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The role of the peripheral target in stimulating eye movements

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ABSTRACT

The present study investigated the role of top-down and bottom-up processes during a deceptive sports strategy called "no-look passes" and how microsaccades and small saccades modulate these processes. The first experiment examined the role of expertise in modulating the shift of covert attention with the bottom-up procedure. Results showed more saccades of greater amplitude and faster peak velocity in amateur than in expert groups. In the second experiment, the shift of covert attention between top-down and bottom-up conditions was investigated in a group of expert basketball players. Analysis showed that athletes make more microsaccades during the bottom-up condition; meanwhile, during the top-down condition, they were pushed to make more small saccades to decide where to send the ball. The findings suggested that the top-down process stimulates the eyes to move more concerning the bottom-up condition. It could be explained by the fact that during the top-down condition, athletes do not have an "eyehold" that stimulates their attention. During the top-down condition, athletes had to shift their attention to both sides before making the pass, resulting in their eyes being more "hesitant" concerning the situation in which they are peripherally stimulated.

1. Introduction

Our athletes receive different sensory stimulation from the environment, which have to be selected in order to get important information. The human body and the brain of expert athletes have been optimised through training to select salient information, directing the focus of attention to filter information relevant to action anticipation and decision-making processes (Guo et al., 2017). In order to orient their visual attention toward salient stimuli, athletes use both foveal and peripheral vision (Piras et al., 2014, 2019; 2021a; 2021b). Foveal vision refers to the small area in which visual information can be gathered with very high visual acuity. The fovea contains the highest density of cone photoreceptor cells and is the only region of the retina where 20/20 vision is attainable. The visual acuity decreases with increasing eccentricity (up to 2° of visual angle, approximately twice the width of the thumbnail at arm's length). However, despite this, the high amount of rod cells in the peripheral vision leads to a high motion sensitivity and helps in body sway stabilization (Piras et al., 2018; Raffi & Piras, 2019). The capacity to select from different visual stimuli can be considered an unwanted side effect or even a disadvantage not only in a sports contest but also for people in natural daily tasks, such as people making ten cups of coffee (Shinozaki et al., 2003), or during air traffic controller (Cummings & Tsonis, 2005).

External attentional processes (i.e. environmental cues received by senses) have been assumed to underlie and determine the quality of decision-making in sports. An important finding in research about visual attention is that the orientation of attention can differ from the orientation of gaze position. We need to distinguish between overt attention (the shifting of attention in space by means of saccades and eye fixations) and covert attention (orienting to stimuli using internal neural adjustments without the movement of the eyes) (Carrasco, 2011). Research directly combining covert attention and vision measures in sports actions has yet to be fully addressed, especially regarding a direct measure of covert attention shift. Some authors suggest manipulating peripheral information together with the position of the gaze (Klostermann et al., 2020; Vater, Williams, & Hossner, 2019). They stated that if players are able to react to a peripheral stimulus without looking at it, this could be seen as an indicator of peripheral vision usage. However, the question is, does attention really shift covertly, or is it a simple response to sensory stimuli in our periphery?

A wide breadth of attention facilitates the perception of unmarked players in dynamic situations during team ball games. Advanced players may have the ability to shift their attention to a particular perceptual skill (Memmert et al., 2010). If attention is diverted to another teammate, a player in possession of the ball sometimes fails to notice an unexpected action, for example, a teammate that calls the ball. This phenomenon is called *breadth of attention* and is more accentuated for actions that happen to the visual periphery (Memmert & Furley, 2007).

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It is unclear why the breadth of attention occurs in some players and not in others; it may be related to the level of expertise or the type of action (passing, receiving, dribbling). The breadth of attention denotes a wide variety of environmental stimuli, and the players must attend to them simultaneously. They need a wide breadth of attention to generate tactical response patterns and seek original solutions in their game plans. Therefore, athletes must be able to perceive unexpected stimuli, incorporate these into response patterns, and modify those patterns as necessary. Many top-level athletes, such as Magic Johnson, Ronaldinho and Ronaldo, have higher sports skills; one of these is a deceptive strategy called "*no-look passes*". It happens when a player fools his opponent by looking in one direction and then passes the ball in another direction without moving his eyes. Theoretical models suggest that these players have an extensive breadth of attention, making it possible to attend to stimuli that may initially appear irrelevant (Memmert et al., 2010). The more cues a player can focus on simultaneously, the more likely he can take a greater variability of tactical decisions.

Applying the expert-novice paradigm to an ecologically valid approach and measuring eye movements may contribute to our understanding of the underlying covert processes that characterize expert actions. More specifically, such an approach may reveal the underlying mechanisms that are believed to characterize experts, such as the use of essential cues to anticipate upcoming actions, the use of different strategies to attend efficiently to the opponent's cues, making fast decisions, and also being able to change decisions rapidly. In sports, several authors have suggested investigating the role of microsaccades in determining the direction of covert attention shift, separating the current location of gaze from the location of attention (for a revision, see Piras & Raffi, 2023). Microsaccades are small and rapid fixational eye movements, with an amplitude less than 1° of visual angle and a peak velocity fewer than 100°/seconds. Microsaccades showed the same peak velocity versus amplitude relationship as larger saccades; for this particularity, microsaccades and saccades shared a common oculomotor origin (Martinez-Conde et al., 2013). In addition, microsaccades help maintain vision during fixation by shifting the retinal image and avoiding adaptation, thus generating neural responses to stationary stimuli in visual neurons (Costela et al., 2013). It has been shown that microsaccades are critically related to covert attention shifts (Engbert & Kliegl, 2003; Hafed & Clark, 2002). Others have shown a relationship between microsaccades and visual perception in natural scenes (McCamy et al., 2014), in the perception of heading (Piras et al., 2016) and in the visual search tasks (Otero-Millan et al., 2008). The spatial location of attention impacts microsaccade rates and directions during fixation as reliable indicators of the perception of a visible target. We need to highlight that brief fixation periods, common during free-viewing, result in more considerable ocular instability and, thus, larger microsaccades in comparison to periods of prolonged fixation. Some of the saccades produced during free-viewing are not involuntary microsaccades but are rather voluntary or exploratory small saccades (Otero-Millan et al., 2008). To distinguish that from microsaccades, we defined small saccades as rapid fixational eye movements with a magnitude less than 3° of visual angle (Van Gisbergen et al., 1981). Saccades and microsaccades have the same roles, including the scanning and exploring visual objects and scenes traditionally ascribed to (large) saccades. For instance, saccades and large microsaccades counteract visual fading with higher efficacy than the smallest microsaccades, forming an oculomotor continuum along the entire spectrum of exploratory scale (Otero-Millan et al., 2013).

