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Understanding the underlying mechanisms of Quiet Eye: the role of microsaccades, small saccades and pupil-size before final movement initiation in a soccer penalty kick

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Abstract

Experts keep a steady final fixation at a specific location just before final movement initiation, the so-called "quiet eye" (QE). However, the eyes are rarely "quiet", and small eye movements occur during visual fixation. The current research investigated the subtle eye movements and underlying mechanisms immediately prior to and during QE. The gaze behaviour of 8 intermediate-level goalkeepers was recorded as they moved (either left or right) in an attempt to predict the future direction of the ball during a soccer penalty kick. Goalkeepers showed more predicted, with longer final movement time, than missed penalties. The temporal sequence of microsaccade rates dropped about 1000 ms just before goalkeepers' final movement initiation. Saccade rates increased, reaching the peak at about 500 ms just before final movement initiation, in concomitant with microsaccades reduction. Microsaccades anticipate the goalkeepers' direction, oriented to the right when goalkeepers moved to the right, and conversely to the left when they moved to the left. Microsaccades may be modulated by attention and appear functionally related to saccadic intrusions. Pupil-size increased proportionally with the approaching of the action, reaching a plateau at final movement initiation. In conclusion, microsaccades could improve the perception of the game, helping athletes during the period that precedes the critical movement initiation, shifting from covert to overt attention, necessary to identify the useful cue to guide the output from the motor system.

Keywords: vision, motor control, attention, perception-action, eye tracking, pupillometry

Introduction

In recent years, attention has been dedicated to examining the distinct gaze patterns that differentiate expert and novice players while performing different actions, recognising that experts kept a steady fixation at a specific location just before the critical movement initiation (Vickers, 1992). This steady fixation was identified in basketball players and termed "quiet eye" (QE; Vickers, 1996). The QE corresponds to the final fixation of at least 100 ms within 1-3° of visual angle prior to the final movement initiation. Experts exhibited longer quiet eye durations compared with non-experts, and longer durations are characteristic of successful rather than unsuccessful actions (Piras & Vickers, 2011; Timmis, Piras, & van Paridon, 2018).

In a recent review, Gonzalez et al (2017) examined the functional mechanism underlying QE, discussing the neural networks that may be involved, and in particular the relationship between attention and eye movements. Attention allocated to a fixation point results in a "suppression" of the oculomotor system (Goldberg et al., 1986), and supports the QE definition (Vickers, 1996); the "suppression" of large eye movements outside of 3° of visual angle enhances the ability to fixate on relevant cues and through discarding irrelevant stimuli, results in a more efficient extraction of information (Gonzalez et al., 2017).

The direction of attention is influenced by stimulus presentation. Overt attention occurs when gaze is directed toward an object of interest; whereas the reallocation of attention in the absence of gaze fixation is termed covert attention (Posner, 1980). Several studies have found that the allocation of covert and overt attention can be detected through microsaccades and saccades (Belopolsky & Theeuwes, 2009; Hafed & Clark, 2002). Saccades are voluntary, rapid eye movements used to re-orientate the gaze. Human saccadic eye movements vary in size from a few minutes of arc to 100°, most naturally occurring, human saccades are 15° or less in magnitude, with peak velocities ranging from 3 to 600 °/seconds (Liversedge et al., 2012). Microsaccades are much smaller (≤1°)involuntary rapid eye movements (≤100 °/sec) that occur 1–2 times/sec during fixations (for a review see

Martinez-Conde et al., 2013). When considering the QE definition, it is important to highlight that the eyes are rarely "quiet", and that small eye movements occur during visual fixation, the so-called fixational eye movements. Microsaccades (a categorisation of fixational eye movements) help to perform high-acuity tasks. These subtle eye movements restore the fixated image which would otherwise fade from view due to neural adaptation (McCamy et al., 2012). Indeed, research has demonstrated that when all eye movements are eliminated (i.e., under retinal stabilization conditions), visual perception rapidly fades to a homogeneous field (Ditchburn & Ginsborg, 1952; Riggs & Ratliff, 1952). Microsaccades counteract fading, and are most effective when they exhibit a high frequency and large amplitude, due to their increased ability to bring the neuronal receptive fields to regions not correlated with the target stimulus (McCamy et al., 2012). This could be linked with QE duration and important for performance. Microsaccades with low frequency and small amplitude may suggest enhanced attention to a small target area only and no or very little peripheral visual information pickup. In contrast, high frequency and large amplitude may suggest that peripheral visual fading is avoided, thus a very accurate fixation may not be required (Piras et al., 2015, 2019). To date only two studies have investigated the role of fixational eye movements in sport (Piras, Raffi, Lanzoni, Persiani, & Squatrito, 2015; Piras, Raffi, Perazzolo, Malagoli Lanzoni, & Squatrito, 2019), showing that microsaccades could be influenced by attentional cues, revealing links between visuomotor performance and covert attention shifts, needed for the prediction of the action development. Therefore, microsaccades may be modulated by attention and appear functionally related to saccadic intrusions, which are also influenced by the shift of attention (Gowen et al., 2007). Thus, these subtle eye movements within QE may provide an important understanding regarding the link between the oculomotor control, visual perception and attention allocation in athletes.

