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Saccades and Microsaccades Coupling During Free-Throw Shots in Basketball Players

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1 **Title:** Saccades and microsaccades coupling during free-throw shots in basketball
2 players

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5
6 **Introduction**

7 In basketball, many matches are won or lost through critical skills, such as free-throw. Thus,
8 being precise during this shooting technique is a fundamental part of the game. Indeed, expert players
9 perform many shooting training sessions to develop and improve their technique. The temporal
10 sequence to follow to make an efficient and efficacious skill is to understand the exact moment the
11 ball has to be released, at what angle and speed, and where the player has to look during the shooting
12 phases (Hamilton & Reinschmidt, 1997). The free-throw is a condition in which the player is “free”
13 from defenders so that the shooter can focalize the visual attention only on the action without visual
14 distractions that could be unexpected and relevant for the performance. Successful free-throw requires
15 both attentional skills and physical ability; therefore, understanding this ability’s attentional demands
16 may guide improving performance (Klostermann, 2019).

17 Visual perception is a dynamic process in which visual information are identified, extracted
18 from the surroundings, and integrated with other sensory inputs. It has been found that elite athletes
19 are better than novices in action anticipation, and this is due to their improved visual perception.
20 Several cognitive factors like expertise, motivation, and development are implicated in favouring the
21 integration between sensory and visual input. Previous studies revealed that elite athletes, concerning
22 novices, used different methods to extract visual information to anticipate an action (Williams &
23 Jackson, 2019). Free-throw is a precision aiming task in which a particular visual search strategy,
24 such as the quiet eye (QE), reveals intra-individual (e.g., successful vs. unsuccessful tasks) as well as
25 inter-individual (e.g., experts vs. novices) differences in motor performance (Vickers, 1996a). The
26 QE is defined as the final fixation or tracking gaze located on a specific object or location in the
27 environment and made before the final movement initiation during perception and action tasks. The
28 QE onset occurs before the critical movement phase is initiated, and the offset is the end of this final
29 fixation. Vickers (1996a) demonstrated earlier QE onsets and longer QE durations in better compared
30 to worse basketball free-throw shooters and longer QE durations for successful compared to
31 unsuccessful trials. Moreover, she found that longer QE duration on a specific target location was
32 exhibited during the early phases of the free-throw sequence. Then, during the execution phase, vision
33 was suppressed to prevent its negative interference with the motor program. She called this

34 phenomenon the *location-suppression hypothesis* in the aiming tasks (for more information, see
35 Vickers, 1996a).

36 More recently, the interest in the role of microsaccades and other small saccades during
37 fixation has been renewed, especially their role during action-perception tasks and the links with
38 visuospatial attention (Piras & Raffi, 2023). Microsaccade generation is modulated by attention and
39 by the stimulus presentation (Hafed & Clark, 2002; Piras et al., 2015), showing a short inhibition after
40 stimulus appearance, followed by a rebound in which both microsaccades and small saccades rate
41 increases (Piras et al., 2021b). During natural viewing conditions, seems that microsaccades are not
42 involuntary, uncontrolled movements, but rather voluntary, memory-guided, spatially accurate and
43 finely controlled (Willeke et al., 2019). Microsaccades are similar to saccades, they just work at
44 different retinal level. Saccades are used to explore the scene larger than 2° of visual angle, shifting
45 the fovea on potentially interesting and relevant stimuli. Microsaccades have a different role, allowing
46 for finer examination of the foveated stimulus (Poletti, 2023). In a recent study, Piras et al. (2021a)
47 investigated the role of saccades and microsaccades in intermediate soccer goalkeepers attempting to
48 predict penalty kicks from different distances. Authors found that microsaccade rates dropped ~ 1000
49 ms before the goalkeeper's final movement initiation, and saccade rates increased, reaching the peak
50 of ~ 500 ms before the final movement initiated, concomitant with microsaccade reduction. The
51 current research highlighted how microsaccades can be suppressed with the increment of the
52 attentional resource during cognitive visual tasks, leading toward intrusion of small saccades, which
53 could have the function of shifting the attention to cues spatially related (Piras et al., 2021a, 2021b).

