Visual Strategies Underpinning the Spatiotemporal Demands During Visuomotor Tasks in Predicting Ball Direction

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Introduction

Team sports are often characterized by spatiotemporal constraint that necessitates the processing of and responding to visual information in a limited time frame (Panchuk & Vickers, 2006). Consequently, spatiotemporal constraints are present in different sporting situations, such as when the athlete's response time, combined with the distance the ball will travel prior to being intercepted, exceeds the ball flight duration (Piras, Lanzoni, et al., 2016). In these conditions, successful performance is based upon the athlete's accurate allocation of visual attention and subsequent decision making prior to initiating a motor behaviour, either at the instance of or immediately after a key action (e.g., the ball being kicked in a soccer penalty kick; Piras et al., 2020; Piras & Vickers, 2011).

In competitive sports, in which precise and correct prediction of the intentions of others are a fundamental component of performance, attending to and processing visual information are key determinants of successful motor execution (Williams, 2009). Indeed, in fast ball sports like table tennis (Piras, Lanzoni, et al., 2016), as well as in team sports such as soccer (Piras et al., 2020; Piras & Vickers, 2011; Timmis et al., 2018) and volleyball (Piras et al., 2010; Piras, Lobietti, et al., 2014), the need to perceive the intentions of the opponent occurs under severe time pressure. This time pressure will be impacted by the distance the object travels once being struck/hit and being intercepted, for example a ball being kicked from different distances (Navia et al., 2017; Panchuk & Vickers, 2006). In a recent article, Navia et al. (2017), comparing expert futsal goalkeepers intercepting penalties taken from 10m in comparison to 6m, reported that more saved penalties occurred when kicked from 10m, with goalkeeper's initiating their movement later, looking for longer towards the ball with respect to the penalty takers' body. In ice hockey, when goaltenders were required to save shots taken from 5m with respect to 10m, the number of saves was not significantly affected by the different distance from which the shot was taken and there was no difference in visual search behaviour between distances (Panchuk & Vickers, 2006).

Although differences in fixation locations through expertise have been reported in the majority of studies (for a review see Mann et al., 2007), a paucity of research has investigated differences between the utilization of the fovea with respect to the periphery during spatiotemporal constraints (Vater et al., 2019). Because of the different functional organization of foveal and peripheral visual field (Raffi & Piras, 2019), the cue's proximity could influence the utilization of the foveal or the peripheral vision to pick-up relevant information necessary to make predictive judgements early in time, just before the initiation of the motor response (Williams, 2009).

Saccadic eye movements bring objects of interest into the fovea, where the visual resolution is highest. During the visual perception of extrafoveal cues, before the eyes start to move, peripheral vision is enhanced, and sensory orientation is restructured by the saccade target location (Piras, Raffi, et al., 2016). These changes occur rapidly, with an influence on the visual perception, as humans perform saccades every few hundred milliseconds (Klein & Ettinger, 2019). However, saccades are not only made to reorient the fovea. Small saccades, termed microsaccades, occur during fixation, with a relatively high rate once the object of interested is foveated (for more information see Martinez-Conde et al., 2013). It has been found that microsaccades serve the function of preventing visual fading during fixation, help in maintaining accurate fixation on point, redirect a preferred small locus on the retina and facilitate fine spatial judgments (Poletti & Rucci, 2016). Close investigations have revealed that the eyes are never stationary, during fixations these microsaccades continuously upset the gaze position. These movements occur even when attempting to maintain steady fixation on a single point during a sport situation (Piras et al., 2015).

The previous work conducted by Navia et al. (2017) and Panchuk and Vickers (2006) which investigated how visual search behaviour changed dependent upon goalkeeper-object distance did not consider the subtle eye movements that may occur prior to goalkeeper movement initiation. In a recent study, Piras et al. (2020), investigated the role of microsaccades, saccades, and pupil diameter during the period that proceed a soccer goalkeeper's movement time in a penalty kick. The authors identified that both saccades and microsaccades (inside 3° of visual angle) occurred during fixation (i.e. quiet eye threshold, for more information see Vickers, 2007). Moreover, they found that microsaccades anticipated the goalkeeper's direction, suggesting that they are not casual, but directed toward the focus of (covert) attention (Hafed & Clark, 2002). Additionally, the authors demonstrated a positive correlation between pupil dilation with the proximity of the motor response. Pupils reached the largest size just before goalkeeper's movement initiation, increasing visual sensitivity to optimize perceptual processes. Task-evoked pupil dilation in well-controlled experimental settings has been referred to as an index of the allocation of cognitive control during mental activity (Beatty, 1982) and in sport settings (Campbell et al., 2019). The advances in neuroscientific methods has further strengthened our understanding that pupils dilate during mental activity, and that pupillometry is a well-established technique for investigating human cognitive processing (Beatty, 1982). Indeed, pupil size can be used as a signal of the relative amount of cognitive effort used to achieve a task and can be referred to as an index of the brain activity. Campbell et al. (2019) found that golfers, during a putting task, exhibited pupil dilation changes of about 30% from baseline. Additional research is needed to consider the importance of the spatiotemporal constraints on the individuals' functional behaviours during performance. Specifically, the aim of the present study was to examine the visual search strategy of soccer goalkeepers in attempting to predict penalty kick direction taken from different distances (near versus far) and from different angles of approaching the ball (left versus right). We hypothesize that, when the distance from the ball is higher, and the image of the kicker with the ball is smaller (i.e. subtends a smaller region of the visual scene), the goalkeeper will utilize a different visual search strategy with respect to the situation in which the kicker and the ball are closer (and subtends a larger region of the visual scene). We suppose that an increased distance between the opponent and the goalkeeper will result in relying on information extracted via the fovea, conversely, when the opponent is closer, the goalkeeper will utilize peripheral vision to monitor players' movements (Williams et al., 1994; Williams & Davids, 1998). Moreover, we can hypothesize that, if the kicker's run-up is an important movement phase for the goalkeeper intercepting the ball, different penalty taker run-up starting point (left versus right angle of approach) could influence the microsaccade/saccade orientations. The emergent search pattern in these situations would appear to be at least partly constrained by the relative distance between player, the ball, and with the angle of approaching the ball. Several studies have found that using the fovea and/or the peripheral vision enables successful prediction of a sporting action and can be detected through microsaccades and saccades (Piras et al., 2015, 2019; Piras, Raffi, et al., 2016). We presume that if more saccades are performed, it should be understood to be automatically induced by the change event for foveal detection; however, the absence/reduction of saccades in favour of microsaccades (fewer fixations of longer duration), would rather favour the participants' ability to use peripheral vision to detect change events (Piras et al., 2020; Vater et al., 2019). Due to the supposed relationship between ocular movements, visual perception, and direction of attention, the present study investigated the role of saccades, microsaccades and pupil-size of soccer goalkeepers during the prediction of a penalty kick in two different spatiotemporal constraints.