With the same cortical areas involved in both the allocation of spatial attention and the control of eye movements (Moore & Fallah, 2001) and during fixation, the allocation of attention produces a saccadic "suppression" in terms of amplitude and peak velocity (Gonzalez et al., 2017). These results strongly support the idea that the allocation of attention leads to an activation of oculomotor circuits, in spite of eye immobility (Sheliga et al., 1995). All these mechanisms could be included to the QE definition, which indicates the suppression of large eye movements within 1–3° of visual angle, with the improved capacity to fixate on relevant cues, and the ability to avoid irrelevant stimuli for a more efficient extraction of information (Piras & Vickers, 2011). Moreover, it could also be important to analyse the pupil diameter during the task, because larger pupil diameter reflects increased attentional resource allocation (Moran et al., 2016). Pupil dilation could be the best predictor of the attentional effort, as it reflects the current rate at which mental energy is used (Kahneman, 2011). In accordance with this, a recent study (Alnæs et al., 2014) has revealed that pupil diameter foresees brain activity in the locus coeruleus, that is the main centre of the brain's noradrenergic system, and it is assumed to modulate the processes of the brain's attentional systems. Task-evoked pupil dilations are extensively conveyed in the literature (Beatty, 1982; Karatekin, Couperus, & Marcus, 2004) and the degree of the pupillary dilation appears to be also a function of the cognitive workload required to perform the task (Porter, Troscianko, & Gilchrist, 2007).

With the assumed relationship among microsaccades, visual perception, and direction of attention, the current research investigated the role of small saccades, microsaccades and pupil-size when a goalkeeper was tasked with predicting the direction of a soccer penalty kick. Our research specifically analysed the time period immediately prior to and during QE period of the soccer penalty kick. Previous research has demonstrated that during a soccer penalty kick, expert goalkeepers tended to spend more time fixating on the opponent's kicking leg, non-kicking leg and ball regions, particularly as the moment of foot-ball contact approached (Kim & Lee, 2006; Piras & Vickers, 2011; Savelsbergh, Williams, Van der Kamp, & Ward, 2002). Piras and Vickers (2011) found that the QE was located between the ball and the kicking action, area subsequently called "visual pivot", that was fixated as the final kicking action occurred. Therefore, we can hypothesize from these elements that athletes, just before final movement initiation, maintain a steady fixation on the visual pivot to predict the outcome of a sporting action, shifting their attention, with microsaccades or small saccades, toward the side where they think that the opponent could kick the ball. Accordingly, the accuracy of prediction depends on the ability to shift visual attention from one location to another by identifying the useful cue in the visual field, using both foveal and para-foveal vision.

Methods

Participants

Eight (n = 8) intermediate-level male goalkeepers with a mean age of 23.5 (SD = 5.2) years and one (n = 1) right footed male kicker of 28 years volunteered for the experiment. Based on the effect size evident in Piras and Vickers' study (2011), G*power, version 3.1.9.2 (Franz Faul, Christian-Albrechts-Universität Kiel, Kiel, Germany), predicted that a total sample size of 7 would give sufficient power (0.80) to detect a significant difference at alpha level of 0.05. One additional participant was included to ensure availability of data in case of missing or corrupt data. 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. All had 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 11 m from the centre of the goal. The kicker was required to start his run-up 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 (goalkeepers' perspective). These videos were used in the experiment.

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 catch the ball as they were in the soccer pitch (Figure 1).

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

The video was presented from when the kicker started approaching the ball up to the ball passing to the right or to the left of the goalkeepers' point of view. In soccer, goalkeeper movements typically occurred through side-steps. Therefore, goalkeepers were instructed to predict the ball direction by moving laterally (left or right) in an attempt to correctly predict the ball direction and catch the ball as they would on a soccer pitch, but without diving. Goalkeepers were given a familiarisation period with the experiment, where they were presented, randomly, with penalties (not the same videos of the experiment) kicked to the right and to the left. In total, each participant faced 30 penalties. Penalties were subdivided into three blocks, with the same ten videoclips in each block interspersed by 5 minutes of rest. Each clip had a mean duration of 6 seconds. The 10 penalties were presented in a random sequence, and the randomization was kept in the same order for each participant. Overall, a total number of 240 clips were analysed.