54 The studies mentioned above have been performed using interceptive timing tasks in which
55 the gaze fixates and/or tracks an object moving toward the performer that must be controlled (e.g.
56 receiving a ball). Gaze strategy, in terms of saccades and microsaccades dynamics, could be different
57 if considering an aiming task (e.g. throwing a ball), in which gaze fixates a critical target location(s)
58 prior to an object being aimed away from the body (Vickers, 2007). Bearing in mind the relationship
59 between eye movements, action-perception coupling and the direction of attention, the current
60 research investigated the role of saccades and microsaccades when different levels of basketball
61 players were engaged in a free-throw task. Previous research has demonstrated that during a
62 basketball free-throw, experts tended to spend more time fixating on the target (hoop and backboard)
63 prior to the shooting action. Then, during the execution phase, vision appears to be suppressed
64 (Vickers, 1996b). Therefore, we can hypothesize from these elements that athletes, just before final
65 movement initiation, maintain a steady fixation on the target to make a more accurate aiming task,
66 focalizing their attention with microsaccades or small saccades toward the point(s) where they want

67 to send the ball. Moreover, based on the location-suppression hypothesis, we hypothesize that
68 saccades and microsaccades are suppressed just before the execution phase.

69

70 **Methods**

71 *Participants*

72 Twenty-four (n = 24) male basketball players, with a mean age of 21.04 (SD = 3.04) years
73 volunteered to participate. Participants were subdivided into two groups; 12 near-expert basketball
74 players who played at the Serie B level (Italy championship), with a score in the free-throw during
75 the previous season $\geq 70\%$, and 12 amateur basketball players who played at the Serie D level (Italy
76 championship) (see Table 1). Based on the sample size of the other studies (Harle & Vickers, 2001;
77 Vickers, 1996b, 1996a) and an effect size f of 0.30, G*power (version 3.1.9.2; Heinrich-Heine-
78 University, Kiel, Germany), predicted that a total sample size of 24 would give appropriate power
79 ($1-\beta$ error probability 0.80) to detect a significant difference at alpha level of 0.05. All players had
80 normal or corrected to normal vision. After receiving oral and written information concerning the
81 study protocol, all participants signed the informed consent to participate in the study. The study was
82 approved by the Bioethics Committee of our University.

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

84 *Apparatus*

85 Eye movements were recorded binocularly with the video-based eye tracking system
86 (EyeLink® II, SR Research), which consisted of two miniature cameras mounted on a leather-padded
87 headband. Pupil tracking was performed at 500 samples/s, with a gaze resolution of $<0.005^\circ$ and noise
88 limited to $<0.01^\circ$. The eye tracker was calibrated at the beginning of the experiment and after every
89 ten throws. Then, data validation and drift correction were performed by applying a corrective offset
90 to the raw eye position data after every pass. Calibration and validation of the system were repeated
91 every time a possible measurement error occurred due to participant movement. The accuracy of eye
92 position was checked after every throw, and if necessary, a drift correction was performed. Practice,
93 calibration, validation and data collection took ~20 minutes per participant.

94 In order to collect the exact time participants made the throw, one inertial sensor (Cometa
95 Systems, Italy) was placed on the dorsal face of the right hand. Inertial sensors were synchronised
96 with the EyeLink system to have corresponding eye and hand movements data.

97 *Procedure*

98 In front of a basketball hoop, wearing the Eyetracker and the inertial sensor, participants made
99 20 free-throws interspersed by 10 minutes of rest after ten trials. Participants stand behind the free-
100 throw line, located 4.19 m from the basket, and shoot a ball, ~24 cm in diameter and ~610 g in weight,
101 into a hoop of ~46 cm in diameter. The hoop is located directly in front, at a height of 3.05 m from
102 the floor (Figure 1).

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

104 *Statistical analysis*

105 The length of the free-throw sequence used for analysis was initially selected. Data was
106 analysed from the start of the sequence to the movement time initiation.

