Scandinavian Journal of Medicine and Science in Sports, 16(5), 345–348. Doi: 10.1111/j.1600-0838.2005.00502.x

Ripoll, H. (1991). The understanding-acting process in sport: The relationship between the semantic and the sensorimotor visual function. International Journal of Sport Psychology, 22(3–4), 221–243.

Roca, A., Ford, P.R., McRobert, A.P., & Williams, A. M. (2011). Identifying the processes underpinning anticipation and decision-making in a dynamic time-constrained task. Cognitive Processing, 12(3), 301-310. Doi: 10.1007/s10339-011-0392-1

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in football. Journal of Sport & Exercise Psychology, 35(2), 144–155. Doi: 10.1123/jsep.35.2.144

Rodrigues, S. T., Vickers, J. N., & Williams, A. M. (1999). Two visual systems and temporal pressure in table tennis. Journal of Sport and Exercise Psychology, 21, S91.

Savelsbergh, G. J. P., Kamp, J. Van Der, Williams, A. M., & Ward, P. (2005). Anticipation and visual search behaviour in expert football goalkeepers. Ergonomics, 48(11–14), 1686–1697. Doi: 10.1080/00140130500101346

Savelsbergh, G. J. P., Williams, A. M., Kamp, J. Van Der, & Ward, P. (2002). Visual search, anticipation and expertise in football goalkeepers. Journal of Sports Sciences, 20, 279–287. Doi: 10.1080/026404102317284826

Schmidt , R. A., Winstein, C. J.; Wulf, G.; Lee, T.; Zelaznik, H.N. (2019). Motor control and learning: A behavioral emphasis. Champaign: Human Kinetics.

Vater, C., Williams, A.M., & Hossner, E.J. (2020) What do we see out of the corner of our eye? The role of visual pivots and gaze anchors in sport. International Review of Sport and

Exercise Psychology, 13(1), 81-103. Doi: 10.1080/1750984X.2019.1582082
Van Maarseveen, M. J. J., Oudejans, R. R. D., Mann, D. L., & Savelsbergh, G. J. P. (2018). Perceptual-cognitive skill and the in situ performance of soccer players. Quarterly Journal of Experimental Psychology, 71(2), 455-470. Doi: 10.1080/17470218.2016.1255236
Ward, P., Hodges, N. J., Starkes, J. L., & Williams, A. M. (2007). The road to excellence: Deliberate practice and the development of expertise. High Ability Studies, 18(2), 119–153. Doi: 10.1080/13598130701709715
Ward, P., Williams, A. M., & Bennett, S. J. (2002). Visual search and biological motion perception in tennis. Research Quarterly for Exercise and Sport, 73(1), 107–112. Doi: 10.1080/02701367.2002.10608997
Williams, A. M., & Burwitz, L. (1993). Advance cueutilization in football. In T. Reilly, J. Clarys, & A. Stibbe (Eds.), Science and Football II (pp. 239–243). London: E & FN Spon.
Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in football. Research Quarterly for Exercise and Sport, 69(2), 111–128. Doi: 10.1080/02701367.1998.10607677
Williams, A. M., Davids, K., Burwitz, L., & Williams, J. G. (1993). Visual search and sports performance. Australian Journal of Science and Medicine in Sport, 25(2), 55–65.
Williams, A. M., Davids, K., Burwitz, L., & Williams, J. G. (1994). Visual search strategies in experienced and inexperienced football players. Research Quarterly for Exercise and Sport, 65(2), 127–135. Doi: 10.1080/02701367.1994.10607607
Williams, A. M., Davids, K., & Williams, J. G. (2005). Visual perception and action in sport. London: Routledge.
Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. Human Movement Science, 24(3), 283–307. Doi: 10.1016/j.humov.2005.06.002
Williams, A. M, Heron, K., Ward, P., & Smeeton, N. J. (2004). Using situational probabilities to train perceptual and cognitive skill in novice football players. In: Science and Football V: The Proceedings of the Fifth World Congress on Sports Science and Football. Routledge, Pp. 348-351.
Wilson, M., Smith, N. C., Chattington, M., Ford, M., Dilwyn, E., Wilson, M., Marple-Horvat, D. E. (2006). The role of effort in moderating the anxiety – performance relationship: Testing the prediction of processing efficiency theory in simulated rally driving. Journal of Sports Sciences, 24(11), 1223–1233. Doi: 10.1080/02640410500497667
Wood, G., & Wilson, M. R. (2010). A moving goalkeeper distracts penalty takers and impairs shooting. Journal of Sports Sciences, 28(9), 937–46. Doi: 10.1080/02640414.2010.495995
Woolley, T.L., Crowther, R.G., Doma, K., & Connor, J. D. (2015). The use of spatial manipulation to examine goalkeepers' anticipation. Journal of Sports Sciences, 33(17), 1766-1774. Doi: 10.1080/02640414.2015.1014830