Eyes and body movement recording

Horizontal and vertical eye movements were recorded binocularly by a video-based eye tracking system (EyeLink® II, SR Research) consisting 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°.

The eye tracker was calibrated at the beginning of the experiment and after every 10 videos. Then, data validation and drift correction were performed 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 trial, and if necessary, a drift correction was performed. Practice, calibration, validation and data collection took about 30 minutes per participant.

In order to collect right and left body movement, two inertial sensors (Cometa Systems, Italy) were positioned on the goalkeepers' anterior superior iliac spine, one to the right and one to the left. Inertial sensors were synchronised with the EyeLink system in order to have corresponding goalkeepers' eyes and body movement data.

Data analysis

The number of video frames used for analysis was initially selected. Due to the QE definition (Vickers, 1996), which is the final fixation before the goalkeeper's final movement initiation, data was analysed from 4000 ms prior to the instance where goalkeepers started their final movement; analysis showed an average response time of 4677 ms in all clips.

Analyses then considered response accuracy (correct or incorrectly predicted) and the final movement time, that is the time in ms from the trial start to goalkeepers' final movement to predict the ball. Goalkeepers were required to react between <150-400> ms after foot-ball contact, otherwise trials were excluded from analysis, due to early or delayed movement necessary to catch the ball (Morya et al., 2003).

Both variables, response accuracy and movement time initiation, were analysed separately, in which a repeated measures ANOVA were performed with trial blocks (1-3) and response accuracy (correct or incorrect prediction) as the within-subjects factors.

Fixation was defined when the gaze was stable inside 1° of visual angle for a minimum of 100 ms (Piras & Vickers, 2011). Microsaccades were defined as eye movements smaller than 1° in amplitude, with a peak velocity smaller than 100°/sec, and that followed the same peak velocity versus amplitude curve as large saccades (Zuber et al., 1968). Microsaccades and saccades were identified using the algorithms of Otero-Millan et al. (2014). In the current study, microsaccades were only considered if they occurred simultaneously in both eyes during at least 3 data samples (6 ms). Data was excluded 200 ms before and after each blink as well as when the pupil was still partially occluded (Otero-Millan et al., 2008). Microsaccade and saccade amplitudes, durations, and peak velocities were first calculated for each goalkeeper in each condition (left and right goalkeepers' direction, correct or incorrect prediction) separately. Then, the values of all subjects in each condition were averaged. Microsaccade rates were calculated considering the duration of each clip (4000 ms).

A 2 x 2 repeated measures ANOVA was performed separately to analyse microsaccade rate, and microsaccade and saccade amplitude, duration, and peak velocity. Goalkeepers' movement direction (right, left) and response accuracy (correct or incorrect prediction) were the within-subjects factors.

Two-dimensional distribution of all microsaccade and saccade orientation were calculated with respect to goalkeepers' movement directions (right, left). The Watson-Williams test for homogeneity of means (Oriana® 4.0) was performed in which the null hypothesis was that the orientations of microsaccades and saccades between goalkeepers' movement direction (left versus right) have similar continuous distribution at the 5% level of significance. Furthermore, analysis considered response accuracy (correct or incorrect prediction) as a dependent variable to reveal any relationships between response accuracy and saccade and microsaccade orientation.

The raw data from the pupil diameters were normalised with z-scores procedure, by expressing every sample as a standard deviation score from the mean calculated within each clip. This procedure allowed data to be comparable across condition (Jainta et al., 2011). Left and right pupil size diameters were correlated with the duration of the corresponding clip, from the trial start to goalkeepers' final movement to predict the ball. Then, each correlation was analysed with a 3 × 2 repeated measures ANOVA where trial blocks (1-3) and response accuracy (correct or incorrect prediction) were the within-subjects factors.

Effect sizes were calculated as the mean difference standardised by the between-subject standard deviation and interpreted according to the following thresholds: trivial, <0.20; small, ≥0.20<0.50; moderate, ≥0.50<0.80; large, ≥0.80 (Cohen, 1988). Partial eta squared (η_p^2) was used during multiple comparisons. Statistical significance was set at $p < 0.05$. Post hoc test was corrected with Bonferroni procedure.

Results

After pre-processing data, in which responses shorter than 150 ms and longer than 400 ms (early or delayed responses) were discarded (see Methods for description), 216 clips were retained for analysis (of a total of 240; 24 clips were excluded).

