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

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1   **Title: Visual strategies underpinning the spatiotemporal demands during visuo-motor tasks in**

2   **predicting ball direction**

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4   **Introduction**

5   Team sports are often characterized by spatiotemporal constraint that necessitates the processing of

6   and responding to visual information in a limited time frame (Panchuk & Vickers, 2006).

7   Consequently, spatiotemporal constraints are present in different sporting situations, such as when

8   the athlete's response time, combined with the distance the ball will travel prior to being intercepted,

9   exceeds the ball flight duration (Piras, Lanzoni, et al., 2016). In these conditions, successful

10   performance is based upon the athlete's accurate allocation of visual attention and subsequent

11   decision making prior to initiating a motor behaviour, either at the instance of or immediately after a

12   key action (e.g., the ball being kicked in a soccer penalty kick; Piras et al., 2020; Piras & Vickers,

13   2011).

14   In competitive sports, in which precise and correct prediction of the intentions of others are a

15   fundamental component of performance, attending to and processing visual information are key

16   determinants of successful motor execution (Williams, 2009). Indeed, in fast ball sports like table

17   tennis (Piras, Lanzoni, et al., 2016), as well as in team sports such as soccer (Piras et al., 2020; Piras

18   & Vickers, 2011; Timmis et al., 2018) and volleyball (Piras et al., 2010; Piras, Lobietti, et al., 2014),

19   the need to perceive the intentions of the opponent occurs under severe time pressure. This time

20   pressure will be impacted by the distance the object travels once being struck/hit and being

21   intercepted, for example a ball being kicked from different distances (Navia et al., 2017; Panchuk &

22   Vickers, 2006). In a recent article, Navia et al. (2017), comparing expert futsal goalkeepers

23   intercepting penalties taken from 10m in comparison to 6m, reported that more saved penalties

24   occurred when kicked from 10m, with goalkeeper's initiating their movement later, looking for longer

25   towards the ball with respect to the penalty takers' body. In ice hockey, when goaltenders were

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26 required to save shots taken from 5m with respect to 10m, the number of saves was not significantly

27 affected by the different distance from which the shot was taken and there was no difference in visual

28 search behaviour between distances (Panchuk & Vickers, 2006).

29 Although differences in fixation locations through expertise have been reported in the majority of

30 studies (for a review see Mann et al., 2007), a paucity of research has investigated differences between

31 the utilization of the fovea with respect to the periphery during spatiotemporal constraints (Vater et

32 al., 2019). Because of the different functional organization of foveal and peripheral visual field (Raffi

33 & Piras, 2019), the cue's proximity could influence the utilization of the foveal or the peripheral

34 vision to pick-up relevant information necessary to make predictive judgements early in time, just

35 before the initiation of the motor response (Williams, 2009).

36 Saccadic eye movements bring objects of interest into the fovea, where the visual resolution is

37 highest. During the visual perception of extrafoveal cues, before the eyes start to move, peripheral

38 vision is enhanced, and sensory orientation is restructured by the saccade target location (Piras, Raffi,

39 et al., 2016). These changes occur rapidly, with an influence on the visual perception, as humans

40 perform saccades every few hundred milliseconds (Klein & Ettinger, 2019). However, saccades are

41 not only made to reorient the fovea. Small saccades, termed microsaccades, occur during fixation,

42 with a relatively high rate once the object of interested is foveated (for more information see Martinez-

43 Conde et al., 2013). It has been found that microsaccades serve the function of preventing visual

44 fading during fixation, help in maintaining accurate fixation on point, redirect a preferred small locus

45 on the retina and facilitate fine spatial judgments (Poletti & Rucci, 2016). Close investigations have

46 revealed that the eyes are never stationary, during fixations these microsaccades continuously upset

47 the gaze position. These movements occur even when attempting to maintain steady fixation on a

48 single point during a sport situation (Piras et al., 2015).

49 The previous work conducted by Navia et al. (2017) and Panchuk and Vickers (2006) which

50 investigated how visual search behaviour changed dependent upon goalkeeper-object distance did not

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51   consider the subtle eye movements that may occur prior to goalkeeper movement initiation. In a

52   recent study, Piras et al. (2020), investigated the role of microsaccades, saccades, and pupil diameter

53   during the period that proceed a soccer goalkeeper's movement time in a penalty kick. The authors

54   identified that both saccades and microsaccades (inside 3° of visual angle) occurred during fixation

55   (i.e. quiet eye threshold, for more information see Vickers, 2007). Moreover, they found that

56   microsaccades anticipated the goalkeeper's direction, suggesting that they are not casual, but directed

57   toward the focus of (covert) attention (Hafed & Clark, 2002). Additionally, the authors demonstrated

58   a positive correlation between pupil dilation with the proximity of the motor response. Pupils reached

59   the largest size just before goalkeeper's movement initiation, increasing visual sensitivity to optimize

60   perceptual processes. Task-evoked pupil dilation in well-controlled experimental settings has been

61   referred to as an index of the allocation of cognitive control during mental activity (Beatty, 1982) and

62   in sport settings (Campbell et al., 2019). The advances in neuroscientific methods has further

63   strengthened our understanding that pupils dilate during mental activity, and that pupillometry is a

64   well-established technique for investigating human cognitive processing (Beatty, 1982). Indeed, pupil

65   size can be used as a signal of the relative amount of cognitive effort used to achieve a task and can

66   be referred to as an index of the brain activity. Campbell et al. (2019) found that golfers, during a

67   putting task, exhibited pupil dilation changes of about 30% from baseline. Additional research is

68   needed to consider the importance of the spatiotemporal constraints on the individuals' functional

69   behaviours during performance. Specifically, the aim of the present study was to examine the visual

70   search strategy of soccer goalkeepers in attempting to predict penalty kick direction taken from

71   different distances (near versus far) and from different angles of approaching the ball (left versus

72   right). We hypothesize that, when the distance from the ball is higher, and the image of the kicker

73   with the ball is smaller (i.e. subtends a smaller region of the visual scene), the goalkeeper will utilize

74   a different visual search strategy with respect to the situation in which the kicker and the ball are

75   closer (and subtends a larger region of the visual scene). We suppose that an increased distance

76   between the opponent and the goalkeeper will result in relying on information extracted via the fovea,

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77   conversely, when the opponent is closer, the goalkeeper will utilize peripheral vision to monitor

78   players' movements (Williams et al., 1994; Williams & Davids, 1998). Moreover, we can hypothesize