Methods

Participants

Eight intermediate-level male goalkeepers with a mean age of 23.5 (±5.2) years, one right footed male kicker of 28 years and one left footed male kicker of 26 years old volunteered for the experiment. Based on the effect size (dz = 0.80) evident on other studies (Piras et al., 2020; Piras & Vickers, 2011), G*power, version 3.1.9.2 (Kiel, Germany), predicted that a total sample size of 7 would give appropriate power (1-β err prob 0.80) to detect a significant difference at alpha level of 0.05. One additional participant was included to guarantee availability of data in case of missing values. At the time of the study, the goalkeepers had been playing soccer for 14.7 years, and trained on average 3.5

times, 7 hours per week, with a competitive match at the end of the week (national level). Goalkeepers reported that they have been playing recreational futsal, with competitive matches at regional level. They self-reported a normal vision, and after receiving oral and written information concerning the study protocol, all participants gave their written informed consent to participate in the study. The study was approved by the Bioethics Committee of the University of Bologna.

Stimuli and procedure

A right footed male kicker was filmed, from the participants' (goalkeepers') perspective, with a digital video camera (Casio® 300 frames/s, with a max resolution 1280 × 960 pixels) positioned in the middle of a standard, full sized (7.32 m wide and 2.44 m height), soccer goal, with the ball (size 5) positioned 11m from the centre of the goal. The kicker was required to start his run-up from the right of goalkeeper's perspective, at least 4 m behind the ball using the same approaching angle for all penalty kicks. Ten penalty kicks were filmed and subsequently subdivided in five directed to the right and five to the left (goalkeeper's perspective).

The same procedure was used for penalties kicked in a futsal court. A left footed male kicker was filmed, from the goalkeeper's perspective, with the same video camera positioned in the middle of a standard, full sized (3 m wide and 2 m height) futsal goal, with the ball (size 4) positioned 6m from the penalty spot. The kicker was required to start his run-up from the left of goalkeeper's perspective, at least 4 m behind the ball using the same approaching angle for all penalty kicks. Ten penalty kicks were filmed and subsequently subdivided in five directed to the right and five to the left (goalkeeper's perspective).

The experiments were performed in the dark. Stimuli were back-projected (Epson EB-W12, 720 × 486 resolution; frame rate 60 Hz) onto the translucent screen positioned 300 cm away. The screen covered 135 × 107° of visual field and was placed 170 cm from the goalkeepers' eyes, who stood in front of the screen ready to predict the ball direction as they were in the soccer pitch. The brightness of the screen was measured using a United Detector Power meter (model 351) equipped with a photosensor (model 263), necessary to identify the different portions of the video clips (field of play; penalty takers' body; the ball). The brightness of the screen was almost equal through the videoclips (p=0.25; d=0.50).

The videos were presented from when the kicker started approaching the ball up to the ball passing to the right or to the left of the goalkeeper's point of view. The goalkeeper was required to predict the direction of the ball moving laterally (left or right) as they would on a soccer pitch, but without diving. In total, each participant faced 60 penalties, 30 kicked from 11m and 30 kicked from 6m. We subdivided penalties in six blocks with the same ten videoclips, with each block interspersed by 5 minutes of rest. Each clip had a mean duration (±SD) of 6046.80±2.89 ms (max value of 6051 and a min value of 6043 ms). The direction of the soccer shots was completely randomized but the same randomised order was used for each participant. Overall, a total number of 480 clips were analysed.

Eyes and body movement recording

We recorded binocular eye movements with a video-based eye tracking system (EyeLink® II, SR Research) comprising of two miniature cameras mounted on a leather-padded headband. Pupil tracking was performed at 500 samples/s, with a gaze resolution <0.005° and noise limited to <0.01°.

We calibrated the eye tracker at the beginning of the experiment and after each block of 10 videoclips. Then, we performed data validation and drift correction by applying a corrective offset to the raw eye position data after every clip. Calibration and validation of the system was repeated every time possible measurement error occurred due to participants' movements. The accuracy of the eye positions was checked after every clip, and if required, a drift correction was performed. Practice, calibration, validation and data collection took ~ 60 minutes per participant.

Two inertial sensors (Cometa Systems, Italy) were placed on the goalkeepers' right and left anterior superior iliac spine to collect lateral body movement. Inertial sensors (IMU; inertial measurement unit, composed of a triaxial accelerometer, gyroscope, and magnetometer) were synchronised with the EyeLink system (TTL trigger signal input via the parallel port) in order to have corresponding goalkeepers' eyes and body movement data. In the present study, only measurements of the triaxial accelerometer were considered and collected at 1000 Hz, then re-sampled at 500Hz to have body and eye movements synchronized. Goalkeepers' body movement response to ball interception was considered to occur if the processed IMU signal exceeded a threshold of 3 standard deviations (SDs) above the baseline (preactivation) triaxial accelerometer signal. If a response was detected, a value of one was assigned, otherwise zero was assigned (The Shewhart threshold, for more details see Stokes et al., 2006). The latency was measured as the time from the start of the trial to onset of the body movement response.

Data analysis

Goalkeepers had to react in a time comprised between <150-250> ms after foot-ball contact, otherwise trials were classified as missed, due to early or delayed movement necessary to intercept the ball (average human reaction time). Then, we selected, from the entire trial duration (6000 ms), the duration of each trial for analysis, using the exact time in which goalkeepers started their final movement, going back for 4000 ms, in order to have trials of the same length.

Response accuracy and movement time. Response accuracy (predicted/missed penalties) and the final movement time, that is the time in ms from the trial start to goalkeepers' final movement to predict the ball were analysed separately using a distance (11m; 6m) x response accuracy (predicted; missed) ANOVA with repeated measures on all factors.

