

# Alma Mater Studiorum Università di Bologna Archivio istituzionale della ricerca

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

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Piras A., Timmis M., Trofè A., Raffi M. (2021). 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. EUROPEAN JOURNAL OF SPORT SCIENCE, 21(5), 685-694 [10.1080/17461391.2020.1788648].

Availability:

This version is available at: https://hdl.handle.net/11585/821388 since: 2024-06-04

Published:

DOI: http://doi.org/10.1080/17461391.2020.1788648

Terms of use:

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (https://cris.unibo.it/). When citing, please refer to the published version.

(Article begins on next page)



## 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

Journal:	European Journal of Sports Science
Manuscript ID	TEJS-2019-1191.R2
Manuscript Type:	Original Paper
Keywords:	Motor Control, Prediction, Cognition, Behavior

L

SCHOLARONE <sup>™</sup>
Manuscripts

# Title: 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

#### 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

#### 25 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 reorientate 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 ( $\leq 1^{\circ}$ )involuntary rapid eye movements (≤100 °/sec) that occur 1-2 times/sec during fixations (for a review see 

Page 3 of 27

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 eve 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 22 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 eve 

saccadic "suppression" in terms of amplitude and peak velocity (Gonzalez et al., 2017). These results 

movements (Moore & Fallah, 2001) and during fixation, the allocation of attention produces a

3 4 5 6 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 8 definition, which indicates the suppression of large eye movements within  $1-3^{\circ}$  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 22 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 

Page 5 of 27

1

60

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.

13 104 Methods

#### 105 **Participants**

19 106 Eight (n = 8) intermediate-level male goalkeepers with a mean age of 23.5 (SD = 5.2) years and one <sup>21</sup> 107 (n = 1) right footed male kicker of 28 years volunteered for the experiment. Based on the effect size 24<sup>108</sup> 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 26 109 <sup>28</sup> 110 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 111 of the study, the goalkeepers had been playing soccer for 14.7 years, and trained on average 3.5 times, 33 112 35 113 7 hours per week, with a competitive match at the end of the week. All had normal vision, and after 37 38 114 receiving oral and written information concerning the study protocol, all participants gave their 40 115 written informed consent to participate in the study. The study was approved by the Bioethics Committee of the University of Bologna. 42 116

#### 45 117 Stimuli and procedure

48 118 A right footed male kicker was filmed, from the participants' (goalkeepers') perspective, with a 49 50 119 digital video camera (Casio® 300 frames/s, with a max resolution  $1280 \times 960$  pixels) positioned in 52 the middle of a standard, full sized (7.32 m wide and 2.44 m height) soccer goal, with the ball (size 53 120 5) positioned 11 m from the centre of the goal. The kicker was required to start his run-up at least 4 55 121 5) positioned 11 m from the same approaching angle for all penalty kicks. Ten penalty kicks were 58 59

filmed and subsequently subdivided in five directed to the right and five to the left (goalkeepers' 123 perspective). These videos were used in the experiment. 124

The experiments were performed in the dark. Stimuli were back-projected (Epson EB-W12, 720  $\times$ 125 10 486 resolution; frame rate 60 Hz) onto the translucent screen positioned 300 cm away. The screen 11 126 12 covered  $135 \times 107^{\circ}$  of visual field and was placed 170 cm from the goalkeepers' eyes, who stood in 13 127 14 15 front of the screen ready to catch the ball as they were in the soccer pitch (Figure 1). 128 16

18 19 129

17

20

1 2 3

4 5

6 7 8

9

## \*\*\*\*\*Figure 1 near here\*\*\*\*\*\*

21 130 The video was presented from when the kicker started approaching the ball up to the ball passing to 22 23 24<sup>131</sup> the right or to the left of the goalkeepers' point of view. In soccer, goalkeeper movements typically 25 26 132 occurred through side-steps. Therefore, goalkeepers were instructed to predict the ball direction by 27 <sup>28</sup> 133 moving laterally (left or right) in an attempt to correctly predict the ball direction and catch the ball 29 30 as they would on a soccer pitch, but without diving. Goalkeepers were given a familiarisation period 134 31 32 with the experiment, where they were presented, randomly, with penalties (not the same videos of the 33 135 34 35 136 experiment) kicked to the right and to the left. In total, each participant faced 30 penalties. Penalties 36 <sup>37</sup> 137 were subdivided into three blocks, with the same ten videoclips in each block interspersed by 5 38 39 40 138 minutes of rest. Each clip had a mean duration of 6 seconds. The 10 penalties were presented in a 41 random sequence, and the randomization was kept in the same order for each participant. Overall, a 42 139 43 <sup>44</sup> 140 total number of 240 clips were analysed. 45

#### 47 141 Eyes and body movement recording 48

<sup>50</sup> 142 Horizontal and vertical eye movements were recorded binocularly by a video-based eye tracking 51 52 53 143 system (EyeLink® II, SR Research) consisting of two miniature cameras mounted on a leather-54 55 144 padded headband. Pupil tracking was performed at 500 samples/s, with a gaze resolution <0.005° and 56 noise limited to <0.01°. 57 145 58

59

46

49

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.