107 Response accuracy and movement time initiation were analysed with repeated measures of
108 ANOVA, in which expertise (near-experts; amateurs) was the between-subjects factor, and response
109 time and accuracy were the within-subjects factors.

110 We defined microsaccades as fixational eye movements less than 1 degree of visual angle and
111 with the same peak velocity versus amplitude curve as large saccades. We applied the Engbert-Kliegl
112 algorithm (2003) to identify saccades and microsaccades. To reduce the potential noise, we
113 considered only binocular saccades and microsaccades lasting at least three data samples (6 ms), with
114 velocity threshold detection set at 6. Saccades and microsaccades rate, amplitude, duration, and peak
115 velocity were calculated for each participant during each shot.

116 Repeated measures ANOVA was performed separately to analyse saccade and microsaccade
117 rate, amplitude, duration, and peak velocity. Expertise (near-experts; amateurs) was the between-
118 subjects factor, response accuracy (correct; incorrect) was the within-subjects factor.

119 The two-dimensional distribution of all saccade and microsaccade orientations was calculated
120 concerning expertise (near-experts; amateurs) and response accuracy (correct; incorrect). The
121 Watson-Williams test for homogeneity of means (Oriana® 4.0) was performed. The null hypothesis
122 was that the orientations of saccades and microsaccades between expertise and response accuracy
123 have similar continuous distribution at the 5% significance level.

124 All statistical analysis was done with SPSS, version 22.0 (Chicago, IL, USA). Effect sizes
125 were calculated as the mean difference standardized by the between-subject standard deviation and
126 interpreted according to the following thresholds: trivial, <0.20 ; small, $\geq 0.20 < 0.50$; moderate,
127 $\geq 0.50 < 0.80$; large, ≥ 0.80 (Cohen, 1988). Partial eta squared (η^2) was used during multiple
128 comparisons. Statistical significance was set at $p < 0.05$. Post hoc testing was corrected with the
129 Bonferroni procedure.

130

131 **Results**

132 All participants made more correct (mean 13.62 ± 0.6 ; 68%) than incorrect (mean 6.37 ± 0.6 ;
133 32%) free-throw ($F_{1,22} = 36.21$; $p < 0.001$; $\eta_p^2 = 0.62$). Meanwhile, we did not find significant
134 differences between groups ($p = 0.63$).

135 Movement time initiation showed no significant differences between correct and incorrect
136 free-throw ($p = 0.60$), not for the interaction between groups x response accuracy ($p = 0.53$).
137 Bonferroni's post-hoc analysis showed significant differences between groups for correct responses
138 ($p = 0.045$; Cohen's $d = 0.85$), in which movement time initiation was shorter in amateur (mean
139 1855.70 ± 57 ms) than near-experts (mean 2048.85 ± 89 ms) groups (see Figure 2).

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

141 The rate, duration, peak velocity, and amplitude of saccades and microsaccades are shown in
142 Figure 3. Analysis revealed significant differences between groups for almost every eye movements
143 parameter investigated. No significant value was found considering correct and incorrect free-throw.
144 Microsaccades showed between-group significant differences for rate ($F_{1,29} = 22.45$; $p < 0.001$; $\eta_p^2 =$
145 0.44), duration ($F_{1,29} = 6.66$; $p = 0.015$; $\eta_p^2 = 0.19$) and peak velocity ($F_{1,29} = 23.13$; $p < 0.001$; $\eta_p^2 =$
146 0.44) but not for amplitude ($p = 0.09$). Saccades showed significant differences for rate ($F_{1,41} = 7.53$;
147 $p = 0.009$; $\eta_p^2 = 0.15$), duration ($F_{1,41} = 8.85$; $p = 0.005$; $\eta_p^2 = 0.18$), peak velocity ($F_{1,41} = 18.13$; $p <$
148 0.001 ; $\eta_p^2 = 0.31$) and amplitude ($F_{1,41} = 6.10$; $p = 0.018$; $\eta_p^2 = 0.13$).