Visual search order. We analysed the mean number of fixations on each interest areas every 1000ms (epochs), starting from the exact time in which goalkeeper's final movement initiation, going back for 4000 ms (1000ms; 2000ms; 3000ms; 4000ms). This was the search sequence used by the athletes. We analysed the gaze positions in relation to the positions of the moving objects using dynamic interest areas, that represent the position and dimensions of important visual scene content over time (Piras, Lanzoni, et al., 2016). For this purpose, the screen was divided into five interest areas (IAs):

(I) the HEAD of the kickers; (II) the TRUNK of the kicker; (III) the LEGS of the kicker; (IV) the VISUAL PIVOT, a location in the middle between the ball, the kicking leg and non-kicking leg (Piras & Vickers, 2011); (V) fixations on the BALL. All fixations outside these IAs were referred to as "OUT" fixations. The mean number of fixations on each interest areas were analysed in block of temporal sequences (four epochs) using epoch (1000ms; 2000ms; 3000ms; 4000ms) x condition (11m, 6m) ANOVA with repeated measure on all factors.

Microsaccade/saccade characteristics. We considered fixation when the gaze was stable inside 1° of visual angle for a minimum of 100 ms. Microsaccades were defined as eye movements ≤1° in amplitude, with a peak velocity ≤100°/sec, and that followed the same peak velocity versus amplitude curve as large saccades. Microsaccades and saccades were identified using the algorithms of Otero-Millan et al. (Otero-Millan et al., 2014). The clustering method of the algorithm finds, automatically and objectively, a boundary between true microsaccades and non-microsaccadic events, including artifacts such as head movements and changes in pupil size. For our study, we considered only microsaccades occurred simultaneously in both eyes during at least 3 data samples (6ms). We excluded 200 ms before and after each blink as well as when the pupil was still partially occluded. Microsaccade and saccade amplitudes, durations, and peak velocities were first calculated for each goalkeeper in each condition (penalties from 11m and from 6m; predicted and missed penalties) separately. Then, the values of all athletes in each condition were averaged. Microsaccade rates were calculated considering the duration of each clip (4000 ms). A response accuracy (2) x condition (2) ANOVA with repeated measures on all factors was performed separately to analyse microsaccade and saccade rate, amplitude, duration, and peak velocity.

Moreover, saccade and microsaccade rate (number per second) was averaged over all trials of 8 participants and obtained a mean rate of about one per second (computed within a moving window of 200 ms). Next, we subdivided the saccades/microsaccade rate in four epochs (1000; 2000; 3000;

4000 ms) in order to analyse them with repeated measures ANOVA with epochs as within-subjects factor and condition (11m; 6m) as between-subjects factor.

Microsaccade/saccade orientation. We computed the two-dimensional distribution of all microsaccade and saccade directions in the two different goalkeeper's movement direction (right, left), subdivided in penalties kicked from 11m and from 6m. We performed the Watson-Williams test for homogeneity of means (Oriana® 4.0) in which the null hypothesis was that the orientations of microsaccades and saccades between penalty condition (11m versus 6m) have similar continuous distribution at the 5% level of significance. Furthermore, analysis considered response accuracy (predicted, missed) as a dependent variable to reveal any possible relationships between response accuracy and saccade/microsaccade orientation.

Pupil size characteristics. The raw data of the pupil diameters were normalised with z-scores technique, by expressing every sample as a standard deviation score from the mean calculated within each videoclip. Pupil size diameter was correlated with the duration of the corresponding videoclip, from the trial start to goalkeepers' final movement initiation. Then, mean correlations were analysed with a Paired sample t-test to investigate differences between penalty distances (11m; 6m).

Mauchly's test was used to assess any violations for sphericity. Effect size of the repeated measure ANOVAs were expressed using partial eta-squared (η_p^2), with values of 0.01, 0.06, and 0.14 representing small, medium, and large effects respectively (Cohen, 1988). Statistical significance was set at $p < 0.05$.

Results

After pre-processing data, in which responses shorter than 150 ms and longer than 250 ms (early or delayed responses) were discarded (see Methods for description), 425 clips were retained for analysis (of a total of 480; 55 clips were excluded).

Response accuracy and movement time

In general, goalkeepers were significantly more accurate than not in predicting shot direction (57.08% vs 42.91%; $F_{1,14} = 5.17$; $p = 0.039$; $n_p^2 = 0.27$). Analysis of variance did not show any significant differences for the interaction effect between accuracy (predicted; missed) and condition (11m; 6m) ($p = 0.36$). Paired sample t-test showed significant differences only for penalties kicked from 11m, in which goalkeepers exhibited successfully predicted than missed penalties (60% vs 40%; t(7)= 2.72; $p = 0.03$; $d = 1.93$, Figure 1A). No significant difference was found for predicted and missed penalties kicked from 6m (54% vs 46%; p = 0.43), although there was an 8% improvement with a medium effect size (d = 0.59).

Final movement time analysis showed a significant main effect for accuracy ($F_{1,7} = 14.07$; $p = 0.007$; $n_p^2 = 0.67$), in which goalkeepers were slower when predicted compared to missed penalties (4706ms vs. 4646ms). When penalties were kicked from 11m, goalkeepers were significantly faster when missing and slower when successfully predicting penalties ($F_{1,7} = 9.19$; $p = 0.019$; $n_p^2 = 0.57$; Figure 1B).

*****Figure 1 near here*****

Visual search order

Analysis of the mean number of fixations showed significant increase for penalties from 11m in comparison to penalties from 6m (2.61 vs 2.24; t(7) = 3.74; $p = 0.008$; $d = 1.32$). Repeated measures ANOVA showed a significant condition x epoch interaction effect ($F_{3,42} = 9.61$; $p < 0.001$; $n_p^2 = 0.41$). Paired sample t-test revealed significant increase for penalties from 11m in comparison to penalties from 6m at the last epoch (4000ms; t(7) = 2.81; $p = 0.026$; d=1.05; Table 1).

*****Table 1 near here*****

Microsaccade/saccade characteristics

Analysis of microsaccade rates showed a significant main effect for condition ($F_{1,14} = 4.82$; $p = 0.046$; $n_p^2 = 0.26$) in which goalkeepers exhibited a greater rate during penalties kicked from 6m than from 11m (0.63±0.19 vs 0.59±0.18 number/sec).