Response accuracy and final movement time

Analysis of variance showed a significant main effect for response accuracy ($F_{1,7} = 48.0$, $p = 0.030$, $\eta_p^2 = 0.51$), with more penalty kicks correctly (60%) than incorrectly predicted (40%) across all blocks. For final movement time analysis, ANOVA showed a significant main effect for response accuracy ($F_{1,7} = 9.77$, $p = 0.017$, $\eta_p^2 = 0.58$), in which goalkeepers showed a slower movement time during correctly than incorrectly predicted penalty kicks (4721ms vs. 4634 ms), and it was exhibited in all blocks.

Saccade and microsaccade characteristics

Microsaccade and saccade rates have been calculated considering the total time in each trial (4000 ms). The temporal sequence of microsaccade rates was mostly constant for all time analysed, lowering about 1000 ms just before goalkeepers' final movement started (Figure 2). Meanwhile, saccade rates increased, reaching the peak at about 500 ms just before the final movement initiated, in concomitant with microsaccades reduction (Figure 2).

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

There was significant difference in microsaccades duration between correctly vs. incorrectly predicted penalty kicks, in which correct prediction showed longer microsaccades than incorrect prediction (37.4 vs 33.3 ms; $F_{1,204} = 4.94$, $p = 0.027$, $\eta_p^2 = 0.024$). No significant differences were observed for amplitude (mean 0.62±0.08 and 0.63±0.07° of visual angle) and peak velocity (mean 42.35±2.10 and 43.01±4.22 °/second) between correctly and incorrectly predicted penalties.

There was no significant difference between correctly and incorrectly predicted penalties for saccades duration (mean 114.91±15.79 and 106.72±10.72 seconds), amplitude (mean 3.50±0.29 and 3.67±0.46° of visual angle) and peak velocity (mean 112.68±3.69 and 121.59±8.07 °/second).

Saccade and microsaccade orientation

Microsaccades orientation showed significant differences between right and left goalkeepers' movement [t-test (7) = 2.62; $p = 0.034$; $d = 0.63$], and given that goalkeepers' gaze behaviour was analysed before their final movement initiation (so the ball was still on the penalty spot), we can suppose that microsaccades anticipate the goalkeepers' direction, showing a main vector directed to the right when goalkeepers moved to the right, and conversely to the left when moving to the left (Figure 3). Saccades orientation instead showed a main vector directed to the left for both left and right goalkeepers' movement direction ($p = 0.45$; Figure 3 lower panel).

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

Pupil size changes

There was a significant positive correlation between pupil size and the progression of the action (r = 0.86), meaning that, the pupil increases as the goalkeepers' perception of the penalty taker intention develops (Figure 4). In fact, pupil size reaches the greatest value just before the goalkeepers started their final movement, and was significantly higher for correctly than incorrectly predicted penalties ($F_{1,7}$ = 12.81, p = 0.009, η_p^2 =0.65).

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

Discussion

The purpose of this study was to deepen our knowledge about what happens before the critical movement initiation and during the QE period, investigating the role of microsaccades, small saccades, and pupil diameter during the approaching of the foot-ball contact. The analysis was focused on the gaze behaviour of intermediate level soccer goalkeepers trying to predict penalty kicks directed to the left and to the right of their goal. Given the relationships between microsaccades, visual perception, and with the allocation of attention when the eyes are fixating, the current study hypothesises that athletes, during the period that precedes the final movement initiation and during QE, shift their attention with microsaccades or small saccades, identifying the useful cue with both foveal and parafoveal vision.

Correct prediction occurred in 60% of trials, with a slower movement time, with respect to 40% of incorrectly predicted penalty kicks. Bar-Eli and Azar (2009) have documented that elite goalkeepers who play at the international level stop a mean of 30% of penalty kicks, then, our results approached this level.

Analysis of microsaccade rates demonstrated a drop about 1000 ms just before goalkeepers' final movement started. Meanwhile, saccade rates increased, reaching the peak at about 500 ms just before the final movement initiated, concomitant with microsaccades reduction. Microsaccades can be suppressed during fine visual tasks, suggesting they may be modulated by attention and appear functionally related to saccadic intrusions, which are also influenced by the shift of attention (Gowen et al., 2007; Piras, Raffi, et al., 2016). Microsaccade generation is modulated by stimulus presentation