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

150 Further analysis was done to investigate the temporal sequence of saccade and microsaccade
151 rates. Near-experts' saccade rates were mostly constant for about 800 ms, increasing and reaching the
152 highest level at ~ 800 ms before the final movement initiation. Amateurs showed a different sequence,
153 peaking at ~ 1000 ms before their final movement initiation (Figure 4 upper panels). Near-experts'
154 microsaccade rates showed a similar trend of saccades, reaching the peak ~ 800 ms before their hands
155 movement initiation. This differs from that of amateurs who exhibited a constant and lower tendency
156 of microsaccade rates (Figure 4 lower panels).

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

158 Microsaccades orientation showed no significant differences between groups ($p = 0.39$; $d =$
159 0.13) in terms of direction. As shown in Figure 5 (upper panel), microsaccade directions were equally
160 distributed to the right and to the left of the participant's visual field.

161 Saccade orientations instead showed a main vector directed to the lower in the near-expert
162 group and equally distributed in the amateurs ($p = 0.47$; $d = 0.07$; Figure 5 lower panel). What is
163 visibly evident is the different number of microsaccades (top-left) and saccades (bottom-right) in
164 near-experts and amateurs, respectively.

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

166

167 **Discussion**

168 The aim of the present study was to investigate the role of saccades and microsaccades when
169 different levels of basketball players were engaged in a free-throw task. The free-throw is an
170 important part of winning or losing a match, and it consists of shooting the ball through a horizontally
171 oriented hoop placed 3.05 m above the floor and 4.19 m in front of the free throw line. This is a
172 unique, uncontested closed skill that does not contain adversarial constraints; the athlete can focus
173 the visual attention toward the hoop without any spatial-temporal demands. This entirely closed type
174 of athletic skill is, therefore, controlled exclusively by the performer. Different studies have tried to
175 identify the gaze behaviour in sports, and in particular, the free-throw has gained considerable
176 attention (Lebeau et al., 2016). Expert and successful free-throw shooters showed longer QE
177 durations than novice and unsuccessful ones (Vickers, 1996b). The QE strategy has been studied in
178 many sports and professional tasks (for more information, see Vickers, 2016), and the original
179 findings have been replicated many times as meta-analysed by Lebeau et al. (2016). Training
180 programs to increase the QE period effectively improve the gaze strategy, leading to performance
181 improvement. To our knowledge, what is missing from the literature is a thorough investigation of
182 the QE definition: “a suppression of large eye movements within 1–3 degrees of visual angle”. It has
183 long been known that our eyes are never still, even during fixation. Researchers agree on the presence
184 of three main types of eye movement during visual fixation in humans: tremors, drifts and
185 microsaccades (Martinez-Conde et al., 2004). We believe that during fixation of 1-3 degrees of visual
186 angle, other types of eye movements fit within normal definitions of fixation (e.g. microsaccades and
187 small saccades). These small micromovements may be used as a favourable strategy for a given task.
188 Piras et al (2021b), during a penalty kick in soccer, found that expert goalkeepers made, during the
189 period that precedes the critical movement initiation, microsaccades and small saccades of 0.6 and 3
190 degrees of visual angle, respectively. Authors argued that these tiny eye movements were necessary
191 to shift from covert to overt attention for identifying the useful cues necessary to guide the action. It
192 is well known that when we program a saccade we also shift our attention, enhancing our visual
193 perception toward the saccade target. This mechanism works not only at peripheral level but also at

194 the foveal region with microsaccades, in which, before making a microsaccade, enhance selectively
195 the fine spatial vision of the target location (pre-microsaccadic attention) (Poletti, 2023; Raffi & Piras,
196 2019). Moreover, the perception of fine visual details is modulated also during microsaccades. Intoy
197 et al. (2021) have found that, during fine spatial examination, the detection of highly localized
198 luminance changes across the foveola is suppressed during microsaccades. The reduction of the visual
199 sensitivity is stronger and faster around the foveola (very centre of gaze), where sensitivity rapidly
200 rebounds at the end of the microsaccade and remains higher than in the surrounding regions during
201 the post-microsaccadic fixation.