Analysis of microsaccade rates time window showed significant main effect between the four-time epochs ($F_{3,42} = 8.50$; $p < 0.001$; $n_p^2 = 0.38$) on each condition (Figure 2). Microsaccades rate analysed during penalties kicked from 11m showed a decrement trend visible from the first to the last epoch (Figure 2A; $p = 0.014$; $d = 1.27$). Looking at figure 2B, microsaccade rates decreased from the first to the second epoch to about 33% ($p = 0.003$; $d = 1.49$), then 1000ms before goalkeeper's final movement started, showed an additional decrease of about 53% with respect to the first epoch ($p = 0.002$; $d = 2.36$).

There were no significant differences between penalties kicked from 11m with respect to 6m for the other microsaccade characteristics; duration (mean 39.54 vs 40.85 ms); amplitude (mean 0.64 vs 0.63° of visual angle) and peak velocity (mean 43.12 vs 39.95°/second).

Microsaccade durations showed a significant main effect for response accuracy ($F_{1,14} = 5.51$; $p = 0.034$; $n_p^2 = 0.28$), with longer duration in predicted than missed penalties (38.71 vs 36.85 ms).

*****Figure 2 near here*****

Analysis of saccade rates showed significant main effect for condition ($F_{1,14} = 4.27$; $p = 0.044$; $n_p^2 = 0.25$), with increased rate in penalties from 11m in comparison to penalties from 6m (1.27 vs 1.03 number/sec). A significant main effect was found for response accuracy ($F_{1,14} = 10.93$; $p = 0.005$; $n_p^2 = 0.44$), with higher saccade rates during predicted than missed penalties (1.18 vs 1.07 number/sec). Analysis of saccade rates time window showed significant main effect between the four epochs ($F_{3,42} = 31.01$; $p < 0.001$; $n_p^2 = 0.70$) on each condition. Saccade rates were almost stable for 3000 ms ($p = 0.15$; $d = 0.08$) in both conditions, increasing in the last epoch ($p < 0.001$; $d = 3.05$), reaching the peak at about 500ms just before the goalkeeper's final movement started (Figure 3).

There were no significant differences between penalties kicked from 11m compared with penalties kicked from 6m for the other saccade characteristics; duration (105.48 vs. 102.58 ms); amplitude (3.57 vs. 3.82° of visual angle) and peak velocity (117.22 vs. 120.10°/second).

*****Figure 3 near here*****

Microsaccade/saccade orientation

Microsaccades orientations were not significantly different comparing penalties from 11m with those from 6m (103.70±11.50° vs. 90.45±8.29°, respectively; $p = 0.39$). It seems that, in both situations, goalkeepers, during fixations, shift their covert attention from the lower to the upper kicker's body.

Saccade orientation showed a significant main effect for condition ($F_{1,14} = 40.52$; $p < 0.001$; $n_p^2 = 0.74$), with a main vector directed to the left during penalties kicked from 11m (222.12±7.21°), and a main vector directed to the right during penalties kicked from 6m (323.25±13.17°) (Figure 4 lower panel). It seems that the different angles of approaching the ball (left versus right) influences the saccades orientation.

No significant difference was observed for response accuracy (predicted; missed) on saccade/microsaccade orientations ($p > 0.05$).

*****Figure 4 near here*****

Pupil size characteristics

Pupil dimension showed a significant correlation with the proximity to the movement time initiation in both penalty conditions. Comparing the correlation values between penalties kicked from 11m with respect to penalties kicked from 6m we found a significant difference ($r^2 = 0.98$ and 0.93; $t(7) = 3.40$; $p = 0.011$; $d = 0.50$). Pupils increased as the goalkeepers' perception of the penalty taker's intention developed, reaching the greatest value just before the goalkeepers' final movement initiation, and it was significantly higher during penalties kicked from 11m compared to 6m (Figure 5).

*****Figure 5 near here*****

Additionally, both curves, represented by the right pupil size, were computed by measurements of the area under the curve (AUC) at the intervals 2000–3400 ms, using the trapezoid rule (technique to calculate the definite integral, approximating the region under the graph of the function as a trapezoid and calculating its area). Analysis showed a significantly different area under the curves ($p<0.001$), with a mean value of 343 for penalties from 6m and a mean value of 559 for penalties from 11m. As showed in Figure 5, in the other part of the temporal sequence the lines were totally (after 3400 ms) or partially (before 2000ms) overlapped.

Discussion

The aim of the present study was to investigate the visual search strategy of soccer goalkeepers engaged in penalties kicked from different distances (11m vs. 6m). Our hypothesis was that athletes, during the period that precedes the final movement time initiation, adopted a different visual search strategy dependent on situational constraints, with more microsaccades and less saccades during near in comparison to far action.

During penalties kicked from 11m, goalkeepers exhibited a microsaccades rate time window with a decrement trend visible from the first to the last epoch. Whereas, during penalties kicked from 6m, microsaccade rates decreased from the first to the second epoch to about 33%, then 1000ms before goalkeeper’s final movement started, exhibited an additional decrease of about 53% with respect to the first epoch (Figure 2). Saccade rate exhibited a similar trend in both 6m and 11m conditions, almost stable for 3000 ms, with an increment in the last epoch, that reach the peak at about 500ms just before the goalkeeper’s final movement started, in concomitant with microsaccades reduction (Figure 3). The current research supports previous literature (Piras et al., 2015, 2019, 2020; Piras, Raffi, et al., 2016) highlighting how microsaccades can be suppressed with the increment of the attentional resource during cognitive visual tasks, leading toward intrusion of small-saccades, which could have the function to shift the attention to cues spatially related.