79   that, if the kicker's run-up is an important movement phase for the goalkeeper intercepting the ball,

80   different penalty taker run-up starting point (left versus right angle of approach) could influence the

81   microsaccade/saccade orientations. The emergent search pattern in these situations would appear to

82   be at least partly constrained by the relative distance between player, the ball, and with the angle of

83   approaching the ball. Several studies have found that using the fovea and/or the peripheral vision

84   enables successful prediction of a sporting action and can be detected through microsaccades and

85   saccades (Piras et al., 2015, 2019; Piras, Raffi, et al., 2016). We presume that if more saccades are

86   performed, it should be understood to be automatically induced by the change event for foveal

87   detection; however, the absence/reduction of saccades in favour of microsaccades (fewer fixations of

88   longer duration), would rather favour the participants' ability to use peripheral vision to detect change

89   events (Piras et al., 2020; Vater et al., 2019). Due to the supposed relationship between ocular

90   movements, visual perception, and direction of attention, the present study investigated the role of

91   saccades, microsaccades and pupil-size of soccer goalkeepers during the prediction of a penalty kick

92   in two different spatiotemporal constraints.

93   **Methods**

94   **Participants**

95   Eight intermediate-level male goalkeepers with a mean age of 23.5 (±5.2) years, one right footed male

96   kicker of 28 years and one left footed male kicker of 26 years old volunteered for the experiment.

97   Based on the effect size (dz = 0.80) evident on other studies (Piras et al., 2020; Piras & Vickers,

98   2011), G*power, version 3.1.9.2 (Kiel, Germany), predicted that a total sample size of 7 would give

99   appropriate power (1-β err prob 0.80) to detect a significant difference at alpha level of 0.05. One

100   additional participant was included to guarantee availability of data in case of missing values. At the

101   time of the study, the goalkeepers had been playing soccer for 14.7 years, and trained on average 3.5

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102   times, 7 hours per week, with a competitive match at the end of the week (national level). Goalkeepers

103   reported that they have been playing recreational futsal, with competitive matches at regional level.

104   They self-reported a normal vision, and after receiving oral and written information concerning the

105   study protocol, all participants gave their written informed consent to participate in the study. The

106   study was approved by the Bioethics Committee of the University of Bologna.

107   **Stimuli and procedure**

108   A right footed male kicker was filmed, from the participants' (goalkeepers') perspective, with a

109   digital video camera (Casio® 300 frames/s, with a max resolution 1280 × 960 pixels) positioned in

110   the middle of a standard, full sized (7.32 m wide and 2.44 m height), soccer goal, with the ball (size

111   5) positioned 11m from the centre of the goal. The kicker was required to start his run-up from the

112   right of goalkeeper's perspective, at least 4 m behind the ball using the same approaching angle for

113   all penalty kicks. Ten penalty kicks were filmed and subsequently subdivided in five directed to the

114   right and five to the left (goalkeeper's perspective).

115   The same procedure was used for penalties kicked in a futsal court. A left footed male kicker was

116   filmed, from the goalkeeper's perspective, with the same video camera positioned in the middle of a

117   standard, full sized (3 m wide and 2 m height) futsal goal, with the ball (size 4) positioned 6m from

118   the penalty spot. The kicker was required to start his run-up from the left of goalkeeper's perspective,

119   at least 4 m behind the ball using the same approaching angle for all penalty kicks. Ten penalty kicks

120   were filmed and subsequently subdivided in five directed to the right and five to the left (goalkeeper's

121   perspective).

122   The experiments were performed in the dark. Stimuli were back-projected (Epson EB-W12, 720 ×

123   486 resolution; frame rate 60 Hz) onto the translucent screen positioned 300 cm away. The screen

124   covered 135 × 107° of visual field and was placed 170 cm from the goalkeepers' eyes, who stood in

125   front of the screen ready to predict the ball direction as they were in the soccer pitch. The brightness

126   of the screen was measured using a United Detector Power meter (model 351) equipped with a

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127   photosensor (model 263), necessary to identify the different portions of the video clips (field of play;

128   penalty takers' body; the ball). The brightness of the screen was almost equal through the videoclips

129   (p=0.25; d=0.50).

130   The videos were presented from when the kicker started approaching the ball up to the ball passing

131   to the right or to the left of the goalkeeper's point of view. The goalkeeper was required to predict the

132   direction of the ball moving laterally (left or right) as they would on a soccer pitch, but without diving.

133   In total, each participant faced 60 penalties, 30 kicked from 11m and 30 kicked from 6m. We

134   subdivided penalties in six blocks with the same ten videoclips, with each block interspersed by 5

135   minutes of rest. Each clip had a mean duration (±SD) of 6046.80±2.89 ms (max value of 6051 and a

136   min value of 6043 ms). The direction of the soccer shots was completely randomized but the same

137   randomised order was used for each participant. Overall, a total number of 480 clips were analysed.

138   **Eyes and body movement recording**

139   We recorded binocular eye movements with a video-based eye tracking system (EyeLink® II, SR

140   Research) comprising of two miniature cameras mounted on a leather-padded headband. Pupil

141   tracking was performed at 500 samples/s, with a gaze resolution <0.005° and noise limited to <0.01°.

142   We calibrated the eye tracker at the beginning of the experiment and after each block of 10 videoclips.

143   Then, we performed data validation and drift correction by applying a corrective offset to the raw eye

144   position data after every clip. Calibration and validation of the system was repeated every time

145   possible measurement error occurred due to participants' movements. The accuracy of the eye

146   positions was checked after every clip, and if required, a drift correction was performed. Practice,

147   calibration, validation and data collection took ~ 60 minutes per participant.

148   Two inertial sensors (Cometa Systems, Italy) were placed on the goalkeepers' right and left anterior

149   superior iliac spine to collect lateral body movement. Inertial sensors (IMU; inertial measurement

150   unit, composed of a triaxial accelerometer, gyroscope, and magnetometer) were synchronised with

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151   the EyeLink system (TTL trigger signal input via the parallel port) in order to have corresponding

152   goalkeepers' eyes and body movement data. In the present study, only measurements of the triaxial

153   accelerometer were considered and collected at 1000 Hz, then re-sampled at 500Hz to have body and

154   eye movements synchronized. Goalkeepers' body movement response to ball interception was

155   considered to occur if the processed IMU signal exceeded a threshold of 3 standard deviations (SDs)

156   above the baseline (preactivation) triaxial accelerometer signal. If a response was detected, a value of

157   one was assigned, otherwise zero was assigned (The Shewhart threshold, for more details see Stokes

158   et al., 2006). The latency was measured as the time from the start of the trial to onset of the body

159   movement response.