Gaze behaviour is strongly influenced by our goals and intentions. When we have a specific goal or task, such as searching for a particular object or reading a text, we use top-down processes to direct our gaze toward relevant locations in the visual scene. These goals can be explicit (e.g., searching for a teammate on the pitch) or implicit (e.g., scanning a scene for potential opponents). In particular, the top-down process refers to the influence of higher-level cognitive processes, such as attention, goals, and expectations, on where we direct our gaze. It involves the deliberate allocation of visual attention based on the individual's intentions, interests, and task demands (Land, 2009). These mechanisms prioritize certain regions or objects in the visual scene for processing, filtering out irrelevant information. Attention can be driven by both endogenous factors (internally generated goals and expectations) and exogenous factors (stimulus-driven cues) (Vickers, 2007). Various cognitive factors, such as memory, knowledge, and expertise, play a role in top-down gaze regulation. For example, prior knowledge about a scene or task can guide where we look as we focus on areas that are more likely to contain relevant information. Memory retrieval processes, or the environment in which action is performed, can also influence gaze behaviour by directing attention to specific locations associated with stored information (Servais et al., 2022).

The other process implicated in gaze behaviour regulation is the bottom-up process, which refers to the influence of salient visual stimuli or features in the environment on where we direct our gaze. It involves the automatic and involuntary capture of attention by stimuli that stand out due to their physical characteristics. Stimuli with high saliency are more likely to attract attention and guide our gaze (Khacharem, 2017). Bottom-up processes can trigger reflexive or involuntary shifts of attention and gaze. When a salient stimulus captures our attention, our gaze automatically or reflexively moves toward that stimulus. For example, if a teammate's movement occurs in our visual periphery, "calling the ball", our gaze is likely to be involuntarily captured by that movement. Moreover, bottom-up processes in gaze regulation can operate at early stages of visual processing (Schütt et al., 2019). Low-level visual features that stand out in the visual scene can guide the initial allocation of attention and gaze. This early orienting allows us to rapidly detect and process relevant information in the environment, which can then be further modulated by the top-down process. It is important to note that the top-down process in gaze regulation interacts with the bottom-up process, which is driven by salient visual stimuli in the environment. The interplay between top-down and bottom-up processes determines our overall gaze behaviour (Schütt et al., 2019; Vickers, 2007).

A typical situation, such as a 2vs1 or 3vs1, occurs frequently in team ball sports. Moreover, perceiving the best solution by passing the ball in the right direction is, in many cases, the best way in complex game situations (Williams & Davids, 1998). Athletes with a broad attentive focus made better tactical decisions than participants with a narrow breadth of attention performance (Memmert & Furley, 2007). Memmert and Furley (2007) have found that team members could capture the attention of other teammates by waving their hands. It is essential to mention that the salient action not only captures the attention of the player's fellow teammates but may also capture the attention of the defending players and, therefore, may no longer have the desired effect of surprising the opposing team.

Sports sequences contain too much information to be perceived at once. Athletes typically pay attention to individual cues one at a time. But which cue? That depends on the types of attentional mechanisms involved. Bottom-up mechanisms are assumed to work on raw sensory input, rapidly and involuntarily shifting attention to salient visual features of potential importance, for example, the rapid movement of the teammate that calls the ball or the opponent moving the leg to kick the ball toward the goal. Top-down mechanisms implement their knowledge from previous experience, shifting attention toward unmarked teammate if we are in possession of the ball or toward rapid movements of the opponent with the ball if we are protecting our goal. Both kinds of information processing are relevant in the context of sports: top-down processing informs the action based on the history of the player, while bottom-up processing maintains the athlete open to salient visual cues. The main goal of the present study was to investigate the role of these two forms of attention guidance, top-down and bottom-up, during the deceptive strategy called "no-look passes" and how microsaccades or small saccades modulate these processes.

2. Experiment 1

In Experiment 1, two groups of basketball players were tested during a bottom-up procedure. The bottom-up condition uses visual signals (e.g., hand up calling the ball) that direct the participant's attention to relevant information. The signals can act as cognitive visual support by eliminating unnecessary visual search processes to relate visual information. This first experiment aimed to investigate whether an unmarked player who waves his arms is perceived consciously by the teammate possessing the ball. Specifically, the role of microsaccades or small saccades during no-look pass sequences under spatiotemporal constraint was evaluated. The hypothesis was to see if higher expertise leads to a broader breadth of attention and its role in modulating the shift of covert attention, represented by more microsaccades and less saccade rates in experts than their lower counterparts.

3. Methods

3.1. Participants

Twenty-four male basketball players were subdivided into two groups: 12 expert basketball players who played at the Serie B level (Italy championship) and 12 amateur basketball players who played at the Serie D level (Italy championship) (see Table 1). All had normal or correct to normal vision. After receiving oral and written information concerning the study protocol, all participants gave their written informed consent to participate in the study. The University Bioethics Committee approved the study.

3.2. 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 passes. 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 participants' movement. The accuracy of eye position was checked after every pass, and if necessary, a drift correction was performed. Practice, calibration, validation and data collection took ~20 min per participant.