Comparing mean number of fixations, saccade and microsaccade rates between conditions, goalkeepers in the 11m condition used a visual search strategy with more fixations, and consequently greater saccade rates in comparison to penalties from 6m, where they exhibited fewer fixations and higher microsaccade rates. The most fixated area during the last epoch before the goalkeepers' final movement time initiation was significantly different between conditions. During penalties kicked from 11m, fixations were located on the visual pivot, a location between the ball and the kicking action (Piras & Vickers, 2011), meanwhile, from 6m, goalkeepers' fixations were located on the kicker's legs (Table 1). Frequent fixations on the visual pivot could be explained by important cues in close proximity to each other that need to be processed via the fovea, with areas inside the pivot characterized by a minimal retinal distance with respect to the fovea (Vater et al., 2019). The functionality of the visual pivot would be to hold the gaze on a location close to relevant cues and initiate small saccades to these cues. During 6m condition, goalkeepers "anchored" their gaze to kicker's legs, a position that optimizes information processing via peripheral vision, in which covert attention is distributed to peripheral cues and eliminates the costs associated with saccadic eye-movements. We can postulate that this could be due to the kicker's and ball different distance, which influence the dimension of the images perceived (kicker and ball); as long as the opponent's distance is large and thus time pressure reduced, gaze can be frequently shifted between the kicker's body and the ball because the costs of saccades are low. On the contrary, closer objects require both foveal and parafoveal to be stimulated for catching information (Williams et al., 2004). Indeed, when the opponent is closer to the observer and time pressure increases, the opponent's body (i.e. the kicker's legs) could turn into a gaze anchor (Piras, Pierantozzi, et al., 2014), where saccades are reduced, and the fovea is not the only important aspect to acquire visual information since it becomes necessary to monitor different cues with the parafovea (likely using microsaccades or small-saccades).

Vater and co-workers (2019) have postulated a theory in which saccades could be considered as a relevant measure to distinguish between gaze anchor (saccade-avoiding) and visual pivot (saccadepreparing), considering that pivots are thought to be optimal locations to initiate saccades to other cues, and frequent saccades to the pivots can be predicted. In agreement with this theory, we identify that during anchoring, experts make micro-saccades to take peripheral information, meanwhile, during pivoting the same subjects produce small saccades to near areas. In this scenario of adapted gaze strategy, the locus of covert attention is more relevant rather than the location (overt attention) of gaze per se (Vater et al., 2019). Therefore, microsaccades with high frequency may suggest attention to peripheral target due to pick up of relevant information, hence a very precise fixation may not be necessary (Piras et al., 2015, 2019). Additionally, it appears that saccades are made in situations with low time pressure to process information in regions of high acuity, in contrast to situations with increased time pressure, where gaze-anchoring behavior is preferred due to the possibility of utilizing microsaccades and avoiding saccades that could compromise the processing of the visual cue(s). The key issue in light of the current discussion is that players demonstrate different visual search behaviours under changing task constraints.

Williams et al. (2004) hypothesized that during a soccer match, when the distance between the ball and the player is great, such as during 11vs11 open-play situation in soccer, players have time to undertake a comprehensive analysis of the situation and seem to rely on information extraction via the fovea. In contrast, when the ball is closer and the time constraints more critical, such as during small-sided games (e.g. 1vs1), both fovea and peripheral vision may be employed, with players initially using the fovea to extract relevant task information, while as the opponent approaches they may rely more on peripheral vision to pick up the relative movement pattern. The emergent search pattern in these situations would appear to be at least partly constrained by the number of players involved in the action (they studied 11vs11; 3vs3 and 1v1 soccer situations) and the relative distance between these players and the ball (Williams et al., 1994; Williams & Davids, 1998). Nevertheless, authors did not consider that in details, such as the distance between players or the distance between players and the ball. Moreover, they did not assess the subtle eye movements, which occur to provide important visual information in determining appropriate subsequent decisions (Piras et al., 2020). As postulated by the authors, empirical evidence is needed to clarify and support a constraints-based explanation of visual search behaviour in sports (Williams et al., 2004). Consequently, our work extents the important works of Williams et al. (1994; 1998), highlighting the important role of microsaccades and the small-saccades, necessary to indicate both the locus of fixation and the locus of attention in team game context.

The ability to quickly shift attention from one relevant cue to another is a prerogative of the athletes (Piras et al., 2015). A recent study found that microsaccades provide a mechanism for precisely relocating gaze in high-acuity tasks, supporting the proposal that microsaccades are exploratory movements, similar to larger saccades (Ko et al., 2010). In a sport situation, Piras et al. (2020) found a significant difference in microsaccade angular orientations during penalties kicked from 11m, showing that microsaccades could anticipate the goalkeeper's intention. Therefore, we have compared the microsaccade angular directions during penalties from 11m with that of penalties from 6m, demonstrating that the main vector has the same direction in both conditions (Figure 4). It could indicate that athletes shift their attention from the lower (legs; visual pivot) to the upper opponent's body (trunk; head) (Piras et al., 2015). Meanwhile, saccades direction during penalty kicked from 6m showed a mean angular direction toward the lower right of the goalkeeper's visual field (Figure 4 lower panel). At this point, we can confirm, in combination with the previous study (Piras et al., 2020), that saccade orientations are conditioned by the penalty taker's body movement, following the direction of the kicker during their approach (run-up) toward the ball.

Pupil size is an effective indicator of cognitive load (Krejtz et al., 2018), and has been associated with motor preparation (Jainta et al., 2011). In the current study, we specifically examined pupil dynamics during a sport situation where the appropriate allocation of visual attention precedes and determines effective motor behaviour. The pupils dilated relatively more during the viewing of small objects visualized at a relatively far distance than at a near distance. It has also been found that the pupil diameter changed with the scope of attention, dilating with broadly spread attention and contracting with narrowly focused attention (Daniels et al., 2012). Interestingly, in the present study, when the goalkeeper saw the pattern enlarging on screen as the kicker approached the ball, pupil diameter increased over time (Piras et al., 2020). Overall, the results of the area under the curve at a specific intervals (2000–3400 ms) showed that pupil size prior to stimulus presentation effectively reflected preparatory set activity related to saccade initiation, and confirmed a direct link between saccade initiation and pupil size (Wang & Munoz, 2015). This increase in pupil diameter could increase visual sensitivity to improve perceptual processes immediately after to redirect the eyes (Piras et al., 2020).