(Hafed & Clark, 2002; Piras, Raffi, Lanzoni, Persiani, & Squatrito, 2015), with a short inhibition after stimulus appearance, followed with an increased rate of microsaccade occurrence, or as in this situation, small saccade manifestation. In the current study the mean saccadic amplitude was about 3° of visual angle, microsaccadic amplitude was about 0.6° of visual angle. Some of the saccades greater than 1° produced during prolonged fixation, and possibly during free-viewing, may be involuntary and could be therefore categorized as microsaccades (Otero-Millan et al., 2008). As highlighted by Gonzalez et al. (2017), in the definition of QE, the term fixation at 1-3° of visual angle, could incorporate different types of eye movements, such as saccades, microsaccades, and smooth pursuit, that may be used as a functional mechanism to predict an action, without fitting inside the normal definitions of fixation. Moreover, a high frequency of microsaccades may facilitate larger saccadic intrusions that may fall inside of the QE threshold. Moderate head motion requires the involvement of oculomotor compensatory mechanisms, such as the vestibulo-ocular response, optokinetic reflexes, smooth pursuit or saccades. This could suggest that other gaze behaviours may be considered in the measured QE period, particularly at the larger 3° threshold (Gonzalez et al., 2017). The eye tracker used in the current study, with high-resolution (under 0.1° of spatial resolution and sampling at 500 Hz), was suitable to identify differences in oculomotor control, and the amount and/or type (pursuit, saccades, microsaccades) of eye movements related to attention/inhibition mechanisms (Gonzalez et al., 2017). In recent years there has been renewed interest in the role of microsaccades and other small saccades during fixation, including their role in perceptual tasks and their links to attention (Kowler, 2011). Recent works suggest that microsaccades may be suitable in tasks where gaze is centrally located between different interest areas (Piras et al., 2015; Piras et al., 2019), as for example inside of 3° of visual angle.

Significant differences were found in microsaccade orientations, in which microsaccades anticipate the goalkeepers' direction, showing a main vector directed to the right when goalkeepers moved to the right, and conversely to the left when moving to the left. These results suggest that microsaccades are not casual, rather they could indicate where our attention is unconsciously focusing (Figure 3, upper panel). A clear polarization of microsaccade orientation means that a specific location has been focused, most likely under the control of covert attention shift. However, saccades reached their peak 500 ms before the goalkeepers' final movement initiation, showing a mean direction to the lower left of the goalkeepers' visual field, irrespective of subsequent movement direction. We can suppose that this saccade orientation may be conditioned by the penalty taker's body movement, as he approached the ball from the right to the left of the goalkeepers' point of view.

Particular attention should be directed toward pupil dilation, given that no research has investigated its role during the prediction of a sport action. To our knowledge, the only two studies that have analysed pupillometry during a sport action were that of Campbell et al (2019) where golfers showed high and consistent pupil dilations during the putting tasks, and that of Moran et al. (Moran et al., 2016) who found that pupillometry can be used to identify skill-based differences in attentional effort during QE in equestrian performers viewing a video-based show-jumping sequence. In the current study, we demonstrated that multisensory integration between stimulus-response influenced these ocular movements. Larger pupil dilation and microsaccade inhibition, as well as saccade response, were observed when a complex visual stimulus was projected to our participants and aligned in space and time with their motor response. The pupil dilates prior to saccade initiation, and this increase in pupil size could increase visual sensitivity to optimize perceptual processes immediately after redirection of the eyes (Wang, Blohm, Huang, Boehnke, & Munoz, 2017). Pupil dilation, microsaccades and saccades occurrence are additional components of orienting (Corneil & Munoz, 2014; Wang & Munoz, 2015), and both can be evoked and modulated following the appearance of relevant stimuli (Wang & Munoz, 2014). Moreover, there is a connection between pupil dimension, microsaccades and saccades. Wang et al. (2012) found the central role of the superior colliculus on pupil dilation and microsaccade generation through recording on single neurons. Because the superior colliculus is importantly involved in both multisensory integration and initiation of the orienting response (Boehnke & Munoz, 2008; Corneil & Munoz, 2014), our results implicate the superior colliculus in coordinating such behaviour. In the current study, the presentation of a salient stimulus has produced a series of coordinated eye movements, between saccades, microsaccades and pupil dilatation, with the intention to orient the body towards the predictive timing task.