#### 156 **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.

52

2 3 Fixation was defined when the gaze was stable inside 1° of visual angle for a minimum of 100 ms 169 4 5 (Piras & Vickers, 2011). Microsaccades were defined as eye movements smaller than 1° in amplitude, 170 6 7 with a peak velocity smaller than 100°/sec, and that followed the same peak velocity versus amplitude 8 171 9 10 172 curve as large saccades (Zuber et al., 1968). Microsaccades and saccades were identified using the 11 12 13 173 algorithms of Otero-Millan et al. (2014). In the current study, microsaccades were only considered if 14 15 174 they occurred simultaneously in both eyes during at least 3 data samples (6 ms). Data was excluded 16 17 175 200 ms before and after each blink as well as when the pupil was still partially occluded (Otero-18 19 Millan et al., 2008). Microsaccade and saccade amplitudes, durations, and peak velocities were first 176 20 21 22 177 calculated for each goalkeeper in each condition (left and right goalkeepers' direction, correct or 23 24 178 incorrect prediction) separately. Then, the values of all subjects in each condition were averaged. 25 <sup>26</sup> 179 Microsaccade rates were calculated considering the duration of each clip (4000 ms). 27 28 <sup>29</sup> 180 A 2 x 2 repeated measures ANOVA was performed separately to analyse microsaccade rate, and 30 31 32<sup>181</sup> microsaccade and saccade amplitude, duration, and peak velocity. Goalkeepers' movement direction 33 (right, left) and response accuracy (correct or incorrect prediction) were the within-subjects factors. 34 182 35 36 <sub>37</sub> 183 Two-dimensional distribution of all microsaccade and saccade orientation were calculated with 38 39 184 respect to goalkeepers' movement directions (right, left). The Watson-Williams test for homogeneity 40 <sup>41</sup> 185

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

3	194
4 5	
5 6	19
7	
8	19
9	
10	10
11	1)
13	19
14	15
15	199
16	
1/	200
10	-
20	20
21	
22	
23	202
24	
25 26	203
27	
28	204
29	
30	20
31	
33	• •
34	20
35	
36	20
37 38	
39	20
40	
41	20
42	
43 11	21
45	
46	21
47	
48	21
49 50	
50	21:
52	<u> </u>
53	
54	214
55	
56 57	21
57 58	
59	21

goalkeepers' final movement to predict the ball. Then, each correlation was analysed with a  $3 \times 2$ 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,  $\ge 0.20 < 0.50$ ; moderate,  $\ge 0.50 < 0.80$ ; large,  $\ge 0.80$  (Cohen, 1988). Partial eta squared ( $\eta_p^2$ ) was used during multiple comparisons. Statistical significance was set at *p* < 0.05. Post hoc test was corrected with Bonferroni procedure.

3 202 **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).

### 206 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.

### 213 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, before goalkeepers' final movement started (Figure 2).

1 2 3 saccade rates increased, reaching the peak at about 500 ms just before the final movement initiated, 217 4 5 in concomitant with microsaccades reduction (Figure 2). 218 6 7 8 \*\*\*\*\*Figure 2 near here\*\*\*\*\* 219 9 10 11 There was significant difference in microsaccades duration between correctly vs. incorrectly 220 12 13 <sub>14</sub> 221 predicted penalty kicks, in which correct prediction showed longer microsaccades than incorrect 15 prediction (37.4 vs 33.3 ms;  $F_{1,204} = 4.94$ , p = 0.027,  $\eta_p^2 = 0.024$ ). No significant differences were 16 222 17 <sup>18</sup> 223 observed for amplitude (mean 0.62±0.08 and 0.63±0.07° of visual angle) and peak velocity (mean 19 20 21 224 42.35±2.10 and 43.01±4.22 °/second) between correctly and incorrectly predicted penalties. 22 23 24<sup>225</sup> There was no significant difference between correctly and incorrectly predicted penalties for saccades 25 26 226 duration (mean 114.91±15.79 and 106.72±10.72 seconds), amplitude (mean 3.50±0.29 and 27 <sup>28</sup> 227  $3.67\pm0.46^{\circ}$  of visual angle) and peak velocity (mean 112.68±3.69 and 121.59±8.07 °/second). 29 30 31 228 Saccade and microsaccade orientation 32 33 34 229 Microsaccades orientation showed significant differences between right and left goalkeepers' 35 36 230 movement [t-test (7) = 2.62; p = 0.034; d = 0.63], and given that goalkeepers' gaze behaviour was 37 38 39 231 analysed before their final movement initiation (so the ball was still on the penalty spot), we can 40 suppose that microsaccades anticipate the goalkeepers' direction, showing a main vector directed to 41 232 42 <sup>43</sup> 233 the right when goalkeepers moved to the right, and conversely to the left when moving to the left 44 45 46 234 (Figure 3). Saccades orientation instead showed a main vector directed to the left for both left and 47 right goalkeepers' movement direction (p = 0.45; Figure 3 lower panel). 48 235 49 50 \*\*\*\*\*Figure 3 near here\*\*\*\*\*\* 51 236 52 53 Pupil size changes 54 237 55 56 57 238 There was a significant positive correlation between pupil size and the progression of the action (r =58 <sup>59</sup> 239 (0.86), meaning that, the pupil increases as the goalkeepers' perception of the penalty taker intention 60