In general, we found successfully predicted than missed penalties (57% vs 43%). When the goalkeeper's final movement time initiated in a time equal or slightly greater than 4.7 seconds, the probability to predict the ball increased. Conversely, faster responses, below 4.7 seconds, raised the probability to miss the direction of the ball at both distances. Moreover, we should consider that from 11m, GKs exhibited successfully predicted than missed penalties (60% vs 40%). At 6m, whilst there was no significant difference for predicted and missed penalties, there was an 8% improvement with a medium effect size (d = 0.59). So, in both penalty distances, GK's were better in predicting than missing, suggesting that they had suitable experience in both environments. This slight reduction in number of predicted penalties at 6m compared to 11m could be attributed to the recreational practice of our goalkeepers, that was more frequent at 11m compared to 6m, therefore, they may have been more familiar with this condition. Additionally, it has been largely demonstrated that it is more difficult to intercept the ball kicked closer than farer, even in the same environment (Navia et al., 2017).

Within the design of the current study, we acknowledge the following limitations. In line with the power analysis, 8 goalkeepers were recruited to the study. Whilst this sample may appear small, it was important to recruit participants of a similar (national level) ability to ensure a homogenous group. Future research may wish to consider how saccades and microsaccades differ as a function of expertise. Second, we presented the right footed penalty taker from a soccer pitch and the left footed penalty taker from the futsal pitch. We decided against presenting a mix of right and left foot penalty kicks for both distances as our intention was not to determine if goalkeepers were more able to intercept the ball kicked with the left or with the right in different distances. Adding additional trials into the study design would have also required a larger sample size, which was not possible. Third, there were differences in ambient conditions between the soccer pitch and the futsal pitch. Whilst it would have been possible to use the same environment (record only from the identical soccer or futsal pitch, just at different distances), this would have impacted the representative nature of the study (c.f. Araújo et al., 2007); moving a soccer ball closer (to 6m) and filming on a soccer pitch (or vice-versa for futsal) was not representative of what a goalkeeper experiences in their natural environment.

In conclusion, when the spatiotemporal constraint is less severe, as it was during penalties from 11m, the goalkeepers exhibit a visual search strategy based on more fixations and small saccades to pick up relevant information from the fovea. When the spatiotemporal constraint is more severe (6m condition), goalkeepers relied on peripheral vision to monitor kicker's movements through the use of microsaccades, due to their increased ability to bring the neuronal receptive fields to stimulus regions.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Figure captions

Figure 1. Histograms represent the percentage values between predicted (in black) and missed (in grey) penalty kicks across condition (11m and 6m) (A); and the response time of the goalkeepers between predicted (in black) and missed (in grey) penalty kicks across condition (11m and 6m) (B).

Figure 2. Time course of microsaccade rates during penalties kicked from 11m (A) and from 6m (B), calculated from the goalkeeper's final movement initiation to backwards for 4000ms. Rates were computed for each GKs using a moving time window of 200ms and then averaged over all athletes. Solid black lines represent the mean rate, meanwhile the shaded grey areas represent the standard error of the mean.

Figure 3. Time course of saccade rates during penalties kicked from 11m (A) and from 6m (B), calculated from the goalkeeper's final movement initiation to backwards for 4000ms. Rates were computed for each GKs using a moving time window of 200ms and then averaged over all athletes. Solid black lines represent the mean rate, meanwhile the shaded grey areas represent the standard error of the mean.

Figure 4. Panels represent the direction of the mean vector of microsaccades (upper) and saccades (lower) across conditions (11m; 6m). each angular sector is 22.50° in width. Radial thick lines are the

mean vectors, curved lines external to the diagrams indicate the standard deviation, with the 95% of confidence interval ($p < 0.05$).

Figure 5. Plot show the pupil size dilations of all GKs during penalties kicked from 11m (solid grey line) and penalties kicked from 6m (dotted black line), correlated with the trial time until the goalkeeper's final movement initiation.

Table 1. Mean Number of Fixations and interest areas

	Epochs							
	1000 ms		**2000 ms**		**3000 ms**		**4000 ms**	
	No. of fix	**IAs**	**No. of fix**	**IAs**	**No. of fix**	**IAs**	**No. of fix**	**IAs**
11m	2.49±0.53	Trunk	2.51±0.48	Legs	2.25±0.32	Trunk	2.97±0.39	Visual Pivot
6m	2.60±0.95	Legs	2.51±0.84	Legs	2.24±0.76	Trunk	2.53±0.44	Legs
p-value	0.323		0.492		0.464		0.025*	
Cohen's *d*	0.12		0.12		0.14		1.05	

Mean (±SD) number of fixations on each interest areas (IAs) across epochs between conditions.
Asterisk indicates significant differences at $p<0.05$