Of note, despite not being reported in the results section, analysis of the final fixation confirmed previous results (Kim & Lee, 2006; Piras & Vickers, 2011; Savelsbergh et al., 2002), showing that a longer fixation duration was located on the visual pivot, a location between the ball and the kicking action just before the final movement initiation. To avoid repetition, these results have not been reported, and instead we focused on saccades and microsaccades produced before final movement initiation. The potential role of visual pivot, and its contribution to goalkeepers making successful saves in a soccer penalty kick, was identified and described in a number of studies (Piras, Lanzoni, Raffi, Persiani, & Squatrito, 2016; Piras, Raffi, Lanzoni, Persiani, & Squatrito, 2015; Piras et al., 2019; Piras, Lobietti, & Squatrito, 2014; Piras & Vickers, 2011; Ripoll, Kerlirzin, Stein, & Reine, 1995; Williams & Elliott, 1999), and reviewed extensively by Vater et al., (2019). The effective use of such “gaze pivot”, with the gaze centrally positioned between different areas, allows the use of both foveal and parafoveal vision, shifting the attention (overt to covert) to acquire information from interest areas in which informational content is high (Piras et al., 2019). Finally, the functionality of the visual pivot would then be to maintain the gaze on a location close to relevant cues and initiate (micro-) saccades to these cues (Vater et al., 2019).

How visual information is presented, and the response required to this information (i.e., representative design c.f. Araújo et al., 2007), can influence individuals’ visual search strategies. If eye movement behaviours and required responses in an experimental setting differ from what participants would experience in a real competitive environment, external validity is reduced, and generalisability of findings are limited (Araújo et al., 2007; Dhami et al., 2004; Dicks et al., 2010). However, whilst representative designs are theoretically desirable, the challenges of achieving truly representative studies necessitate that hybrid designs may have to be used as an alternative (Dhami et al., 2004; Dicks et al., 2010). Hybrid designs may incorporate aspects of systematic design (e.g., increased experimental control over conditions, control or removal of variables that are irrelevant, or that may mask effects) (Dicks et al., 2010; Pluijms et al., 2013), whilst attempting to be as representative as possible. In the current study, a hybrid design was used where goalkeepers were required to move in response to a 'life-size' projection of a soccer penalty kick taker. This design was necessitated by the requirements of the eye tracker (binocular with at least 250 Hz of sample/s) and to our knowledge, in commerce there is no device with these characteristics that can be used in a more dynamic situation (Dhami et al., 2004; Pluijms et al., 2013).

Future research should be directed to analyse goalkeepers' gaze behaviour with respect to penalty taker movement phases to have information about time course of microsaccade/saccade orientation in relation to penalty taker's run up/kicking action (Piras et al., 2015). Moreover, could be interesting to better understanding the subtle eye movements and underlying mechanisms immediately prior to the critical movement initiation of athletes during aiming tasks (e.g., penalty taker in soccer; attacker in volleyball) through the use of deceptive gaze behaviours to cover their intentions. A deceptive strategy and a blind-pass strategy (also known as no-look pass) are performed when a player looks in one direction but shoot or pass the ball to another direction. This is a typical sport action in which gaze direction and attention are separated (Piras et al., 2019). Despite the extensive use of deceptive gaze and no-look pass in sports, little empirical evidence exists to support the utility of such behaviours (Wood et al., 2017). Therefore, future research could address more specifically the microsaccade occurrence and features during these strategies.

In conclusion, the results of the present experiment suggest that microsaccades are important to anticipate the goalkeepers' direction, modulated by visual attention and functionally related to saccadic intrusions. These microsaccades could improve the perception of the game, helping athletes during the period that precedes the critical movement initiation, shifting from covert to overt attention, necessary to identify the useful cue with both foveal and parafoveal vision.

Disclosure statement

No potential conflict of interest was reported by the authors.

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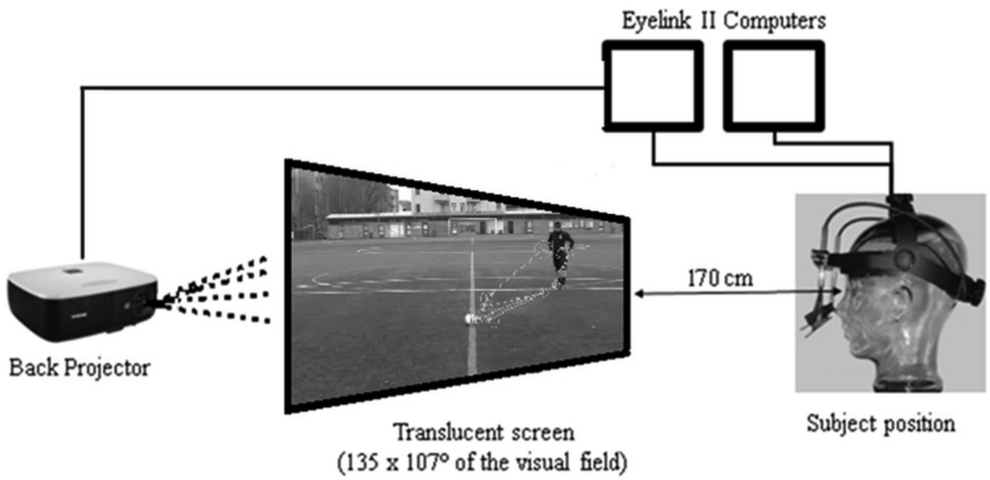
Figure captions