160   **Data analysis**

161   Goalkeepers had to react in a time comprised between <150-250> ms after foot-ball contact,

162   otherwise trials were classified as missed, due to early or delayed movement necessary to intercept

163   the ball (average human reaction time). Then, we selected, from the entire trial duration (6000 ms),

164   the duration of each trial for analysis, using the exact time in which goalkeepers started their final

165   movement, going back for 4000 ms, in order to have trials of the same length.

166   *Response accuracy and movement time.* Response accuracy (predicted/missed penalties) and the

167   final movement time, that is the time in ms from the trial start to goalkeepers' final movement to

168   predict the ball were analysed separately using a distance (11m; 6m) x response accuracy (predicted;

169   missed) ANOVA with repeated measures on all factors.

170   *Visual search order.* We analysed the mean number of fixations on each interest areas every 1000ms

171   (epochs), starting from the exact time in which goalkeeper's final movement initiation, going back

172   for 4000 ms (1000ms; 2000ms; 3000ms; 4000ms). This was the search sequence used by the athletes.

173   We analysed the gaze positions in relation to the positions of the moving objects using dynamic

174   interest areas, that represent the position and dimensions of important visual scene content over time

175   (Piras, Lanzoni, et al., 2016). For this purpose, the screen was divided into five interest areas (IAs):

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176   (I) the HEAD of the kickers; (II) the TRUNK of the kicker; (III) the LEGS of the kicker; (IV) the

177   VISUAL PIVOT, a location in the middle between the ball, the kicking leg and non-kicking leg (Piras

178   & Vickers, 2011); (V) fixations on the BALL. All fixations outside these IAs were referred to as

179   "OUT" fixations. The mean number of fixations on each interest areas were analysed in block of

180   temporal sequences (four epochs) using epoch (1000ms; 2000ms; 3000ms; 4000ms) x condition

181   (11m, 6m) ANOVA with repeated measure on all factors.

182   *Microsaccade/saccade characteristics.* We considered fixation when the gaze was stable inside 1° of

183   visual angle for a minimum of 100 ms. Microsaccades were defined as eye movements ≤1° in

184   amplitude, with a peak velocity ≤100°/sec, and that followed the same peak velocity versus amplitude

185   curve as large saccades. Microsaccades and saccades were identified using the algorithms of Otero-

186   Millan et al. (Otero-Millan et al., 2014). The clustering method of the algorithm finds, automatically

187   and objectively, a boundary between true microsaccades and non-microsaccadic events, including

188   artifacts such as head movements and changes in pupil size. For our study, we considered only

189   microsaccades occurred simultaneously in both eyes during at least 3 data samples (6ms). We

190   excluded 200 ms before and after each blink as well as when the pupil was still partially occluded.

191   Microsaccade and saccade amplitudes, durations, and peak velocities were first calculated for each

192   goalkeeper in each condition (penalties from 11m and from 6m; predicted and missed penalties)

193   separately. Then, the values of all athletes in each condition were averaged. Microsaccade rates were

194   calculated considering the duration of each clip (4000 ms). A response accuracy (2) x condition (2)

195   ANOVA with repeated measures on all factors was performed separately to analyse microsaccade

196   and saccade rate, amplitude, duration, and peak velocity.

197   Moreover, saccade and microsaccade rate (number per second) was averaged over all trials of 8

198   participants and obtained a mean rate of about one per second (computed within a moving window

199   of 200 ms). Next, we subdivided the saccades/microsaccade rate in four epochs (1000; 2000; 3000;

8

200   4000 ms) in order to analyse them with repeated measures ANOVA with epochs as within-subjects

201   factor and condition (11m; 6m) as between-subjects factor.

202   ***Microsaccade/saccade orientation.*** We computed the two-dimensional distribution of all

203   microsaccade and saccade directions in the two different goalkeeper's movement direction (right,

204   left), subdivided in penalties kicked from 11m and from 6m. We performed the Watson-Williams test

205   for homogeneity of means (Oriana® 4.0) in which the null hypothesis was that the orientations of

206   microsaccades and saccades between penalty condition (11m versus 6m) have similar continuous

207   distribution at the 5% level of significance. Furthermore, analysis considered response accuracy

208   (predicted, missed) as a dependent variable to reveal any possible relationships between response

209   accuracy and saccade/microsaccade orientation.

210   ***Pupil size characteristics.*** The raw data of the pupil diameters were normalised with z-scores

211   technique, by expressing every sample as a standard deviation score from the mean calculated within

212   each videoclip. Pupil size diameter was correlated with the duration of the corresponding videoclip,

213   from the trial start to goalkeepers' final movement initiation. Then, mean correlations were analysed

214   with a Paired sample t-test to investigate differences between penalty distances (11m; 6m).

215   Mauchly's test was used to assess any violations for sphericity. Effect size of the repeated measure

216   ANOVAs were expressed using partial eta-squared (η_p^2), with values of 0.01, 0.06, and 0.14

217   representing small, medium, and large effects respectively (Cohen, 1988). Statistical significance was

218   set at $p < 0.05$.

219   **Results**

220   After pre-processing data, in which responses shorter than 150 ms and longer than 250 ms (early or

221   delayed responses) were discarded (see Methods for description), 425 clips were retained for analysis

222   (of a total of 480; 55 clips were excluded).

223   ***Response accuracy and movement time***

224   In general, goalkeepers were significantly more accurate than not in predicting shot direction (57.08%

225   vs 42.91%; $F_{1,14}$ = 5.17; p = 0.039; $n_p{}^2$ = 0.27). Analysis of variance did not show any significant

226   differences for the interaction effect between accuracy (predicted; missed) and condition (11m; 6m)

227   (p = 0.36). Paired sample t-test showed significant differences only for penalties kicked from 11m, in

228   which goalkeepers exhibited successfully predicted than missed penalties (60% vs 40%; t(7)= 2.72;

229   p = 0.03; d = 1.93, Figure 1A). No significant difference was found for predicted and missed penalties

230   kicked from 6m (54% vs 46%; p = 0.43), although there was an 8% improvement with a medium

231   effect size (d = 0.59).