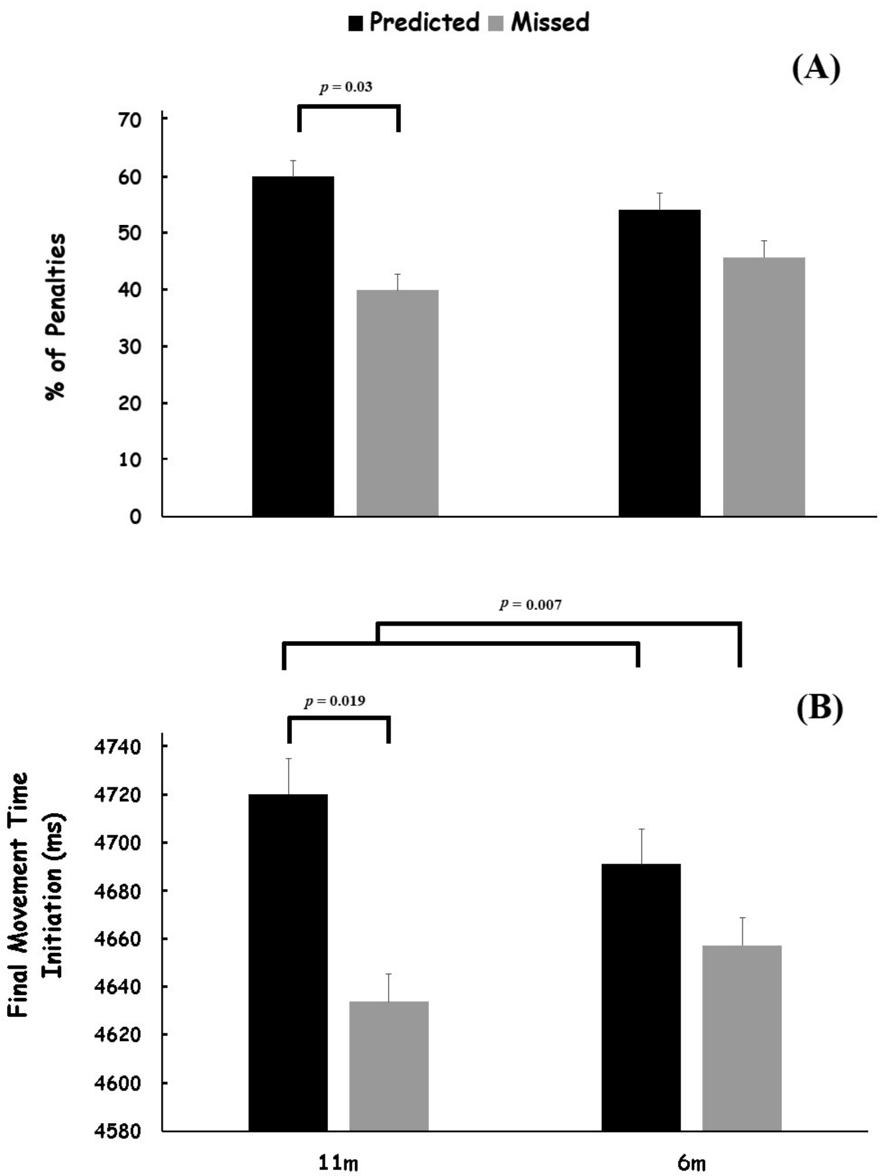

Figure 1. Histograms represent the percentage values between predicted (in black) and missed (in grey) penalty kicks across condition (11m and 6m) (A); and the response time of the goalkeepers between predicted (in black) and missed (in grey) penalty kicks across condition (11m and 6m) (B).

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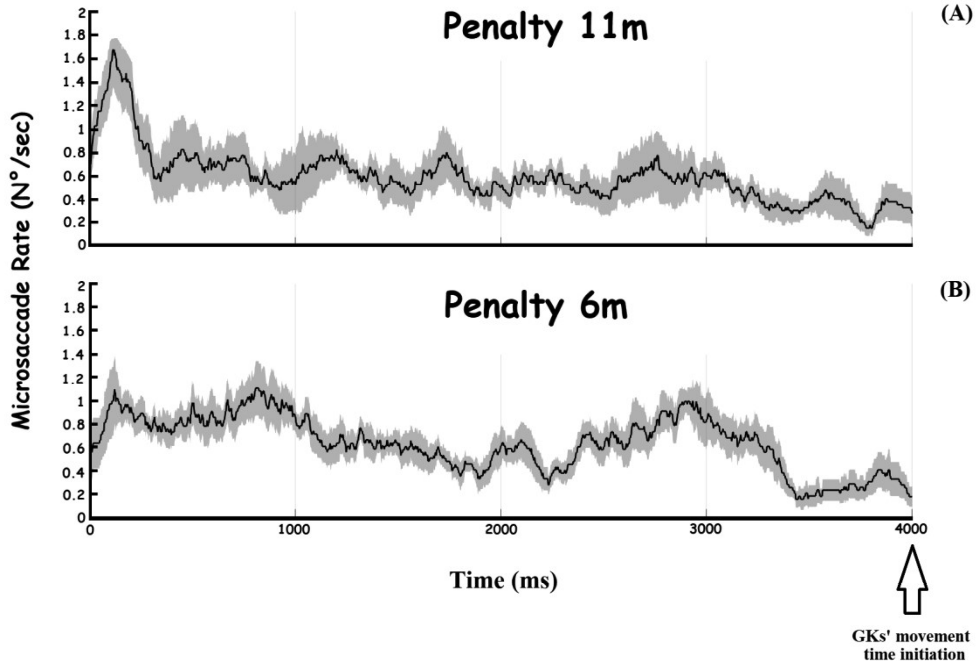

Figure 2. Time course of microsaccade rates during penalties kicked from 11m (A) and from 6m (B), calculated from the goalkeeper's final movement initiation to backwards for 4000ms. Rates were computed for each GKs using a moving time window of 200ms and then averaged over all athletes. Solid black lines represent the mean rate, meanwhile the shaded grey areas represent the standard error of the mean.

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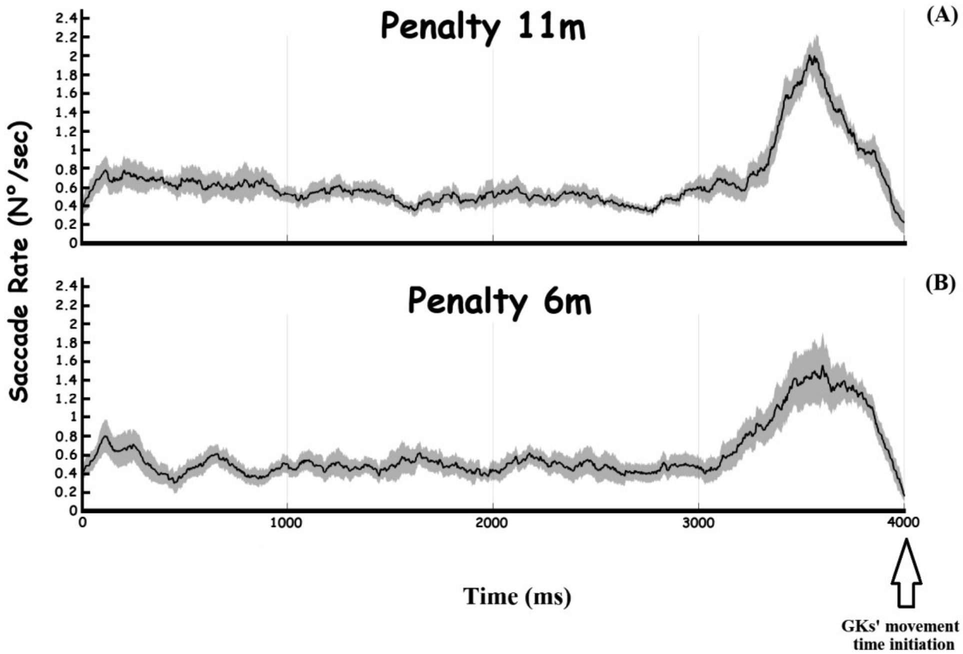

Figure 3. Time course of saccade rates during penalties kicked from 11m (A) and from 6m (B), calculated from the goalkeeper's final movement initiation to backwards for 4000ms. Rates were computed for each GKs using a moving time window of 200ms and then averaged over all athletes. Solid black lines represent the mean rate, meanwhile the shaded grey areas represent the standard error of the mean.