In order to collect the exact time participants made the pass, one inertial sensor (Cometa Systems, Italy) was placed on the dorsal face of the right hand. Inertial sensors were synchronized with the EyeLink system to obtain corresponding eye and hand movement data. The detection threshold for the onset activity was identified from the accelerometer when the value exceeded the mean plus three standard deviations of the entire trace length (Martinez-Mendez et al., 2011).

Table 1
Participant characteristics.

	Experts (12)	Amateurs (12)	P-value	Cohen's *d*
Age (yrs.)	21.58 ± 4.12	20.50 ± 1.31	0.401	0.35
Weight (kg)	88.50 ± 9.73	78.17 ± 7.07	0.005[a]	1.27
Height (cm)	192.42 ± 7.12	183.33 ± 7.16	0.007[a]	1.22
Body Mass Index (kg/m²)	23.83 ± 1.12	23.23 ± 1.21	0.221	0.51
Practice in basketball (yrs.)	14.25 ± 5.15	13.92 ± 2.35	0.841	0.08
Training sessions (number/week)	7.25 ± 1.91	3.83 ± 0.72	0.000[a]	1.44
Training sessions (hours/week)	14.42 ± 3.12	7.75 ± 1.36	0.000[a]	2.40
Expertise level (2021–22)	B	D	\	\
Foot laterality	Right	Right	\	\
Hand laterality	Right	Right	\	\

[a] Significant different at $p < 0.05$

3.3. Procedure

In a basketball court, the participant in possession of the ball (P), wearing the Eye tracker and with the inertial sensor placed on the right hand, was positioned in the middle of the three-point line. The other two teammates were positioned one to the left (TL) and one to the right (TR) of the player in possession of the ball. All three players made a triangle, and the angle formed by the player in possession of the ball with the other two teammates was about 156° (see Figure 1). In front of the player in possession of the ball, there was an opponent (O), who was unable to see any movements from TR or TL.

Before each trial started, only TR and TL knew who had to call the ball. P and O were unaware of which teammates were designed to call the ball. A sound indicated the start of the recording; as soon as possible, TR or TL called the ball, raising his arm. At the same time, O ran against P to constrain and put pressure on his passing action. P had to maintain fixation on O and try, with his peripheral vision, to see which teammates called the ball, then do the no-look pass as soon as possible, always without moving his eyes or his head.

The passing sequence was subdivided into two blocks of ten passes each, interspersed by 5 min of rest. The 20 passes were presented in a random sequence, and the randomization was kept in the same order for each participant. Overall, a total number of 480 (20 passes x 24 participants) passes were analysed.

3.4. Statistical analysis

The length of the passing sequence used for analysis was initially selected by the moment the teammate raised his arm to the instance when the participant started his final movement. Passes in which the participants' eyes exceeded 3° of visual angle were excluded from the analysis. This cut-off value has been decided following the quiet eye studies (for more information, see Vickers, 2007), corresponding to the final fixation within 1–3° of visual angle before the final movement initiation. Since its conception, the quiet eye has been predominantly associated with the pre-programming of action, which in sports would equate to movement organization occurring before the initiation of the final movement without visual or proprioceptive feedback influencing the action (Causer et al., 2017).

Movement time initiation was analysed with univariate ANOVA in which expertise (experts; amateurs) and passing direction (right; left) were the between-subject factors (SPSS version 22.0 software, Chicago, IL, USA).

Microsaccades were defined as fixational eye movements less than 1 degree of visual angle and with the same peak velocity versus amplitude curve as large saccades. To identify microsaccades and, consequently, saccades, the Engbert-Kliegl algorithm (2003) was applied. To reduce the potential noise, only binocular microsaccades lasting at least three data samples (6 ms), with velocity threshold detection set at six, were considered. Microsaccade amplitude, duration, and peak velocity were first calculated for each participant under each passing direction (left and right). Microsaccade rates were calculated considering only the time spent in fixation: the total number of microsaccades in each participant under each passing direction was divided by the total time spent in fixation during that condition. Univariate ANOVA was performed to analyse microsaccades and small saccades rate, amplitude, duration, and peak velocity. Expertise (experts; amateurs) and passing direction (right; left) were the between-subject factors.

The two-dimensional distribution of all microsaccade and small

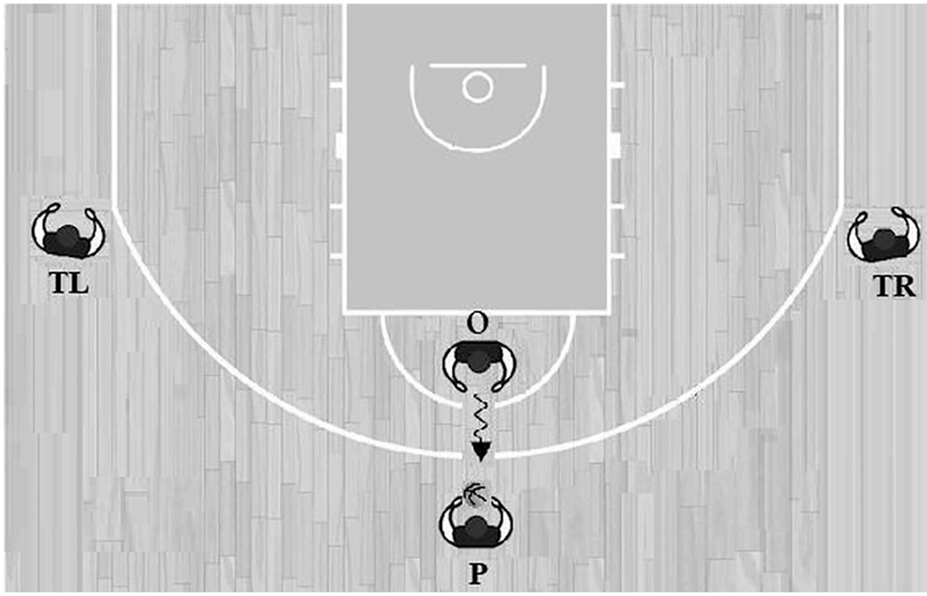

Figure 1. Experimental protocol representation. A portion of the basketball court in which a player in possession of the ball (P) had to make a pass to a teammate located to the right (TR) or to the left (TL) while he is spatiotemporally constrained by an opponent player (O).

saccade orientations was calculated with respect to expertise (experts; amateurs) and passing direction (right; left). The Watson-Williams test for homogeneity of means (Oriana® 4.0) was performed in which the null hypothesis was that the orientations of microsaccades between expertise (experts; amateurs) and passing direction (right; left) have similar continuous distribution at the 5 % level of significance.