232   Final movement time analysis showed a significant main effect for accuracy ($F_{1,7}$ = 14.07; p = 0.007;

233    $n_p{}^2$ = 0.67), in which goalkeepers were slower when predicted compared to missed penalties (4706ms

234   vs. 4646ms). When penalties were kicked from 11m, goalkeepers were significantly faster when

235   missing and slower when successfully predicting penalties ($F_{1,7}$ = 9.19; p = 0.019; $n_p{}^2$ = 0.57; Figure

236   1B).

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

238   *Visual search order*

239   Analysis of the mean number of fixations showed significant increase for penalties from 11m in

240   comparison to penalties from 6m (2.61 vs 2.24; t(7) = 3.74; p = 0.008; d = 1.32). Repeated measures

241   ANOVA showed a significant condition x epoch interaction effect ($F_{3,42}$ = 9.61; $p < 0.001$; $n_p{}^2$ = 0.41).

242   Paired sample t-test revealed significant increase for penalties from 11m in comparison to penalties

243   from 6m at the last epoch (4000ms; t(7) = 2.81; p = 0.026; d=1.05; Table 1).

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

245   *Microsaccade/saccade characteristics*

246   Analysis of microsaccade rates showed a significant main effect for condition ($F_{1,14} = 4.82$; $p = 0.046$;

247    $n_p^2 = 0.26$) in which goalkeepers exhibited a greater rate during penalties kicked from 6m than from

248   11m (0.63 ± 0.19 vs 0.59 ± 0.18 number/sec).

249   Analysis of microsaccade rates time window showed significant main effect between the four-time

250   epochs ($F_{3,42} = 8.50$; $p < 0.001$; $n_p^2 = 0.38$) on each condition (Figure 2). Microsaccades rate analysed

251   during penalties kicked from 11m showed a decrement trend visible from the first to the last epoch

252   (Figure 2A; $p = 0.014$; $d = 1.27$). Looking at figure 2B, microsaccade rates decreased from the first

253   to the second epoch to about 33% ($p = 0.003$; $d = 1.49$), then 1000ms before goalkeeper's final

254   movement started, showed an additional decrease of about 53% with respect to the first epoch ($p =$

255   0.002; $d = 2.36$).

256   There were no significant differences between penalties kicked from 11m with respect to 6m for the

257   other microsaccade characteristics; duration (mean 39.54 vs 40.85 ms); amplitude (mean 0.64 vs

258   0.63° of visual angle) and peak velocity (mean 43.12 vs 39.95°/second).

259   Microsaccade durations showed a significant main effect for response accuracy ($F_{1,14} = 5.51$; $p =$

260   0.034; $n_p^2 = 0.28$), with longer duration in predicted than missed penalties (38.71 vs 36.85 ms).

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

262   Analysis of saccade rates showed significant main effect for condition ($F_{1,14} = 4.27$; $p = 0.044$; $n_p^2 =$

263   0.25), with increased rate in penalties from 11m in comparison to penalties from 6m (1.27 vs 1.03

264   number/sec). A significant main effect was found for response accuracy ($F_{1,14} = 10.93$; $p = 0.005$; n_p^2

265    $= 0.44$), with higher saccade rates during predicted than missed penalties (1.18 vs 1.07 number/sec).

266   Analysis of saccade rates time window showed significant main effect between the four epochs ($F_{3,42}$

267    $= 31.01$; $p < 0.001$; $n_p^2 = 0.70$) on each condition. Saccade rates were almost stable for 3000 ms ($p =$

268   0.15; $d = 0.08$) in both conditions, increasing in the last epoch ($p < 0.001$; $d = 3.05$), reaching the

269   peak at about 500ms just before the goalkeeper's final movement started (Figure 3).

11

270   There were no significant differences between penalties kicked from 11m compared with penalties

271   kicked from 6m for the other saccade characteristics; duration (105.48 vs. 102.58 ms); amplitude

272   (3.57 vs. 3.82° of visual angle) and peak velocity (117.22 vs. 120.10°/second).

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

274   *Microsaccade/saccade orientation*

275   Microsaccades orientations were not significantly different comparing penalties from 11m with those

276   from 6m (103.70±11.50° vs. 90.45±8.29°, respectively; $p = 0.39$). It seems that, in both situations,

277   goalkeepers, during fixations, shift their covert attention from the lower to the upper kicker's body.

278   Saccade orientation showed a significant main effect for condition ($F_{1,14} = 40.52$; $p < 0.001$; $n_p^2 =$

279   0.74), with a main vector directed to the left during penalties kicked from 11m (222.12±7.21°), and

280   a main vector directed to the right during penalties kicked from 6m (323.25±13.17°) (Figure 4 lower

281   panel). It seems that the different angles of approaching the ball (left versus right) influences the

282   saccades orientation.

283   No significant difference was observed for response accuracy (predicted; missed) on

284   saccade/microsaccade orientations ($p > 0.05$).

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

286   *Pupil size characteristics*

287   Pupil dimension showed a significant correlation with the proximity to the movement time initiation

288   in both penalty conditions. Comparing the correlation values between penalties kicked from 11m with

289   respect to penalties kicked from 6m we found a significant difference ($r^2 = 0.98$ and 0.93; $t(7) = 3.40$;

290    $p = 0.011$; $d = 0.50$). Pupils increased as the goalkeepers' perception of the penalty taker's intention

291   developed, reaching the greatest value just before the goalkeepers' final movement initiation, and it

292   was significantly higher during penalties kicked from 11m compared to 6m (Figure 5).

                                                                                                        12

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

294   Additionally, both curves, represented by the right pupil size, were computed by measurements of

295   the area under the curve (AUC) at the intervals 2000–3400 ms, using the trapezoid rule (technique to

296   calculate the definite integral, approximating the region under the graph of the function as a trapezoid

297   and calculating its area). Analysis showed a significantly different area under the curves ($p<0.001$),

298   with a mean value of 343 for penalties from 6m and a mean value of 559 for penalties from 11m. As

299   showed in Figure 5, in the other part of the temporal sequence the lines were totally (after 3400 ms)

300   or partially (before 2000ms) overlapped.

301   **Discussion**

302   The aim of the present study was to investigate the visual search strategy of soccer goalkeepers

303   engaged in penalties kicked from different distances (11m vs. 6m). Our hypothesis was that athletes,

304   during the period that precedes the final movement time initiation, adopted a different visual search

305   strategy dependent on situational constraints, with more microsaccades and less saccades during near

306   in comparison to far action.