1	
2 3	240
4 5	
6	241
7 8	242
9	
10 11	243
12 13	
14	244
15 16	
17	245
18 19	246
20 21	_
22	247
23 24	248
25	240
26 27	249
28 29	250
30	251
31 32	201
33	252
34 35	253
36 37	
38	254
39 40	255
41	255
42 43	256
44 45	257
46	237
47 48	
49	258
50 51	259
52 53	_
54	260
55 56	261
57	167
58 59	202

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 ( $F_{1,7} = 12.81, p = 0.009, \eta_p^2 = 0.65$ ).

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

## 244 Discussion

The purpose of this study was to deepen our knowledge about what happens before the critical 45 movement initiation and during the QE period, investigating the role of microsaccades, small 46 saccades, and pupil diameter during the approaching of the foot-ball contact. The analysis was 17 18 focused on the gaze behaviour of intermediate level soccer goalkeepers trying to predict penalty kicks 19 directed to the left and to the right of their goal. Given the relationships between microsaccades, 50 visual perception, and with the allocation of attention when the eyes are fixating, the current study 51 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 52 53 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

54

2 3 (Hafed & Clark, 2002; Piras, Raffi, Lanzoni, Persiani, & Squatrito, 2015), with a short inhibition after 264 4 5 265 stimulus appearance, followed with an increased rate of microsaccade occurrence, or as in this 6 7 situation, small saccade manifestation. In the current study the mean saccadic amplitude was about 8 266 9 10 267 3° of visual angle, microsaccadic amplitude was about 0.6° of visual angle. Some of the saccades 11 <sup>12</sup> 268 greater than 1° produced during prolonged fixation, and possibly during free-viewing, may be 13 14 <sub>15</sub> 269 involuntary and could be therefore categorized as microsaccades (Otero-Millan et al., 2008). As 16 highlighted by Gonzalez et al. (2017), in the definition of QE, the term fixation at 1-3° of visual angle, 17 270 18 19 could incorporate different types of eve movements, such as saccades, microsaccades, and smooth 271 20 21 22 **272** pursuit, that may be used as a functional mechanism to predict an action, without fitting inside the 23 24 273 normal definitions of fixation. Moreover, a high frequency of microsaccades may facilitate larger 25 <sup>26</sup> 274 saccadic intrusions that may fall inside of the QE threshold. Moderate head motion requires the 27 28 275 involvement of oculomotor compensatory mechanisms, such as the vestibulo-ocular response, 29 30 optokinetic reflexes, smooth pursuit or saccades. This could suggest that other gaze behaviours may 31 276 32 33 277 be considered in the measured QE period, particularly at the larger 3° threshold (Gonzalez et al., 34 35 278 2017). The eye tracker used in the current study, with high-resolution (under 0.1° of spatial resolution 36 37 <sub>38</sub> 279 and sampling at 500 Hz), was suitable to identify differences in oculomotor control, and the amount 39 40 280 and/or type (pursuit, saccades, microsaccades) of eye movements related to attention/inhibition 41 <sup>42</sup> 281 mechanisms (Gonzalez et al., 2017). In recent years there has been renewed interest in the role of 43 44 45<sup>282</sup> microsaccades and other small saccades during fixation, including their role in perceptual tasks and 46 their links to attention (Kowler, 2011). Recent works suggest that microsaccades may be suitable in 47 283 48 <sup>49</sup> 284 tasks where gaze is centrally located between different interest areas (Piras et al., 2015; Piras et al., 50 51 52 285 2019), as for example inside of  $3^{\circ}$  of visual angle. 53