202 The free-throw shot success is around 70% in the National Collegiate Athletic Association
203 (NCAA) and 75% in the National Basketball Association (NBA) (increased from 72.8% in 1999 to
204 77.1% in 2010) (Branch, 2009). Our study showed that all participants made more correct (68%) than
205 incorrect (32%) free-throw shots, with no significant differences between groups. Kozar et al. (1995)
206 compared the performance of NCAA players in practice versus competitions. They highlighted the
207 difference between the number of shots attempted in sequence during game time (e.g., typically in
208 groups of two) in contrast to the many consecutive shots often undertaken by players during practice.
209 They demonstrated that the accuracy in games (69.2%) was similar to the first two shots during
210 practice (69.8%), but that additional practice shots were much more successful (76.6%) than game
211 performance.

212 Movement time initiation showed significant differences between groups for correct
213 responses, in which amateurs started the throwing movement before near-experts groups. This long
214 duration in near-experts could be linked to more time needed to focalize the visual attention on the
215 target. In fact, gaze strategy showed significant differences between groups regarding microsaccade
216 and saccade characteristics. Near-experts' gaze was more stable, highlighted by more microsaccades,
217 longer and slower than that exhibited by amateurs. Conversely, amateurs made more saccades,
218 shorter, faster and with greater amplitude in comparison to near-experts. Longer fixation period with
219 higher microsaccade rates allow athletes an extended duration of programming (goal-directed
220 control), focalizing attention to the target and minimizing distraction from other environmental cues
221 (stimulus-driven control) (Eysenck et al., 2007; Wilson et al., 2009). Our results suggest that near-
222 experts maintain a fixation on a single target, contrary to amateurs who directed their gaze to several
223 cues near the hoop for shorter periods. We demonstrated that higher-level players controlled their
224 gaze to a smaller area, focusing on one specific target point. They had a lower saccade frequency and
225 amplitude during each shot, making more microsaccades, than less skilled counterparts.

226 Near-experts' saccade rates were mostly constant for about 800 ms, increasing and reaching
227 the peak at ~800 ms before the final movement initiation, while amateurs showed a different

228 sequence, with the peak at ~1000 ms before the hands movement started. Looking at the near-experts'
229 microsaccade rates we can see a similar trend of saccades, reaching the peak ~ 800 ms before their
230 hands movement initiation, different from that of amateurs who exhibited a constant and lower
231 tendency of microsaccade rates. A visually inspection of the Figure 4 showed that, in near-experts,
232 microsaccades increased after the saccades peak, on the contrary, in amateurs, the saccades peak is
233 shown after the decrease in microsaccade rates. The spatiotemporal characteristics of microsaccades
234 and saccades may reflect an optimal sampling method by which the brain discretely acquires visual
235 information and can differentiate between participants that use a fixation before the critical movement
236 time (and then QE strategy) with participants who move the eyes in order to catch more visual cues
237 to make decisions. Moreover, microsaccades and saccades have been suppressed just before the
238 execution of the free-throw task, and this suppression was anticipated in amateurs. Within the time
239 course of a trial, microsaccade and saccade rates decreased with time, with almost no eye movements
240 made in the final milliseconds of the task, that is, just before athletes made the shoot. Such suppression
241 might reflect of the cognitive processes involved in such tasks, including perceptual decision-making
242 and modulations in temporal attention. This suppression is different from that documented by Vickers
243 in basketball (1996b), in which she found that expert athletes suppressed their vision (using the blink)
244 during the execution phase, assuming that vision could have interfered with the motor phase. The
245 suppression just before the movement time initiation, of both micro-saccades, was similar to that
246 found in table tennis (Piras et al., 2015, 2019) and in soccer penalty kicks (Piras et al., 2021b, 2021a).
247 We can hypothesize that these tiny eye movements precisely relocate the gaze according to the spatial
248 position between different interest areas and thus enhance perception during free-viewing of a
249 stationary narrow region. Thus, such eye movements suppression, that happens just before the action
250 initiation, could not be due to the detrimental of the task (Nanjappa & McPeck, 2021), but because at
251 that point, all interest areas are under the cover attention, thus avoiding the need for any further gaze
252 shifts. Further evidences are necessary to confirm this hypothesis, even because this suppression
253 should happen at the right time, not too early, but neither too late.

