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

Published Version:
Piras A., Del Santo F., Meoni A., Raffi M. (2024). Saccades and Microsaccades Coupling During Free-Throw Shots in Basketball Players. JOURNAL OF SPORT & EXERCISE PSYCHOLOGY, 46(4), 229-237 [10.1123/jsep.2023-0161].

Availability:
This version is available at: https://hdl.handle.net/11585/977514 since: 2024-08-12

Published:
DOI: http://doi.org/10.1123/jsep.2023-0161

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Date of first submission: June, 12 2023

Introduction

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

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

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

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

Methods

Participants

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

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

Apparatus

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

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

Procedure

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

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

Statistical analysis

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

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

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

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

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

All statistical analysis was done with SPSS, version 22.0 (Chicago, IL, USA). Effect sizes were calculated as the mean difference standardized by the between-subject standard deviation and interpreted according to the following thresholds: trivial, <0.20; small, $\geq 0.20 < 0.50$; moderate, $\geq 0.50 < 0.80$; large, ≥ 0.80 (Cohen, 1988). Partial eta squared ($\eta p2$) was used during multiple comparisons. Statistical significance was set at $p<0.05$. Post hoc testing was corrected with the Bonferroni procedure.

Results

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

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

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

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

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

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

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

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

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

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

Discussion

The aim of the present study was to investigate the role of saccades and microsaccades when different levels of basketball players were engaged in a free-throw task. The free-throw is an important part of winning or losing a match, and it consists of shooting the ball through a horizontally oriented hoop placed 3.05 m above the floor and 4.19 m in front of the free throw line. This is a unique, uncontested closed skill that does not contain adversarial constraints; the athlete can focus the visual attention toward the hoop without any spatial-temporal demands. This entirely closed type of athletic skill is, therefore, controlled exclusively by the performer. Different studies have tried to identify the gaze behaviour in sports, and in particular, the free-throw has gained considerable attention (Lebeau et al., 2016). Expert and successful free-throw shooters showed longer QE durations than novice and unsuccessful ones (Vickers, 1996b). The QE strategy has been studied in many sports and professional tasks (for more information, see Vickers, 2016), and the original findings have been replicated many times as meta-analysed by Lebeau et al. (2016). Training programs to increase the QE period effectively improve the gaze strategy, leading to performance improvement. To our knowledge, what is missing from the literature is a thorough investigation of the QE definition: “a suppression of large eye movements within 1–3 degrees of visual angle”. It has long been known that our eyes are never still, even during fixation. Researchers agree on the presence of three main types of eye movement during visual fixation in humans: tremors, drifts and microsaccades (Martinez-Conde et al., 2004). We believe that during fixation of 1-3 degrees of visual angle, other types of eye movements fit within normal definitions of fixation (e.g. microsaccades and small saccades). These small micromovements may be used as a favourable strategy for a given task. Piras et al (2021b), during a penalty kick in soccer, found that expert goalkeepers made, during the period that precedes the critical movement initiation, microsaccades and small saccades of 0.6 and 3 degrees of visual angle, respectively. Authors argued that these tiny eye movements were necessary to shift from covert to overt attention for identifying the useful cues necessary to guide the action. It is well known that when we program a saccade we also shift our attention, enhancing our visual perception toward the saccade target. This mechanism works not only at peripheral level but also at the foveal region with microsaccades, in which, before making a microsaccade, enhance selectively the fine spatial vision of the target location (pre-microsaccadic attention) (Poletti, 2023; Raffi & Piras, 2019). Moreover, the perception of fine visual details is modulated also during microsaccades. Intoy et al. (2021) have found that, during fine spatial examination, the detection of highly localized luminance changes across the foveola is suppressed during microsaccades. The reduction of the visual sensitivity is stronger and faster around the foveola (very centre of gaze), where sensitivity rapidly rebounds at the end of the microsaccade and remains higher than in the surrounding regions during the post-microsaccadic fixation.

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

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

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

Polar plots of microsaccade and saccade orientations between groups showed that near-experts modulated their visual attention differently from amateurs. The distribution of microsaccade orientations was broader in near-experts than amateurs, on the contrary, the distribution of saccade orientations was broader in amateurs than near-experts. This probably means that amateurs allocated their overt attention to different cues present in the scene, different from near-experts who prefer to adopt a broad focus of attention as they shifted their covert attention around them, supported by more microsaccade and fewer saccade rates than amateurs. The dynamic properties support the view that microsaccades and small saccades enhance visual perception and, therefore, represent a fundamental motor process with a specific purpose for gaze behaviour. Microsaccades are strongly modulated by visual attention in spatial cueing tasks (Engbert & Kliegl, 2003; Hafed & Clark, 2002). Effects are related to rate (rate effect) and to the angular orientation (orientation effect). Therefore, microsaccades might be crucial for visual perception, supporting top-down processes by high-level attentional stimuli (Engbert, 2006).

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

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

Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

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

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Figure captions

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

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

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

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

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