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, 289 290 upper panel). A clear polarization of microsaccade orientation means that a specific location has been 291 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 21 296 23 297 its role during the prediction of a sport action. To our knowledge, the only two studies that have <sup>25</sup> 298 analysed pupillometry during a sport action were that of Campbell et al (2019) where golfers showed <sub>28</sub> 299 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 30 300 <sup>32</sup> 301 during QE in equestrian performers viewing a video-based show-jumping sequence. In the current <sub>35</sub> 302 study, we demonstrated that multisensory integration between stimulus-response influenced these ocular movements. Larger pupil dilation and microsaccade inhibition, as well as saccade response, 37 303 <sup>39</sup> 304 were observed when a complex visual stimulus was projected to our participants and aligned in space 42 305 and time with their motor response. The pupil dilates prior to saccade initiation, and this increase in 44 306 pupil size could increase visual sensitivity to optimize perceptual processes immediately after 46 307 redirection of the eyes (Wang, Blohm, Huang, Boehnke, & Munoz, 2017). Pupil dilation, 308 microsaccades and saccades occurrence are additional components of orienting (Corneil & Munoz, <sub>51</sub> 309 2014; Wang & Munoz, 2015), and both can be evoked and modulated following the appearance of 53 310 relevant stimuli (Wang & Munoz, 2014). Moreover, there is a connection between pupil dimension, <sup>55</sup> 311 microsaccades and saccades. Wang et al. (2012) found the central role of the superior colliculus on 58 312 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 60 313

1

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 320 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

Page 15 of 27

55

representative designs are theoretically desirable, the challenges of achieving truly representative 338 339 studies necessitate that hybrid designs may have to be used as an alternative (Dhami et al., 2004; 340 Dicks et al., 2010). Hybrid designs may incorporate aspects of systematic design (e.g., increased 10 341 experimental control over conditions, control or removal of variables that are irrelevant, or that may 12 13 342 mask effects) (Dicks et al., 2010; Pluijms et al., 2013), whilst attempting to be as representative as 15 343 possible. In the current study, a hybrid design was used where goalkeepers were required to move in 17 344 response to a 'life-size' projection of a soccer penalty kick taker. This design was necessitated by the 345 requirements of the eye tracker (binocular with at least 250 Hz of sample/s) and to our knowledge, in 21 22 346 commerce there is no device with these characteristics that can be used in a more dynamic situation 24 347 (Dhami et al., 2004; Pluijms et al., 2013).

<sub>28</sub> 348 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 30 349 <sup>32</sup> 350 in relation to penalty taker's run up/kicking action (Piras et al., 2015). Moreover, could be interesting <sub>35</sub> 351 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 37 352 <sup>39</sup> 353 in volleyball) through the use of deceptive gaze behaviours to cover their intentions. A deceptive 42 <sup>354</sup> strategy and a blind-pass strategy (also known as no-look pass) are performed when a player looks in 44 355 one direction but shoot or pass the ball to another direction. This is a typical sport action in which 46 356 gaze direction and attention are separated (Piras et al., 2019). Despite the extensive use of deceptive 357 gaze and no-look pass in sports, little empirical evidence exists to support the utility of such <sub>51</sub> 358 behaviours (Wood et al., 2017). Therefore, future research could address more specifically the microsaccade occurrence and features during these strategies. 53 359

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

European Journal of Sport Science

Page 16 of 27

1		
2 3 3 4	63	during the period that precedes the critical movement initiation, shifting from covert to overt
5 6 7	64	attention, necessary to identify the useful cue with both foveal and parafoveal vision.
8 9 3	65	Disclosure statement
10 11 12 13 13	66	No potential conflict of interest was reported by the authors.
15 15 16	67	References
17 18 3 19	68	Alnæs, D., Sneve, M. H., Espeseth, T., Endestad, T., van de Pavert, S. H. P., & Laeng, B. (2014).
20 21 22	69	Pupil size signals mental effort deployed during multiple object tracking and predicts brain
23 3 24	70	activity in the dorsal attention network and the locus coeruleus. Journal of Vision, 14(4).
25 3 26 27	71	https://doi.org/10.1167/14.4.1
28 3 29	72	Araújo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and
30 31 32	73	correspondence between experimental task constraints and behavioral setting: Comment on
33 33 34	74	Rogers, Kadar, and Costall (2005). In <i>Ecological Psychology</i> (Vol. 19, Issue 1, pp. 69–78).
35 3 36 37	75	Lawrence Erlbaum Associates Inc. https://doi.org/10.1080/10407410709336951
38 3 39	76	Bar-Eli, M., & Azar, O. H. (2009). Penalty kicks in soccer: An empirical analysis of shooting
40 41 42	77	strategies and goalkeepers' preferences. Soccer and Society, 10(2), 183-191.
42 43 44	78	https://doi.org/10.1080/14660970802601654
45 46 47	79	Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing
47 48 3 49	80	resources. Psychological Bulletin, 91(2), 276–292. https://doi.org/10.1037/0033-2909.91.2.276
50 51 3 52	81	Belopolsky, A. V., & Theeuwes, J. (2009). When are attention and saccade preparation dissociated?
53 3 54 55	82	Psychological Science, 20(11), 1340–1347. https://doi.org/10.1111/j.1467-9280.2009.02445.x
56 3 57	83	Boehnke, S. E., & Munoz, D. P. (2008). On the importance of the transient visual response in the
58 59 60	84	superior colliculus. In Current Opinion in Neurobiology (Vol. 18, Issue 6, pp. 544–551).
<sup>60</sup> 3	85	https://doi.org/10.1016/j.conb.2008.11.004