307   During penalties kicked from 11m, goalkeepers exhibited a microsaccades rate time window with a

308   decrement trend visible from the first to the last epoch. Whereas, during penalties kicked from 6m,

309   microsaccade rates decreased from the first to the second epoch to about 33%, then 1000ms before

310   goalkeeper's final movement started, exhibited an additional decrease of about 53% with respect to

311   the first epoch (Figure 2). Saccade rate exhibited a similar trend in both 6m and 11m conditions,

312   almost stable for 3000 ms, with an increment in the last epoch, that reach the peak at about 500ms

313   just before the goalkeeper's final movement started, in concomitant with microsaccades reduction

314   (Figure 3). The current research supports previous literature (Piras et al., 2015, 2019, 2020; Piras,

315   Raffi, et al., 2016) highlighting how microsaccades can be suppressed with the increment of the

316   attentional resource during cognitive visual tasks, leading toward intrusion of small-saccades, which

317   could have the function to shift the attention to cues spatially related.

13

318   Comparing mean number of fixations, saccade and microsaccade rates between conditions,

319   goalkeepers in the 11m condition used a visual search strategy with more fixations, and consequently

320   greater saccade rates in comparison to penalties from 6m, where they exhibited fewer fixations and

321   higher microsaccade rates. The most fixated area during the last epoch before the goalkeepers' final

322   movement time initiation was significantly different between conditions. During penalties kicked

323   from 11m, fixations were located on the visual pivot, a location between the ball and the kicking

324   action (Piras & Vickers, 2011), meanwhile, from 6m, goalkeepers' fixations were located on the

325   kicker's legs (Table 1). Frequent fixations on the visual pivot could be explained by important cues

326   in close proximity to each other that need to be processed via the fovea, with areas inside the pivot

327   characterized by a minimal retinal distance with respect to the fovea (Vater et al., 2019). The

328   functionality of the visual pivot would be to hold the gaze on a location close to relevant cues and

329   initiate small saccades to these cues. During 6m condition, goalkeepers "anchored" their gaze to

330   kicker's legs, a position that optimizes information processing via peripheral vision, in which covert

331   attention is distributed to peripheral cues and eliminates the costs associated with saccadic eye-

332   movements. We can postulate that this could be due to the kicker's and ball different distance, which

333   influence the dimension of the images perceived (kicker and ball); as long as the opponent's distance

334   is large and thus time pressure reduced, gaze can be frequently shifted between the kicker's body and

335   the ball because the costs of saccades are low. On the contrary, closer objects require both foveal and

336   parafoveal to be stimulated for catching information (Williams et al., 2004). Indeed, when the

337   opponent is closer to the observer and time pressure increases, the opponent's body (i.e. the kicker's

338   legs) could turn into a gaze anchor (Piras, Pierantozzi, et al., 2014), where saccades are reduced, and

339   the fovea is not the only important aspect to acquire visual information since it becomes necessary to

340   monitor different cues with the parafovea (likely using microsaccades or small-saccades).

341   Vater and co-workers (2019) have postulated a theory in which saccades could be considered as a

342   relevant measure to distinguish between gaze anchor (saccade-avoiding) and visual pivot (saccade-

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343   preparing), considering that pivots are thought to be optimal locations to initiate saccades to other

344   cues, and frequent saccades to the pivots can be predicted. In agreement with this theory, we identify

345   that during anchoring, experts make micro-saccades to take peripheral information, meanwhile,

346   during pivoting the same subjects produce small saccades to near areas. In this scenario of adapted

347   gaze strategy, the locus of covert attention is more relevant rather than the location (overt attention)

348   of gaze per se (Vater et al., 2019). Therefore, microsaccades with high frequency may suggest

349   attention to peripheral target due to pick up of relevant information, hence a very precise fixation may

350   not be necessary (Piras et al., 2015, 2019). Additionally, it appears that saccades are made in situations

351   with low time pressure to process information in regions of high acuity, in contrast to situations with

352   increased time pressure, where gaze-anchoring behavior is preferred due to the possibility of utilizing

353   microsaccades and avoiding saccades that could compromise the processing of the visual cue(s). The

354   key issue in light of the current discussion is that players demonstrate different visual search

355   behaviours under changing task constraints.

356   Williams et al. (2004) hypothesized that during a soccer match, when the distance between the ball

357   and the player is great, such as during 11vs11 open-play situation in soccer, players have time to

358   undertake a comprehensive analysis of the situation and seem to rely on information extraction via

359   the fovea. In contrast, when the ball is closer and the time constraints more critical, such as during

360   small-sided games (e.g. 1vs1), both fovea and peripheral vision may be employed, with players

361   initially using the fovea to extract relevant task information, while as the opponent approaches they

362   may rely more on peripheral vision to pick up the relative movement pattern. The emergent search

363   pattern in these situations would appear to be at least partly constrained by the number of players

364   involved in the action (they studied 11vs11; 3vs3 and 1v1 soccer situations) and the relative distance

365   between these players and the ball (Williams et al., 1994; Williams & Davids, 1998). Nevertheless,

366   authors did not consider that in details, such as the distance between players or the distance between

367   players and the ball. Moreover, they did not assess the subtle eye movements, which occur to provide

368   important visual information in determining appropriate subsequent decisions (Piras et al., 2020). As

369   postulated by the authors, empirical evidence is needed to clarify and support a constraints-based

370   explanation of visual search behaviour in sports (Williams et al., 2004). Consequently, our work

371   extents the important works of Williams et al. (1994; 1998), highlighting the important role of

372   microsaccades and the small-saccades, necessary to indicate both the locus of fixation and the locus

373   of attention in team game context.

374   The ability to quickly shift attention from one relevant cue to another is a prerogative of the athletes

375   (Piras et al., 2015). A recent study found that microsaccades provide a mechanism for precisely

376   relocating gaze in high-acuity tasks, supporting the proposal that microsaccades are exploratory

377   movements, similar to larger saccades (Ko et al., 2010). In a sport situation, Piras et al. (2020) found

378   a significant difference in microsaccade angular orientations during penalties kicked from 11m,

379   showing that microsaccades could anticipate the goalkeeper's intention. Therefore, we have

380   compared the microsaccade angular directions during penalties from 11m with that of penalties from

381   6m, demonstrating that the main vector has the same direction in both conditions (Figure 4). It could

382   indicate that athletes shift their attention from the lower (legs; visual pivot) to the upper opponent's

383   body (trunk; head) (Piras et al., 2015). Meanwhile, saccades direction during penalty kicked from 6m

384   showed a mean angular direction toward the lower right of the goalkeeper's visual field (Figure 4

385   lower panel). At this point, we can confirm, in combination with the previous study (Piras et al.,

386   2020), that saccade orientations are conditioned by the penalty taker's body movement, following the

387   direction of the kicker during their approach (run-up) toward the ball.