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, ≥0.20 < 0.50; moderate, ≥0.50 < 0.80; large, ≥0.80 (Cohen, 1988). Partial eta squared (ηp2) was used during multiple comparisons. Statistical significance was set at p < 0.05. Post hoc testing was corrected using the Bonferroni procedure.

4. Results

After pre-processing data, passes in which eyes exceeded 3° of visual angle were discarded, and 472 clips were retained for analysis (of a total of 480, 8 passes were excluded; 5 trials were from amateurs, and 3 were from experts).

Experts resulted taller and more weighed than amateurs. Moreover, significant differences between groups were found in terms of the number of hours of training a week (see Table 1).

Movement time initiation showed no significant differences between groups (experts = 1152.74 ms; amateurs = 1070.61 ms; $p = 0.101$) nor for passing direction ($p = 0.833$).

Analysis showed no significant differences in microsaccade characteristics (rate, amplitude, peak velocity, and duration) for expertise or passing direction (see Table 2). Significant difference between groups for small saccade rate ($F_{1,44} = 7.71$; p = 0.008; $\eta_p^2 = 0.15$); amplitude ($F_{1,44} = 4.15$; p = 0.047; $\eta_p^2 = 0.09$) and peak velocity ($F_{1,44} = 4.72$; p = 0.035; $\eta_p^2 = 0.11$) were found. Amateurs showed more saccades of greater amplitude and faster peak velocity than experts (see Table 2).

Watson-Williams test was used to analyse microsaccade and small saccade orientations. Results showed no significant difference between groups/passing direction for microsaccade and small saccade orientations (see Figures 2 and 3).

5. Discussion

Could the sports experience influence the shift of covert attention through microsaccade parameters in a bottom-up condition?

In this first experiment, the intention was to investigate the role of expertise in modulating the shift of covert attention and its influence on the breadth of attention during a no-look sequence under spatiotemporal constraint. Expert and amateur basketball players, visually stimulated by a teammate placed peripherally, who called the ball waving his hand, had to make a no-look pass when an opponent player went against them to obstruct the action.

The results indicated that both groups took approximately 1 s to make the pass, showing no significant differences in movement time initiation. This lack of difference may be due to the simplicity of the task we used. When we look at research in sports science, we find that studies using simple response time have produced inconsistent results. Some show faster response times for expert athletes (Kioumourtzoglou et al., 1998), while others do not (McLeod, 1987; Mori et al., 2002). Previous researchers have found that experienced performers are more affected than novices by conditions that draw their attention to individual task components (Beilock et al., 2002). It seems that experts are better than novices at handling conditions that create dual-task environments (e.g.,

Table 2
Small saccade and microsaccade parameters.

	Experts	Amateurs	*P*	η_p^2	95%CI
Small saccades					
Rate (N/sec)	1.65 ± 0.0	1.97 ± 0.0	0.008[a]	0.15	0.08–0.52
Amplitude (deg)	2.24 ± 0.13	2.71 ± 0.14	0.047[a]	0.09	0.01–0.83
Peak Velocity (deg/s)	135.57 ± 10.9	169.08 ± 10.9	0.035[a]	0.10	2.44–64.58
Duration (ms)	35.44 ± 4.7	43.20 ± 4.7	0.25	0.03	−5.54–21.07
Microsaccades					
Rate (N/sec)	1.94 ± 0.1	1.93 ± 0.1	0.96	0.00	−0.31–0.30
Amplitude (deg)	0.50 ± 0.0	0.53 ± 0.0	0.39	0.02	−0.05–0.13
Peak Velocity (deg/s)	47.60 ± 5.0	56.81 ± 5.4	0.22	0.04	−5.75–24.16
Duration (ms)	12.59 ± 1.3	11.14 ± 1.4	0.45	0.01	−5.30–2.38

[a] Significant different at $p < 0.05$

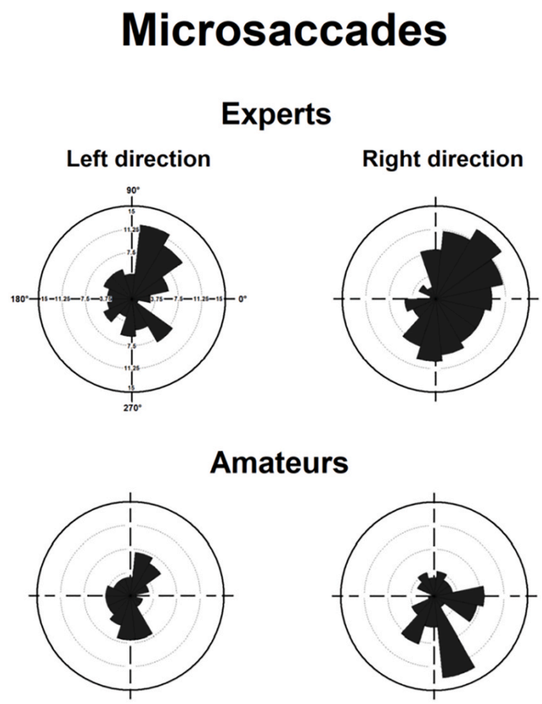

Figure 2. Panels represent the mean vector direction of microsaccades in both groups (experts and amateurs) across left and right directions. Each angular sector is 24.00° in width.