Page 17 of 27

1 2		
2 3 4	386	Campbell, M. J., Moran, A. P., Bargary, N., Surmon, S., Bressan, L., & Kenny, I. C. (2019).
5 6	387	Pupillometry during golf putting: A new window on the cognitive mechanisms underlying
/ 8 9	388	quiet eye. Sport, Exercise, and Performance Psychology, 8(1), 53-62.
) 10 11 12	389	https://doi.org/10.1037/spy0000148
13 14	390	Cohen, J. (1988). Statistical power analysis for the behavioral sciences, (2nd ed.). Hillsdale, NJ :
15 16 17	391	Lawrence Erlbaum. Hillsdale, NJ, 20–26.
18 19	392	Corneil, B. D., & Munoz, D. P. (2014). Overt responses during covert orienting. Neuron, 82(6),
20 21 22	393	1230–1243. https://doi.org/10.1016/j.neuron.2014.05.040
23 24 25	394	Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence
26 27	395	for a common attentional mechanism. Vision Research, 36(12), 1827–1837.
28 29 30	396	https://doi.org/10.1016/0042-6989(95)00294-4
31 32	397	Dhami, M. K., Hertwig, R., & Hoffrage, U. (2004). The role of representative design in an
33 34	398	ecological approach to cognition. In Psychological Bulletin (Vol. 130, Issue 6, pp. 959–988).
35 36 37	399	https://doi.org/10.1037/0033-2909.130.6.959
30 39 40	400	Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video
41 42	401	simulation task constraints reveals differences in information pickup for perception and action.
43 44 45	402	Atten. Percept. Psychophys., 72(3), 706-720. https://doi.org/Doi 10.3758/App.72.3.706
46 47	403	Ditchburn, R. W., & Ginsborg, B. L. (1952). Vision with a stabilized retinal image. Nature,
48 49 50	404	170(4314), 36-37. https://doi.org/10.1038/170036a0
51 52	405	Goldberg, M. E., Bushnell, M. C., & Bruce, C. J. (1986). The effect of attentive fixation on eye
55 55	406	movements evoked by electrical stimulation of the frontal eye fields. Experimental Brain
56 57 58	407	Research, 61(3), 579–584. https://doi.org/10.1007/bf00237584
59 60	408	Gonzalez, C. C., Causer, J., Miall, R. C., Grey, M. J., Humphreys, G., & Williams, A. M. (2017).