Figure 1. Experimental setup showing subject wearing the eye tracker, standing in front of the translucent wide screen, in which the videos were back projected**.**

Figure 2. Time course of microsaccades and saccades rate calculated from the final movement initiation to backwards for 4000 ms. Rates were computed for each goalkeeper using a moving time window of 200 ms and then averaged over all participants. Solid lines represent the mean rate of microsaccades (upper plot) and saccades (lower plot), with the shaded area around each curve that represents the standard error of the mean.

Figure 3. Panels represent the mean vector direction of microsaccade (upper) and saccades (lower) across condition (left; right goalkeepers' movement). 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 4. Plot show the increases of left (grey line) and right (black line) pupil size (z-score) of all participants, correlated with the time of the trial, reaching a plateau at the goalkeepers' final movement initiation.



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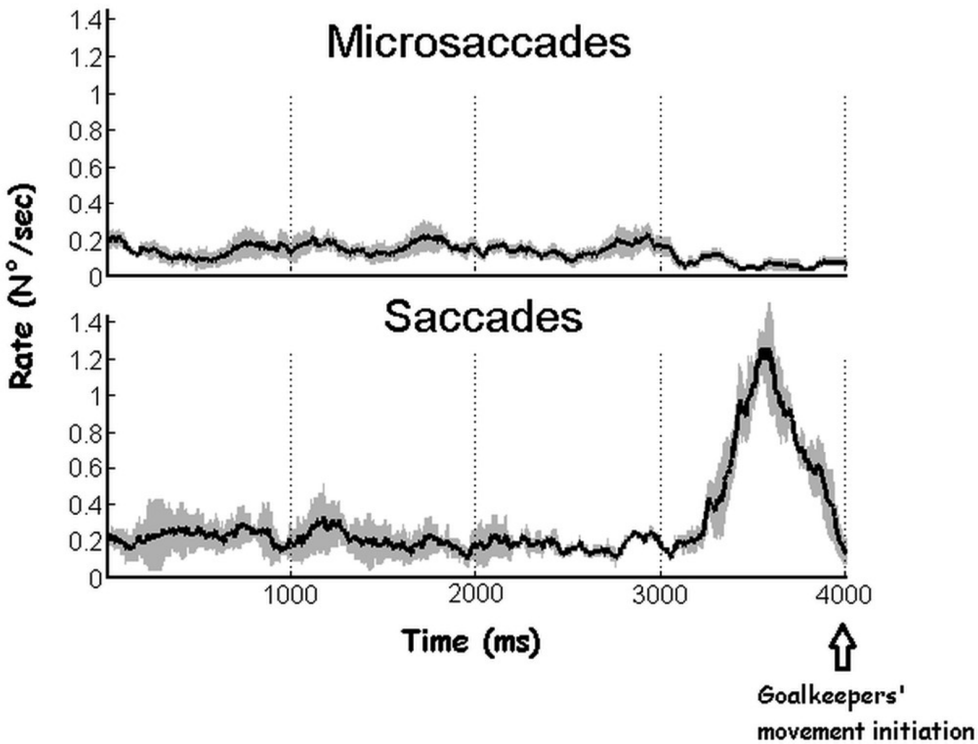
43x20mm (600 x 600 DPI)