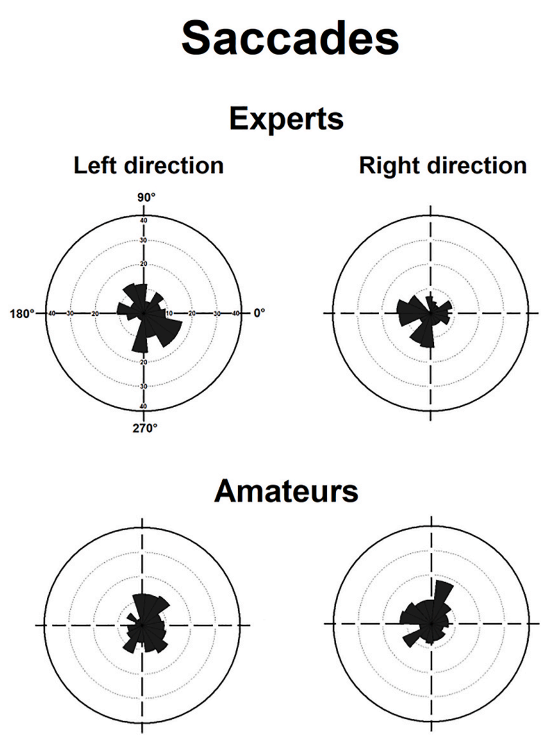

Figure 3. Panels represent the mean vector direction of saccades in both groups (experts and amateurs) across left and right directions. Each angular sector is 24.00° in width.

dribbling a soccer ball while performing an auditory-monitoring task) compared to conditions that require a focus on specific skills (dribbling a soccer ball).

All microsaccade parameters exhibited no significant differences between groups. Conversely, small saccades differed significantly between groups, with more saccades of greater amplitude and faster peak velocity in the amateur than in the expert group. Eye stability during fixation was different between groups, and the skilled performance emerged when the teammate called the ball and the opponent obstructed the visual field. This condition requires extensive attention and can be linked to the player's ability to focus simultaneously on the opponent and what is happening in the visual scene. When the command to call the ball occurs while the athlete focuses on the opponent, attention has to change from an engaged to a disengaged state; this processing takes some time, adding to an attentional shift (Fischer & Breitmeyer, 1987).

Some athletes, such as volleyball, basketball, soccer and hockey players (i.e., team sports) show a broader attentional focus than controls (Bosel, 1998; Castiello & Umiltà, 1992; Nougier et al., 1992), while other athletes, such as shooters, show a narrow attentional focus upon the target (Di Russo et al., 2003; Tremayne & Barry, 2001). Thus, the effect of sports practice on elementary visuomotor tasks, such as manual response to a visual stimulus, seems related to the specific skills to the extensive practice required by the sport.

6. Experiment 2

There is evidence that human visual attention is controlled by prior knowledge in the field, suggesting the role of top-down guidance on comprehension of an external display (e.g. to which teammate I have to pass the ball without external cues). Accordingly, the selection of essential visual information from the surroundings depends on how the information is presented and the quantity and specificity (e.g. expertise) of the pre-existing knowledge. In Experiment 2, only the group of expert basketball players were considered and tested during a top-down condition. Then, this data was compared with data obtained from the same athletes tested in experiment 1. The study examined how bottom-up (signalling techniques) and top-down (prior knowledge) guidance influence attention allocation and cognitive processing during a game sequence. The use of postural signals is assumed to be directed by the bottom-up, stimulus-driven attentional control. In contrast, the use of contextual and situational probability information is more likely to employ the top-down, goal-directed attentional system (Corbetta & Shulman, 2002). The main research question of this second experiment was to verify if the shift of covert attention through microsaccades during a no-look pass sequence under spatiotemporal constraint is mediated by signalling technique through bottom-up capture task or is based on a participant's prior voluntary decision to direct attention to a particular location through top-down visual search task. We hypothesized that athletes would make more microsaccades and less saccades during the bottom-up than during the top-down conditions. Moreover, if attention were captured bottom–up, we would expect that a more salient stimulus would increase the probability of fixations with respect to the visual scan process, characterized by more saccades of greater amplitude versus peak velocity relationships, which is representative of the top-down condition.

7. Methods

7.1. Participants

In this experiment were tested only the 12 expert basketball players tested in experiment 1, who played at the Serie B level (Italy championship) (see Table 1).

7.2. Apparatus

The same instrument as in Experiment 1 was used.

7.3. Procedure

A week after the first experiment, the second experiment was conducted. In a basketball court, the participant in possession of the ball (P), wearing the Eye tracker and with the inertial sensor placed on the right hand, was positioned in the middle of the three-point line. The other two teammates were positioned one to the left (TL) and one to the right (TR) of the player in possession of the ball. All three players make a triangle in which the angle formed by the player in possession of the ball with the other two teammates was about 156° (see Fig. 1). In front of the player in possession of the ball, there was an opponent (O), who was unable to see any movements from TR or TL.

A sound indicated the start of the recording; as soon as possible, O ran against P to constrain and put pressure on his passing action. P had to maintain fixation on O and to decide at which teammate pass the ball, doing this as soon as possible, always without moving his eyes or his head.

The passing sequence was subdivided into two blocks of ten passes each, interspersed by 5 min of rest. The 20 passes were equally subdivided into passing to the right and passing to the left. Overall, 240 (20 passes x 12 participants) passes from the top-down condition were recorded and analysed, and then compared to the other 240 passes from the bottom-up condition.

7.4. Statistical analysis

The length of the passing sequence used for analysis was initially selected by the sound that announced the start of the test to the instance when the participant started his final movement. Passes in which the participants' eyes exceeded 3° of visual angle were excluded from the analysis.