European Journal of Sport Science

Page 18 of 27

1 ว		
2 3 4	409	Identifying the causal mechanisms of the quiet eye. In European Journal of Sport Science
5 6 7	410	(Vol. 17, Issue 1, pp. 74-84). https://doi.org/10.1080/17461391.2015.1075595
8 9	411	Gowen, E., Abadi, R. V., Poliakoff, E., Hansen, P. C., & Miall, R. C. (2007). Modulation of
10 11 12	412	saccadic intrusions by exogenous and endogenous attention. Brain Research, 1141(1), 154-
13 14	413	167. https://doi.org/10.1016/j.brainres.2007.01.047
15 16 17	414	Granholm, E., Asarnow, R. F., Sarkin, A. J., & Dykes, K. L. (1996). Pupillary responses index
18 19	415	cognitive resource limitations. <i>Psychophysiology</i> , 33(4), 457–461.
20 21 22	416	https://doi.org/10.1111/j.1469-8986.1996.tb01071.x
23 24 25	417	Hafed, Z. M., & Clark, J. J. (2002). Microsaccades as an overt measure of covert attention shifts.
26 27	418	Vision Research, 42(22), 2533-2545. https://doi.org/10.1016/S0042-6989(02)00263-8
28 29 30	419	Iqbal, S., Zheng, X., Human, B. BC. extended abstracts on, & 2004, undefined. (n.d.). Task-
31 32	420	evoked pupillary response to mental workload in human-computer interaction. Dl.Acm.Org.
33 34 35	421	Jainta, S., Vernet, V., Yang, Y., & Kapoula, Z. (2011). The pupil reflects motor preparation for
36 37	422	saccades - even before the eye starts to move. Frontiers in Human Neuroscience,
39 40	423	SEPTEMBER. https://doi.org/10.3389/fnhum.2011.00097
41 42 43	424	Juris, M., & Velden, M. (1977). The pupillary response to mental overload. Physiological
44 45	425	Psychology, 5(4), 421-424. https://doi.org/10.3758/BF03337847
46 47 48	426	Kahneman, D. (2011). Thinking , Fast and Slow Thinking , Fast and Slow. In Reflections on the
49 50	427	Liar.
51 52 53	428	Karatekin, C., Couperus, J. W., & Marcus, D. J. (2004). Attention allocation in the dual-task
54 55 56	429	paradigm as measured through behavioral and psychophysiological responses.
57 58	430	Psychophysiology, 41(2), 175–185. https://doi.org/10.1111/j.1469-8986.2004.00147.x
59 60	431	Kim, S., & Lee, S. (2005). Gaze Behavior of Elite Soccer Goalkeeper in Successful Penalty Kick

1 ว	
<sup>2</sup> 3 432 4	Defense. Gaze Behavior of Elite Soccer Goalkeeper in Successful Penalty Kick Defense, 16(4),
5 6 433 7	117–127.
8 9 434	Kowler, E. (2011). Eye movements: The past 25 years. In Vision Research (Vol. 51, Issue 13, pp.
10 11 435 12	1457–1483). https://doi.org/10.1016/j.visres.2010.12.014
13 14 436 15	Liversedge, S. P., Gilchrist, I. D., & Everling, S. (2012). The Oxford Handbook of Eye Movements.
16 437 17	In The Oxford Handbook of Eye Movements. Oxford University Press.
<sup>18</sup> 438 19 20	https://doi.org/10.1093/oxfordhb/9780199539789.001.0001
21 439 22	Martinez-Conde, S., Otero-Millan, J., & Macknik, S. L. (2013). The impact of microsaccades on
23 24 440	vision: towards a unified theory of saccadic function. Nature Reviews. Neuroscience, 14(2),
25 26 441 27	83-96. https://doi.org/10.1038/nrn3405
28 29 442 30	McCamy, M. B., Otero-Millan, J., Macknik, S. L., Yang, Y., Troncoso, X. G., Baer, S. M., Crook,
31 443 32	S. M., & Martinez-Conde, S. (2012). Microsaccadic efficacy and contribution to foveal and
<sup>33</sup> 34 444	peripheral vision. Journal of Neuroscience, 32(27), 9194-9204.
35 36 445 37	https://doi.org/10.1523/JNEUROSCI.0515-12.2012
38 39 446 40	Moore, T., & Fallah, M. (2001). Control of eye movements and spatial attention. Proceedings of the
41 447 42	National Academy of Sciences of the United States of America, 98(3), 1273–1276.
<sup>43</sup> 448 44 45	https://doi.org/10.1073/pnas.98.3.1273
<sup>46</sup> 449 47	Moran, A., Quinn, A., Campbell, M., Rooney, B., Brady, N., & Burke, C. (2016). Using
48 49 450	pupillometry to evaluate attentional effort in quiet eye: A preliminary investigation. Sport,
50 51 451 52	Exercise, and Performance Psychology, 5(4), 365–376. https://doi.org/10.1037/spy0000066
53 54 452 55	Morya, E., Ranvaud, R., & Pinheiro, W. M. (2003). Dynamics of visual feedback in a laboratory
56 453 57	simulation of a penalty kick. Journal of Sports Sciences, 21(2), 87-95.
58 59 60	https://doi.org/10.1080/0264041031000070840