254 Polar plots of microsaccade and saccade orientations between groups showed that near-
255 experts modulated their visual attention differently from amateurs. The distribution of microsaccade
256 orientations was broader in near-experts than amateurs, on the contrary, the distribution of saccade
257 orientations was broader in amateurs than near-experts. This probably means that amateurs allocated
258 their overt attention to different cues present in the scene, different from near-experts who prefer to
259 adopt a broad focus of attention as they shifted their covert attention around them, supported by more
260 microsaccade and fewer saccade rates than amateurs. The dynamic properties support the view that
261 microsaccades and small saccades enhance visual perception and, therefore, represent a fundamental

262 motor process with a specific purpose for gaze behaviour. Microsaccades are strongly modulated by
263 visual attention in spatial cueing tasks (Engbert & Kliegl, 2003; Hafed & Clark, 2002). Effects are
264 related to rate (rate effect) and to the angular orientation (orientation effect). Therefore,
265 microsaccades might be crucial for visual perception, supporting top-down processes by high-level
266 attentional stimuli (Engbert, 2006).

267 The main limitation in the current study is the lack of information related to the free-throw
268 scores of amateurs group during the previous season. Maybe their personal score was greater than
269 70%. This could have conditioned the response accuracy results of our experiment. Another
270 limitation, that is common in sport performances, is to find players at very high level, where the
271 number of elite players is usually relatively low. For example, in NBA, the number of players that
272 have exhibited a score greater than 80% in the previous season (2022-23) are only 75 in front of about
273 560 athletes ([https://www.teamrankings.com/nba/player-stat/free-throw-
274 percentage?season_id=220](https://www.teamrankings.com/nba/player-stat/free-throw-percentage?season_id=220)).

275 In conclusion, the results of the present study suggest that microsaccades and small saccades
276 i) are functionally related to each other, ii) are important for the execution of fine motor tasks, and
277 iii) modulate visual perception and attention. These tiny eye movements could improve the action
278 perception, helping athletes during the critical moment that precedes the motor response, shifting
279 from covert to overt attention necessary to identify the critical cues related to the perception of the
280 motor outcome.

281

282 **Disclosure statement**

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

284

285 **Data availability statement**

286 Due to the nature of this research within a high-performance environment, athletes of this study did
287 not agree for their data to be shared publicly, so supporting data are not available.

288

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362 **Figure captions**

363 **Figure 1.** Experimental setup with the participant wearing the Eye-tracker and the inertial sensor
364 placed on the right hand during the free-throw.

365 **Figure 2.** Histograms represent movement time initiation (mean±SD) in both near-expert and amateur
366 basketball players across correct (black) and incorrect (grey) responses. Asterisks represent
367 significant differences at $p < 0.05$.

368 **Figure 3.** Histograms represent values (mean±SD) of microsaccade and saccade characteristics (rate,
369 duration, peak velocity and amplitude) in both near-expert (black) and amateur (white) basketball
370 players. Asterisks represent significant differences at $p < 0.05$.

371 **Figure 4.** The time course of microsaccade and saccade rates was calculated from the start of the
372 sequence to the movement time initiation (vertical dashed lines). Rates were computed for each
373 participant using a moving time window of 200 ms and then averaged over all participants. Dashed
374 (near-experts) and solid (amateurs) lines represent the mean rate of saccades (upper plot) and
375 microsaccades (lower plot), with the shaded area around each curve representing the standard error
376 of the mean.

377 **Figure 5.** Panels represent the mean vector direction of microsaccades (upper) and saccades (lower)
378 in both groups (near-experts and amateurs). Each angular sector is 24.00° in width. Radial thick lines
379 are the mean vectors, and curved lines external to the diagrams indicate the standard deviation, with
380 a 95% confidence interval ($p < 0.05$).