Movement time initiation was analysed with univariate ANOVA in which conditions (top-down; bottom-up) and passing direction (right; left) were the between-subject factors (SPSS version 22.0 software, Chicago, IL, USA).

Univariate ANOVA was performed to analyse microsaccade and small saccade rate, amplitude, duration, and peak velocity. Conditions (top-down; bottom-up) and passing direction (right; left) were the between-subject factors.

The two-dimensional distribution of all microsaccades and small saccade orientations were calculated with respect to conditions (top-down; bottom-up) and passing direction (right; left). The Watson-Williams test for homogeneity of means (Oriana® 4.0) was performed in which the null hypothesis was that the orientations of microsaccades between conditions (top-down; bottom-up) and passing direction (right; left) have similar continuous distribution at the 5 % level of significance.

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, 0.20–0.50; moderate, 0.50–0.80; large, ≥0.80 (Cohen, 1988). Partial eta squared (ηp2) was used during multiple comparisons. Statistical significance was set at $p < 0.05$. Post hoc testing was corrected using the Bonferroni procedure.

8. Results

After pre-processing data, passes in which eyes exceeded 3° of visual angle were discarded, and 460 clips were retained for analysis (of a total of 480, 20 passes were excluded; 3 trials were from the bottom-up condition, and 17 were from the top-down condition).

Movement time initiation showed significant differences between conditions ($F_{1,44} = 11.36$; $p = 0.002$; $\eta_p^2 = 0.23$). During the bottom-up process, experts were slower in making passes than during the top-down condition (1152.74 vs 960.76 ms). Passing direction did not show significant differences ($p = 0.621$).

Analysis showed significant differences between conditions for microsaccade rate ($F_{1,44} = 7.61$; $p = 0.008$; $\eta_p^2 = 0.12$), amplitude ($F_{1,44} = 16.85$; $p < 0.001$; $\eta_p^2 = 0.31$) and peak velocity ($F_{1,44} = 9.67$; $p = 0.004$; $\eta_p^2 = 0.21$), but not for duration. The top-down condition revealed microsaccades of greater amplitude and faster peak velocity with respect to the bottom-up condition (see Table 3).

Analysis showed significant differences between conditions for small saccade rate ($F_{1,44} = 19.89$; $p < 0.001$; $\eta_p^2 = 0.34$), duration ($F_{1,44} = 23.40$; $p < 0.001$; $\eta_p^2 = 0.38$), amplitude ($F_{1,44} = 4.05$; $p = 0.035$; $\eta_p^2 = 0.10$) and peak velocity ($F_{1,44} = 20.25$; $p < 0.001$; $\eta_p^2 = 0.35$). The top-down condition showed more saccades of longer duration, with greater amplitude and faster peak velocity in comparison to the bottom-up condition (see Table 3).

Watson-Williams test was used to analyse microsaccade and small saccade orientations. Results showed no significant difference between conditions/passing direction for microsaccades and small saccade orientations (see Figures 4 and 5).

9. Discussion

Could visual attention be influenced by peripheral stimuli? Or is the shift of visual attention guided by prior knowledge?

The second experiment examined how bottom-up (signalling techniques) and top-down (prior knowledge) influence attention allocation and cognitive processing during a game sequence. The main research question of this second experiment was to verify if the shift of covert attention through microsaccades during a no-look pass sequence under spatiotemporal constraint is mediated by signalling technique through bottom-up capture task or is based on a participant's prior voluntary decision to direct attention to a particular location through top-down visual search task. We hypothesized that athletes would make more microsaccades and less saccades during the bottom-up than during the top-down condition. Moreover, if attention were captured bottom–up, one would expect that a more salient stimulus would increase the probability of fixations with respect to the visual scan process, characterized by more saccades of greater amplitude versus peak velocity relationships, that is representative of the top-down condition.

Analysis showed that during the bottom-up condition, athletes' visual receptive fields were peripherally stimulated, making a greater number of microsaccades with respect to the top-down condition. Indeed, during the top-down condition, in which athletes did not receive peripheral stimulation, they were pushed to make more small saccades to decide where to send the ball. We found that the top-down process stimulates the eyes to make more movements with respect to the bottom-up condition. During the top-down condition, athletes did not have an "eyehold" on where to focus their attention, as in this situation,

Table 3
Small saccade and microsaccade parameters.

	Bottom-up	Top-down	P	η_p^2	95%CI
Small saccades					
Rate (N/sec)	1.65 ± 0.0	2.36 ± 0.1	<0.001[a]	0.34	0.39–1.03
Amplitude (deg)	2.24 ± 0.1	2.98 ± 0.1	0.035[a]	0.10	3.13–5.53
Peak Velocity (deg/s)	135.57 ± 10.9	219.38 ± 14.0	<0.001[a]	0.35	46.11–121.52
Duration (ms)	35.44 ± 4.7	60.45 ± 3.9	<0.001[a]	0.38	14.55–35.49
Microsaccades					
Rate (N/sec)	1.94 ± 0.1	1.61 ± 0.0	0.008[a]	0.12	−0.06–0.57
Amplitude (deg)	0.50 ± 0.0	0.66 ± 0.0	<0.001[a]	0.31	0.09–0.25
Peak Velocity (deg/s)	47.60 ± 5.0	65.65 ± 4.44	0.004[a]	0.21	6.29–29.81
Duration (ms)	12.59 ± 1.3	13.75 ± 2.4	0.71	0.00	−7.43–5.11