1		
2 3 4	455	Otero-Millan, J., Castro, J. L. A., Macknik, S. L., & Martinez-Conde, S. (2014). Unsupervised
5 6	456	clustering method to detect microsaccades. Journal of Vision, 14, 1-17.
7 8 9	457	https://doi.org/10.1167/14.2.18
10 11 12	458	Otero-Millan, J., Troncoso, X. G., Macknik, S. L., Serrano-Pedraza, I., & Martinez-Conde, S.
13 14	459	(2008). Saccades and microsaccades during visual fixation, exploration, and search:
15 16	460	Foundations for a common saccadic generator. Journal of Vision, 8(14), 1–18.
17 18 19	461	https://doi.org/10.1167/8.14.21
20 21	462	Piras, A., Lanzoni, I. M., Raffi, M., Persiani, M., & Squatrito, S. (2016). The within-task criterion
22 23 24	463	to determine successful and unsuccessful table tennis players. International Journal of Sports
25 26 27	464	Science and Coaching, 11(4), 523-531. https://doi.org/10.1177/1747954116655050
28 29	465	Piras, A., Lobietti, R., & Squatrito, S. (2014). Response time, visual search strategy, and
30 31	466	anticipatory skills in volleyball players. Journal of Ophthalmology, 2014(1), 185–197.
32 33 34	467	https://doi.org/10.1155/2014/189268
35 36 37	468	Piras, A., Raffi, M., Lanzoni, I. M., Persiani, M., & Squatrito, S. (2015). Microsaccades and
38 39	469	prediction of a motor act outcome in a dynamic sport situation. Investigative Ophthalmology
40 41 42	470	and Visual Science, 56(8), 4520-4530. https://doi.org/10.1167/iovs.15-16880
43 44	471	Piras, A., Raffi, M., Perazzolo, M., Malagoli Lanzoni, I., & Squatrito, S. (2019). Microsaccades and
45 46	472	interest areas during free-viewing sport task. Journal of Sports Sciences, 37(9), 980-987.
47 48 49	473	https://doi.org/10.1080/02640414.2017.1380893
50 51 52	474	Piras, A., Raffi, M., Persiani, M., Perazzolo, M., & Squatrito, S. (2016). Effect of heading
53 54	475	perception on microsaccade dynamics. Behavioural Brain Research, 312, 246-252.
55 56 57	476	https://doi.org/10.1016/j.bbr.2016.06.030
58 59	477	Piras, A., & Vickers, J. N. (2011). The effect of fixation transitions on quiet eye duration and
60	478	performance in the soccer penalty kick: Instep versus inside kicks. Cognitive Processing,

1		
2 3 2 4 5	479	12(3), 245–255. https://doi.org/10.1007/s10339-011-0406-z
5 6 4 7	480	Pluijms, J., Cañal-Bruland, R., Kats, S., & Savelsbergh, G. (2013). Translating key methodological
8 9	481	issues into technological advancements when running in-situ experiments in sports: An
10 11 4 12	482	example from sailing. International Journal of Sports Science and Coaching, 8(1), 89–104.
13 ⊿ 14	483	https://doi.org/10.1260/1747-9541.8.1.89
15 16 4 17	484	Porter, G., Troscianko, T., & Gilchrist, I. D. (2007). Effort during visual search and counting:
18 19	485	Insights from pupillometry. Quarterly Journal of Experimental Psychology, 60(2), 211–229.
20 21 <sup>4</sup> 22	486	https://doi.org/10.1080/17470210600673818
23 24	487	Posner, M. I. (1980). Orienting of attention. The Quarterly Journal of Experimental Psychology,
25 26 4 27	488	32(1), 3-25. https://doi.org/10.1080/00335558008248231
28 29 4	489	Riggs, L. A., & Ratliff, F. (1952). The effects of counteracting the normal movements of the eye.
30 31 <u>/</u> 32	490	Journal of the Optical Society of America, 42, 872–873.
33 34 ⊿ 35	491	Ripoll, H., Kerlirzin, Y., Stein, J. F., & Reine, B. (1995). Analysis of information processing,
36 37	492	decision making, and visual strategies in complex problem solving sport situations. Human
38 39 <sup>4</sup> 40	493	Movement Science, 14(3), 325-349. https://doi.org/10.1016/0167-9457(95)00019-0
41 42 4	494	Savelsbergh, G. J. P., Williams, A. M., Van der Kamp, J., & Ward, P. (2002). Visual search,
43 44 4 45	495	anticipation and expertise in soccer goalkeepers. Journal of Sports Sciences, 20(3), 279-287.
46 47	496	https://doi.org/10.1080/026404102317284826
48 49 50	497	Sheliga, B. M., Riggio, L., & Rizzolatti, G. (1995). Spatial attention and eye movements.
51 52 <sup>4</sup> 53	498	Experimental Brain Research, 105(2), 261-275. https://doi.org/10.1007/BF00240962
54 55	499	Timmis, M. A., Piras, A., & van Paridon, K. N. (2018). Keep Your Eye on the Ball; the Impact of
56 57 <sup>5</sup> 58	500	an Anticipatory Fixation During Successful and Unsuccessful Soccer Penalty Kicks. Frontiers
59 g 60	501	in Psychology, 9. https://doi.org/10.3389/fpsyg.2018.02058