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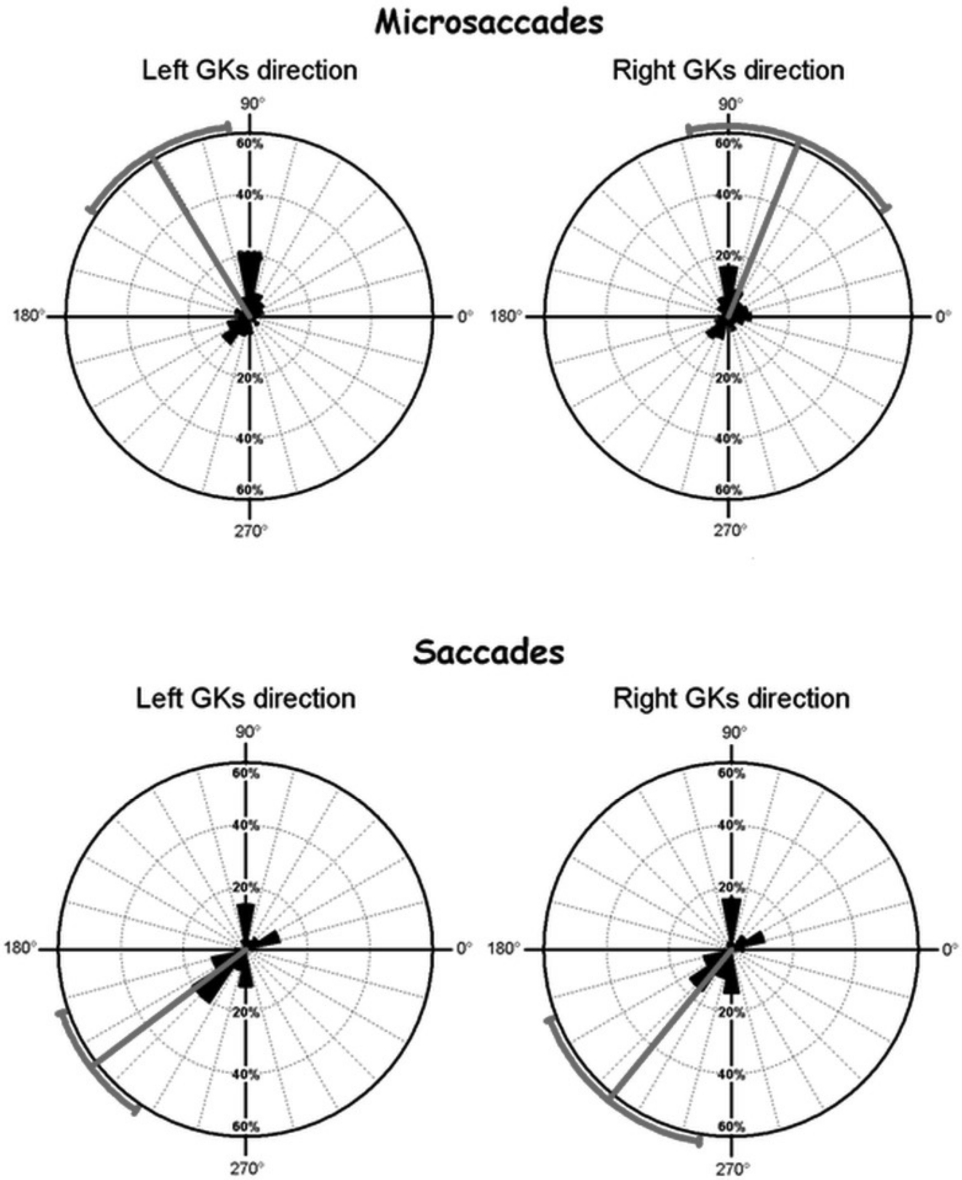

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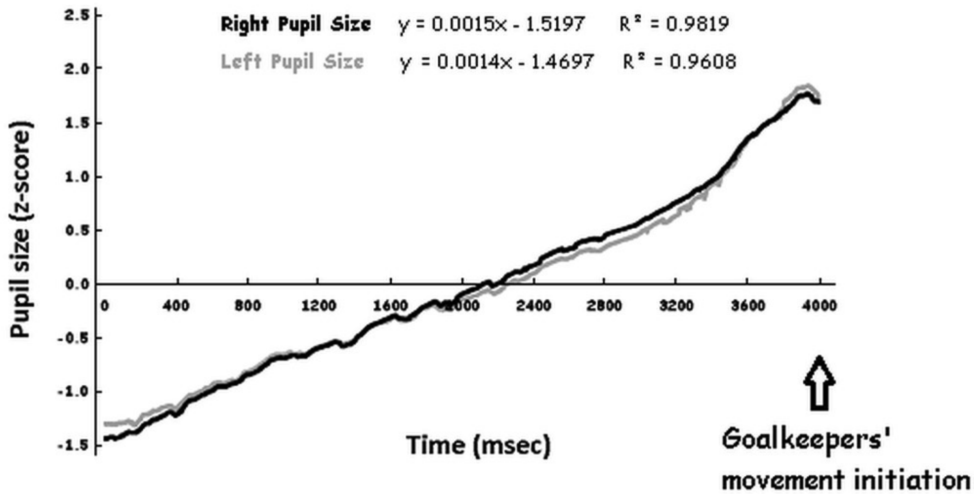

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43x23mm (600 x 600 DPI)