[a] Significant different at $p < 0.05$

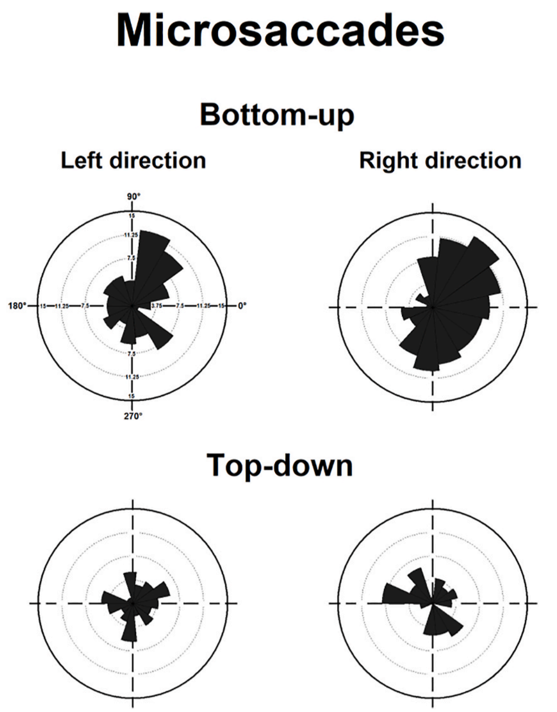

Figure 4. Panels represent the mean vector direction of microsaccades in both conditions (top-down and bottom-up) across left and right directions. Each angular sector is 24.00° in width.

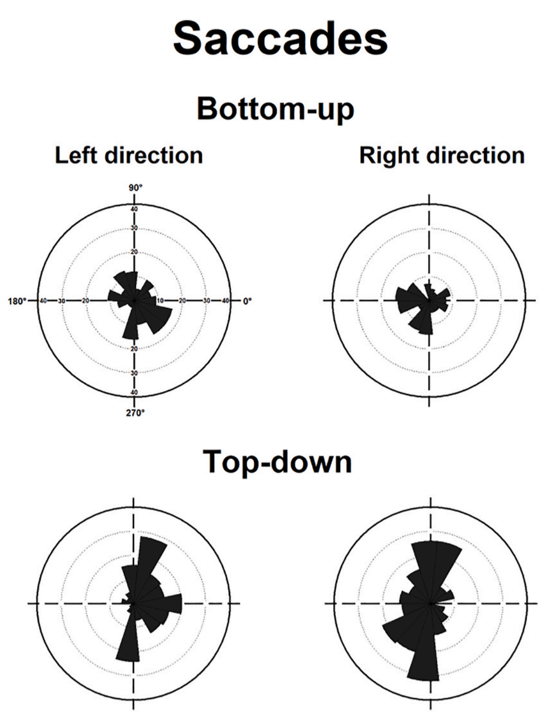

Figure 5. Panels represent the mean vector direction of saccades in both conditions (top-down and bottom-up) across left and right directions. Each angular sector is 24.00° in width.

the teammate's arm was not raised calling the ball. Even if the action was faster in the top-down process, maybe because it was pre-programmed, at the moment in which athletes had to shift their attention to make the pass, their eyes became more "hesitant" with respect to the situation in which they were peripherally stimulated.

General discussion

Our senses are continuously stimulated with a multitude of sensory impressions. A key challenge is to select which stimuli are relevant and which should be ignored. This process of selecting a subset of the input and ignoring the rest is referred to as attention (Desimone & Duncan, 1995). Two types of attention are generally distinguished in the literature: bottom-up and top-down attention or stimulus-driven and goal-oriented attention (Carrasco, 2011). Top-down attention refers to the voluntary allocation of attention toward a particular object or region in the field (Giesbrecht et al., 2003). On the other hand, attention is also voluntarily directed. Salient stimuli can attract attention, even though the athlete had no intentions to attend to these stimuli; this is the bottom-up condition. The dynamic interaction of these features controls where, how and to what we pay attention to in the visual surroundings. The main goals of the present study were to explore the role of expertise in modulating the shift of covert attention and then investigate how expert basketball players utilize the top-down and the bottom-up systems during a particular deceptive strategy called "no-look passes". The dynamic nature of sports means that the situation's context and a player's associated strategic intentions can rapidly change from one instant to the next (Murphy et al., 2019). With these experiments, the intention was to create a representative task design in which basketball players in possession of the ball, placed in a real basketball field alongside the 3-point line, were able to shoot the ball toward the basket. The opponent had the role to avoid it, so the athlete decided to pass the ball to one of the teammates placed peripherally. In the first experiment, the teammate calls the ball, raising his hand; in experiment two, the athlete decides who to pass the ball to. More specifically, the first experiment aimed to investigate whether an unmarked player who waves his arms is perceived consciously by the teammate in possession of the ball. The role of microsaccades or small saccades during no-look pass sequence under spatiotemporal constraint was evaluated. The hypothesis was to see if higher expertise is related to a broader breadth of attention due to precise microsaccade parameters with respect to lower expertise. Results indicated that amateur exhibited a visual search strategy with more saccades of greater amplitude and faster peak velocity than expert groups. These results bring us to the conclusion that when teammates call the ball and the opponent makes an obstruction in the expert's visual field, they exhibit more eye stability during fixation than amateurs. This condition requires extensive attention and can be linked to the player's ability to focus simultaneously on the opponent and what is happening in the visual scene. When the command to call the ball occurs while the athlete focuses on the opponent, attention has to change from an engaged to a disengaged state; this processing takes some time, adding to an attentional shift (Fischer & Breitmeyer, 1987).