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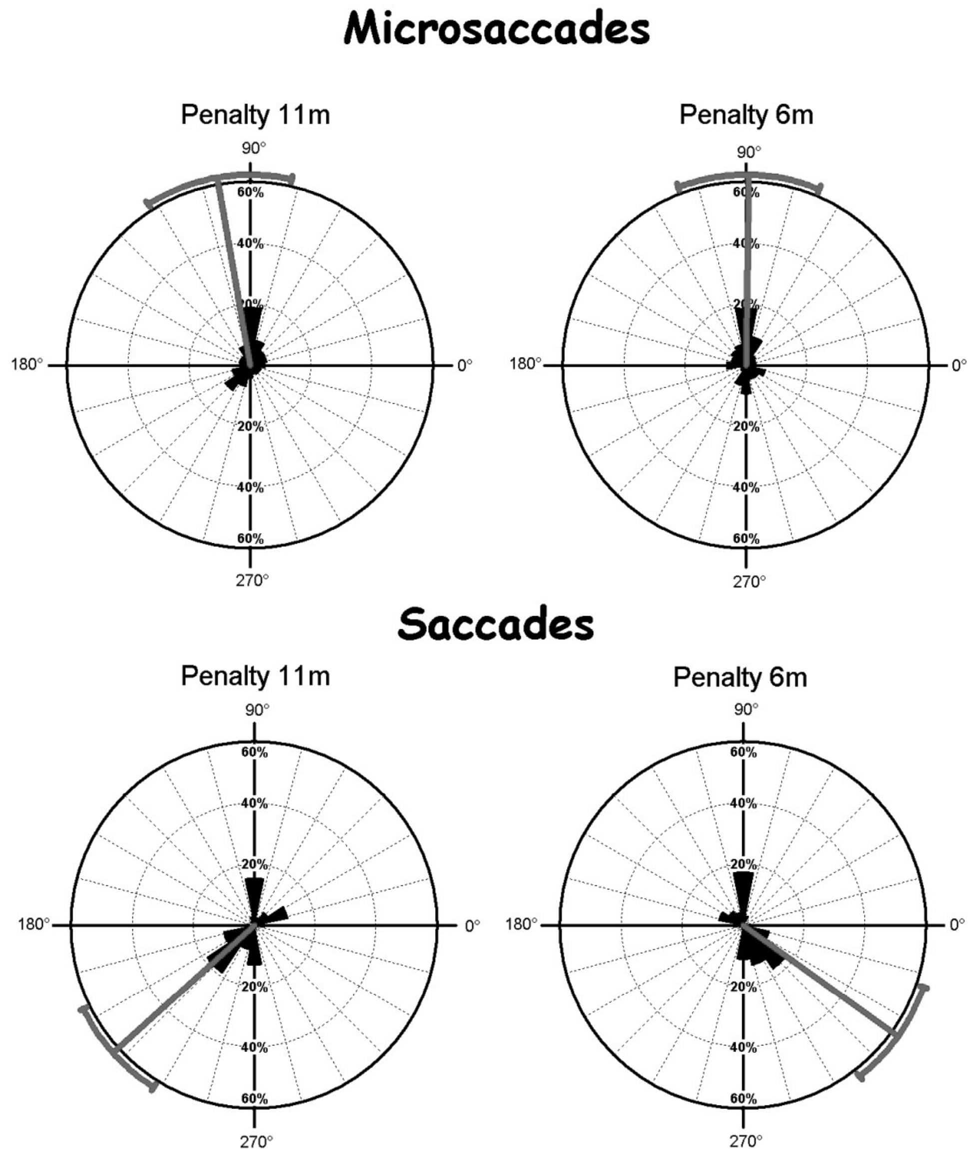

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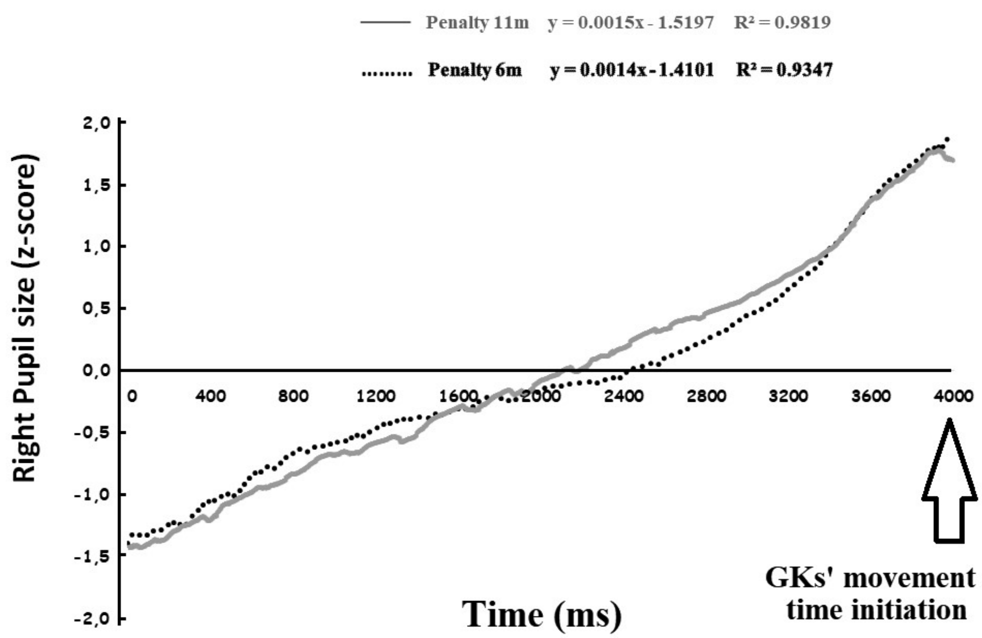

Figure 5. Plot show the pupil size dilations of all GKs during penalties kicked from 11m (solid grey line) and penalties kicked from 6m (dotted black line), correlated with the trial time until the goalkeeper's final movement initiation.

40x27mm (600 x 600 DPI)