388   Pupil size is an effective indicator of cognitive load (Krejtz et al., 2018), and has been associated with

389   motor preparation (Jainta et al., 2011). In the current study, we specifically examined pupil dynamics

390   during a sport situation where the appropriate allocation of visual attention precedes and determines

391   effective motor behaviour. The pupils dilated relatively more during the viewing of small objects

392   visualized at a relatively far distance than at a near distance. It has also been found that the pupil

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393   diameter changed with the scope of attention, dilating with broadly spread attention and contracting

394   with narrowly focused attention (Daniels et al., 2012). Interestingly, in the present study, when the

395   goalkeeper saw the pattern enlarging on screen as the kicker approached the ball, pupil diameter

396   increased over time (Piras et al., 2020). Overall, the results of the area under the curve at a specific

397   intervals (2000–3400 ms) showed that pupil size prior to stimulus presentation effectively reflected

398   preparatory set activity related to saccade initiation, and confirmed a direct link between saccade

399   initiation and pupil size (Wang & Munoz, 2015). This increase in pupil diameter could increase visual

400   sensitivity to improve perceptual processes immediately after to redirect the eyes (Piras et al., 2020).

401   In general, we found successfully predicted than missed penalties (57% vs 43%). When the

402   goalkeeper's final movement time initiated in a time equal or slightly greater than 4.7 seconds, the

403   probability to predict the ball increased. Conversely, faster responses, below 4.7 seconds, raised the

404   probability to miss the direction of the ball at both distances. Moreover, we should consider that from

405   11m, GKs exhibited successfully predicted than missed penalties (60% vs 40%). At 6m, whilst there

406   was no significant difference for predicted and missed penalties, there was an 8% improvement with

407   a medium effect size (d = 0.59). So, in both penalty distances, GK's were better in predicting than

408   missing, suggesting that they had suitable experience in both environments. This slight reduction in

409   number of predicted penalties at 6m compared to 11m could be attributed to the recreational practice

410   of our goalkeepers, that was more frequent at 11m compared to 6m, therefore, they may have been

411   more familiar with this condition. Additionally, it has been largely demonstrated that it is more

412   difficult to intercept the ball kicked closer than farer, even in the same environment (Navia et al.,

413   2017).

414   Within the design of the current study, we acknowledge the following limitations. In line with the

415   power analysis, 8 goalkeepers were recruited to the study. Whilst this sample may appear small, it

416   was important to recruit participants of a similar (national level) ability to ensure a homogenous

417   group. Future research may wish to consider how saccades and microsaccades differ as a function of

418   expertise. Second, we presented the right footed penalty taker from a soccer pitch and the left footed

419   penalty taker from the futsal pitch. We decided against presenting a mix of right and left foot penalty

420   kicks for both distances as our intention was not to determine if goalkeepers were more able to

421   intercept the ball kicked with the left or with the right in different distances. Adding additional trials

422   into the study design would have also required a larger sample size, which was not possible. Third,

423   there were differences in ambient conditions between the soccer pitch and the futsal pitch. Whilst it

424   would have been possible to use the same environment (record only from the identical soccer or futsal

425   pitch, just at different distances), this would have impacted the representative nature of the study (c.f.

426   Araújo et al., 2007); moving a soccer ball closer (to 6m) and filming on a soccer pitch (or vice-versa

427   for futsal) was not representative of what a goalkeeper experiences in their natural environment.

428   In conclusion, when the spatiotemporal constraint is less severe, as it was during penalties from 11m,

429   the goalkeepers exhibit a visual search strategy based on more fixations and small saccades to pick

430   up relevant information from the fovea. When the spatiotemporal constraint is more severe (6m

431   condition), goalkeepers relied on peripheral vision to monitor kicker's movements through the use of

432   microsaccades, due to their increased ability to bring the neuronal receptive fields to stimulus regions.

433   **Disclosure statement**

434   No potential conflict of interest was reported by the authors.

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437   correspondence between experimental task constraints and behavioral setting: Comment on

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538

539   **Figure captions**

540   **Figure 1.** Histograms represent the percentage values between predicted (in black) and missed (in

541   grey) penalty kicks across condition (11m and 6m) (A); and the response time of the goalkeepers

542   between predicted (in black) and missed (in grey) penalty kicks across condition (11m and 6m) (B).

543   **Figure 2.** Time course of microsaccade rates during penalties kicked from 11m (A) and from 6m (B),

544   calculated from the goalkeeper's final movement initiation to backwards for 4000ms. Rates were

545   computed for each GKs using a moving time window of 200ms and then averaged over all athletes.

546   Solid black lines represent the mean rate, meanwhile the shaded grey areas represent the standard

547   error of the mean.

548   **Figure 3.** Time course of saccade rates during penalties kicked from 11m (A) and from 6m (B),

549   calculated from the goalkeeper's final movement initiation to backwards for 4000ms. Rates were

550   computed for each GKs using a moving time window of 200ms and then averaged over all athletes.

551   Solid black lines represent the mean rate, meanwhile the shaded grey areas represent the standard

552   error of the mean.

553   **Figure 4.** Panels represent the direction of the mean vector of microsaccades (upper) and saccades

554   (lower) across conditions (11m; 6m). each angular sector is 22.50° in width. Radial thick lines are the

23

555   mean vectors, curved lines external to the diagrams indicate the standard deviation, with the 95% of

556   confidence interval ($p < 0.05$).

557   **Figure 5.** Plot show the pupil size dilations of all GKs during penalties kicked from 11m (solid grey

558   line) and penalties kicked from 6m (dotted black line), correlated with the trial time until the

559   goalkeeper's final movement initiation.