European Journal of Sport Science

Page 22 of 27

1	
<sup>2</sup> 3 502 4	Vater, C., Williams, A. M., & Hossner, EJ. (2019). What do we see out of the corner of our eye?
5 6 503	The role of visual pivots and gaze anchors in sport. International Review of Sport and Exercise
7 8 504 9	Psychology, 1-23. https://doi.org/10.1080/1750984x.2019.1582082
10 11 505 12	Vickers, J. N. (1992). Gaze control in putting. Perception, 21(1), 117–132.
13 506 14	https://doi.org/10.1068/p210117
15 16 507 17	Vickers, J. N. (1996). Visual control when aiming at a far target. Journal of Experimental
<sup>18</sup> 508 19	Psychology. Human Perception and Performance, 22(2), 342–354.
20 21 509 22	https://doi.org/10.1037/0096-1523.22.2.342
23 24 510	Wang, C. A., Blohm, G., Huang, J., Boehnke, S. E., & Munoz, D. P. (2017). Multisensory
25 26 511 27	integration in orienting behavior: Pupil size, microsaccades, and saccades. Biological
<sup>28</sup> 512 29	Psychology, 129, 36-44. https://doi.org/10.1016/j.biopsycho.2017.07.024
<sup>31</sup> 513 32	Wang, C. A., Boehnke, S. E., White, B. J., & Munoz, D. P. (2012). Microstimulation of the monkey
<sup>33</sup> 34 <sup>514</sup>	superior colliculus induces pupil dilation without evoking saccades. Journal of Neuroscience,
35 36 515 37	32(11), 3629–3636. https://doi.org/10.1523/JNEUROSCI.5512-11.2012
38 39 516 40	Wang, C. A., & Munoz, D. P. (2014). Modulation of stimulus contrast on the human pupil orienting
41 517 42	response. European Journal of Neuroscience, 40(5), 2822–2832.
43 44 45	https://doi.org/10.1111/ejn.12641
46 47 47	Wang, C. A., & Munoz, D. P. (2015). A circuit for pupil orienting responses: Implications for
48 49 520	cognitive modulation of pupil size. In Current Opinion in Neurobiology (Vol. 33, pp. 134-
50 51 521 52	140). https://doi.org/10.1016/j.conb.2015.03.018
53 54 522 55	Williams, A. M., & Elliott, D. (1999). Anxiety, expertise, and visual search strategy in karate.
56 523 57	Journal of Sport and Exercise Psychology, 21(4), 362–375.
58 59 60	https://doi.org/10.1123/jsep.21.4.362

1	
2 3 525 4	Wood, G., Vine, S. J., Parr, J., & Wilson, M. R. (2017). Aiming to deceive: Examining the role of
5 6 526	the quiet eye during deceptive aiming actions. Journal of Sport and Exercise Psychology,
7 8 527 9	39(5), 327-338. https://doi.org/10.1123/jsep.2017-0016
10 11 528 12	Zuber, B. L., Semmlow, J. L., & Stark, L. (1968). Frequency Characteristics of the Saccadic Eye
13 529 14	Movement. Biophysical Journal, 8(11), 1288-1298. https://doi.org/10.1016/S0006-
<sup>15</sup> 530 16 17	3495(68)86556-7
<sup>18</sup> 531 19 20	Figure captions
21 22 22	Figure 1. Experimental setup showing subject wearing the eye tracker, standing in front of the
23 24 533 25 26	translucent wide screen, in which the videos were back projected.
<sup>27</sup> 534	Figure 2. Time course of microsaccades and saccades rate calculated from the final movement
29 30 535	initiation to backwards for 4000 ms. Rates were computed for each goalkeeper using a moving time
32 536 33	window of 200 ms and then averaged over all participants. Solid lines represent the mean rate of
<sup>34</sup> 537 35	microsaccades (upper plot) and saccades (lower plot), with the shaded area around each curve that
36 37 538 38 39	represents the standard error of the mean.
40 41 539	Figure 3. Panels represent the mean vector direction of microsaccade (upper) and saccades (lower)
42 43 540	across condition (left; right goalkeepers' movement). Each angular sector is 22.50° in width. Radial
44 45 541 46	thick lines are the mean vectors, curved lines external to the diagrams indicate the standard deviation,
47 48 49	with the 95% of confidence interval ( $p < 0.05$ ).
50 51 543 52	Figure 4. Plot show the increases of left (grey line) and right (black line) pupil size (z-score) of all
53 54 55	participants, correlated with the time of the trial, reaching a plateau at the goalkeepers' final
55 56 57 58 59 60	movement initiation.





Figure 2. Time course of microsaccades and saccades rate calculated from the final movement initiation to backwards for 4000 milliseconds. 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.

43x34mm (600 x 600 DPI)





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.

43x23mm (600 x 600 DPI)