24

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 $p < 0.05$
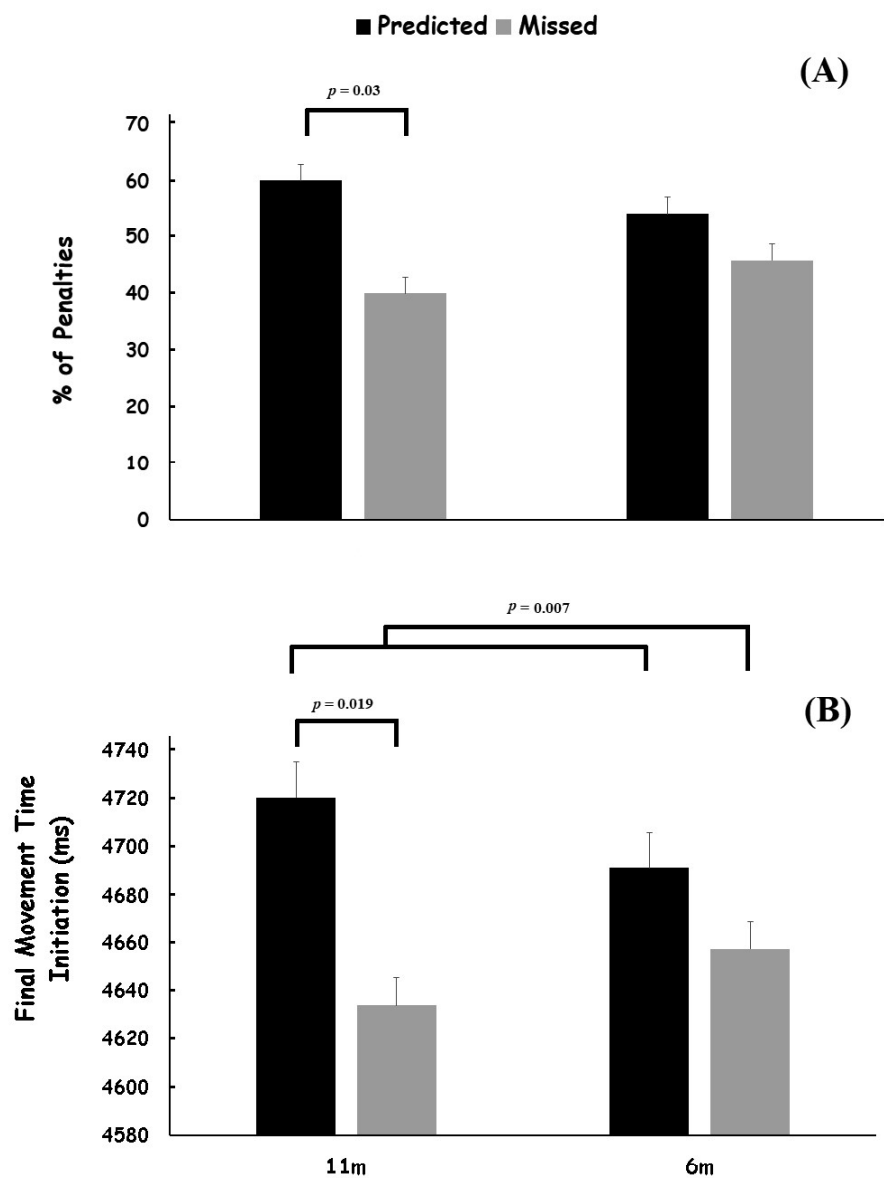
Figure 1. Histograms represent the percentage values between predicted (in black) and missed (in grey) penalty kicks across condition (11m and 6m) (A); and the response time of the goalkeepers between predicted (in black) and missed (in grey) penalty kicks across condition (11m and 6m) (B).
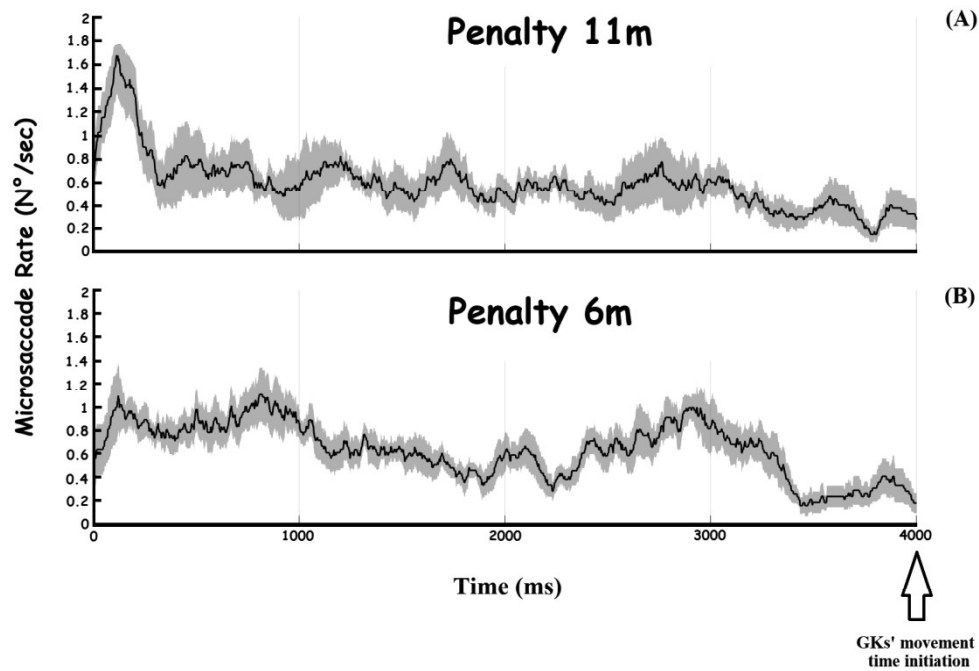
42x56mm (600 x 600 DPI)

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.
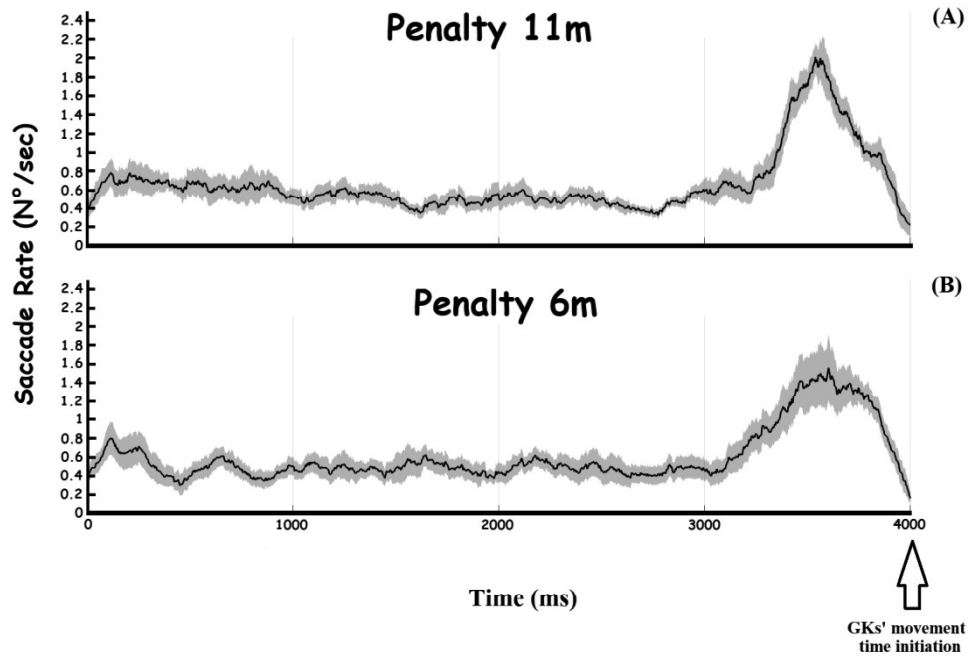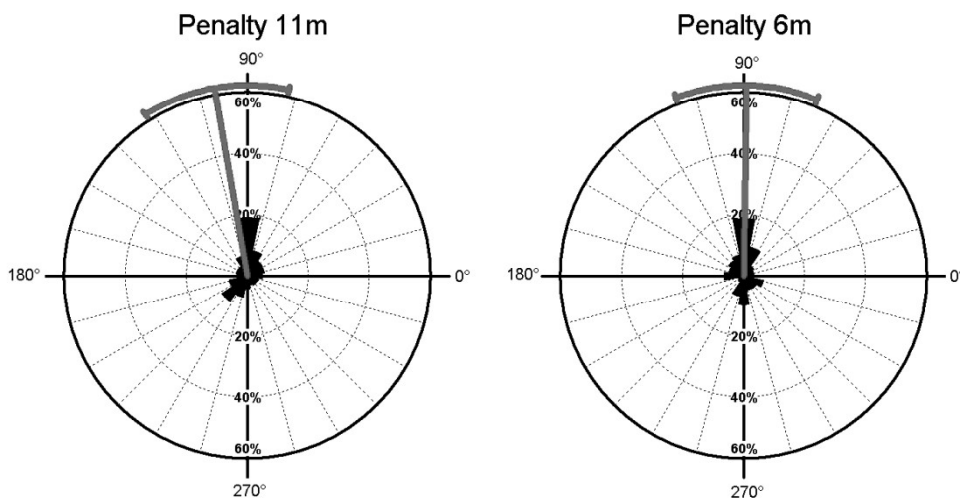
72x50mm (600 x 600 DPI)

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.
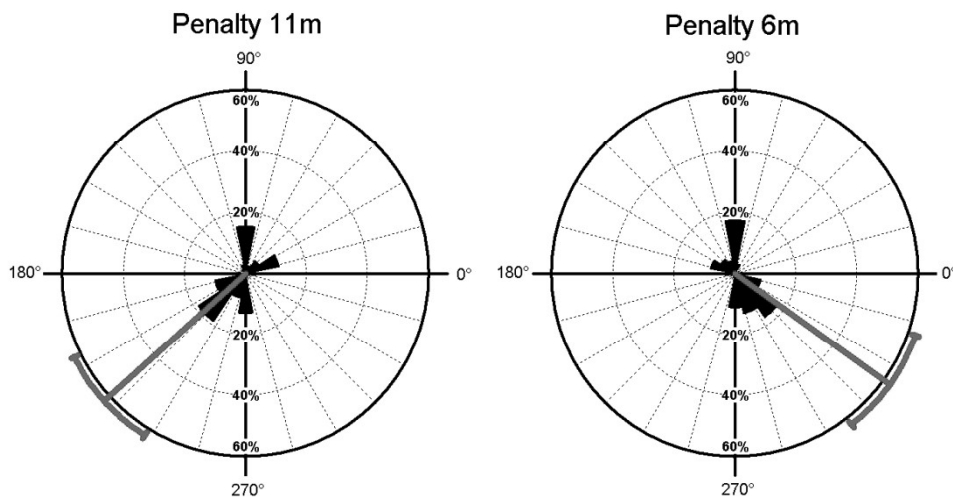
72x50mm (600 x 600 DPI)

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).
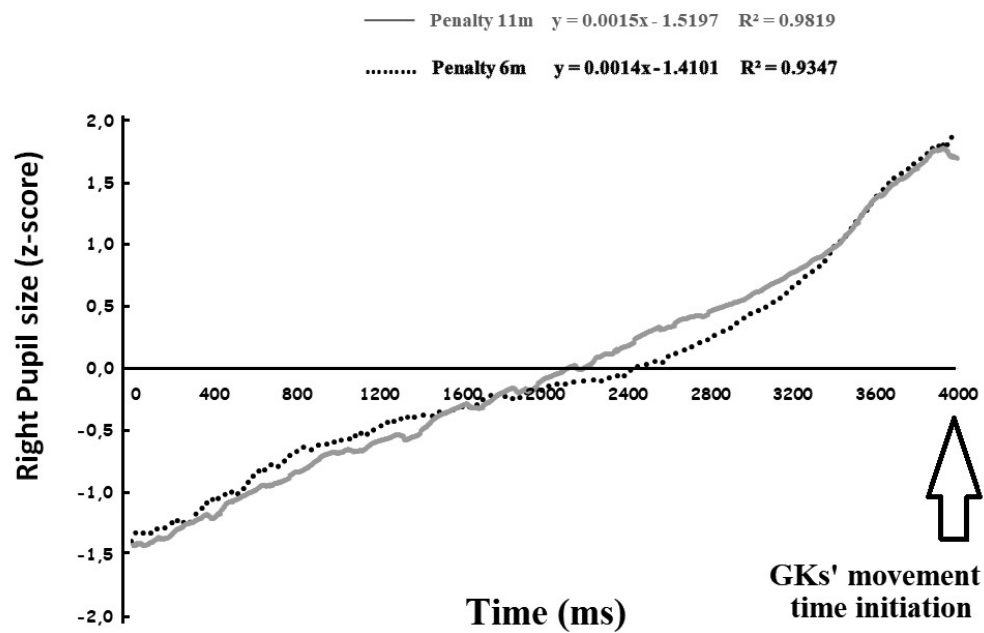
60x73mm (600 x 600 DPI)

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)