The second experiment examined how bottom-up and top-down guidance influences the experts' attention allocation and cognitive processing during a game sequence. The main research question of this second experiment was to verify if the shift of covert attention through microsaccades during a no-look pass sequence under spatiotemporal constraint is mediated by signalling technique through bottom-up capture task or is based on experts' prior voluntary decision to direct attention to a particular location through top-down visual search task. We hypothesized that athletes would make more microsaccades and less saccades during the bottom-up than during the top-down condition. Moreover, if attention were captured bottom–up, one would expect that a more salient stimulus would increase the probability of fixations with respect to the visual scan process, characterized by more saccades of greater amplitude versus peak velocity relationships, that is representative of the top-down condition. The findings suggested that during the bottom-up condition, athletes make more microsaccades due to the teammates' arms being raised, stimulating their eyes peripherally. Contrarily, during top-down conditions, athletes did not receive peripheral information, forcing them to make more small saccades to decide where to send the ball. Additionally, in the top-down condition, athletes knew beforehand to send the ball because they did not receive any external cue. What we do not know is the "timing of decision". The open question is: Have they decided just before starting the experiment (before the sound) or just before making the pass (after the sound)? We are oriented towards the first hypothesis. The reason is that comparing the movement time initiation between conditions, we found that during the top-down, participants were faster, by about 190 ms, than during the bottom-up condition. We hypothesized that they had decided where to send the ball just before hearing the sound. This was possible because they did not have to localize any external cues as they did during the bottom-up condition. Moreover, the absence of an external cue may have forced athletes to make more saccades of greater amplitude, exceeding 3 degrees of visual angle. In fact, in the second experiment, 17 trials were excluded from the analysis, with respect to the bottom-up condition, in which only 3 trials were excluded. Given that, during a non-look pass, the teammate does not "call" the ball, but it is the player in possession of the ball who decides to use this strategy, our athletes had difficulty keeping their gaze steady during the top-down condition. This could mean that our experts were not at a very high-level in terms of tactical creativity despite being professionals. An unexpected no-look pass to a teammate is considered an example of a creative solution in team ball sports (Memmert, 2011). The cognitive processing of information from the surroundings is supposed to stimulate eye movements in a top-down manner, even if subjects are not consciously aware of this selection process (Rothkopf et al., 2007). During the top-down condition, athletes do not have an “eyehold” where to focus their attention, so their eyes make more movements with respect to the bottom-up condition.

Important differences between these two types of attention have emerged. The top-down condition is referred to as endogenous attention, and the bottom-up condition is exogenous attention (Carrasco, 2011). While the bottom-up condition is influenced by attentional guidance that originates from exogenous stimuli, which is under automatic/involuntary control, the top-down processes refer to influences on attentional guidance from what athletes want to process, which is under voluntary control (endogenous influences). The top-down process is the ability to voluntarily shift what is subjectively perceived as spatial attention towards a specific location without moving the eyes (Posner, 1980). The results of the present study also highlighted that the action was faster in the top-down condition than in the bottom-up. During this process, athletes can trigger a shift of attention based on their prior voluntary decision to direct attention to a particular location or to look for a particular object, a kind of voluntarily chosen search criterion (e.g., a decision to look for passing the ball). Human observers are better at detecting an item in a visual environment when they know in advance something about its characteristics, such as its location, motion or colour (Corbetta & Shulman, 2002). This simplification depends on our ability to represent this advanced information and to use it to bias the processing of incoming visual information. Similarly, responses to a stimulus are quicker when athletes know in advance what type of movement they have to make (e.g. which arm to move or the direction of the movement). The different nomenclature also refers to the different periods of time in which the two conditions are sustained. Top-down attention is called sustained because athletes typically direct their attention to objects or locations in space for sustained periods of time. Bottom-up attention is transiently captured (Ling & Carrasco, 2006; Liu et al., 2007). The similarity between top-down and bottom-up allocation of attention is that, although the reason for attentional distribution is different, the effects are mostly the same. The attended location receives preferential processing in both conditions, leading to increased neural response, corresponding to better memory storage (Ciaramelli et al., 2008).

The angular distributions of microsaccades and small saccades showed no significant differences between groups/conditions or passing directions. In a scene-viewing paradigm, it has been found that humans tend to make the first saccade to the left, then scan to the right (Rothkegel et al., 2016), which is consistent with the reading direction of the participants (Chokron & De Agostini, 1995). Dickinson and Intraub (2009) found that, in humans, attention is biased to the left side of the image, resulting in more early fixations on the left and a better memory for objects on that side. Eye movements to the left have been explained by the dominance of the right hemisphere in spatial attention (Foulsham et al., 2013). Our results could have been conditioned by the shift of covert attention from left to right to decide where to send the ball and also by the attention from the opponent, who increased the spatiotemporal demand. Moreover, the great peripheral distance of the two teammates could have conditioned the (micro-) saccade orientations. Salient visual stimuli in the peripheral visual fields have been considered essential triggers and targets for saccades and are usually referred to as bottom-up information. In natural settings, different vision researchers have suggested that many eye movements are proactive, meaning that they are not induced by salient stimuli, rather than reactive, that are induced by salient stimuli (Hayhoe & Ballard, 2005; Land & Furneaux, 1997). Bottom-up and top-down information could play an essential role in saccade and/or microsaccade planning. However, it is still unknown how each of them is weighted and how they interact in eye movement control during sports situations recorded in an ecological setting. The respective influences of visual stimulation and top-down information on the hundreds of thousands of daily saccades/microsaccades are generally challenging to differentiate, as both often exist simultaneously (Piras et al., 2019; 2021a; 2021b).

Future studies are needed to delve deeply into the role of eye movements in attention shift. To reach a comprehensive understanding of the interaction between (micro-) saccades and attention, it will be crucial to analyse (micro-) saccades from various other attention-related sports domains. In this regard, future experimental conditions could be where participants know beforehand where to send the ball without an "external" cue. It could also be interesting to consider a group of novel participants in comparison to expert counterparts to see if years of practice are involved in training participants to shift their attention. Moreover, to make the situation more dynamic, ask the opponent to move to one side to force/suggest to the athlete where to send the ball and analyse the ball’s velocity and precision in hitting the target. As hypothesized above, the lack of a significant difference between experts and amateurs in terms of movement time initiation could be due to the simplicity of the task we used. Future research should consider the situation in which the teammates are marked so that participants will have to make real-time decisions about where to send the ball. This could affect the motor response’s latency and help distinguish between experts and amateurs.

In summary, current results suggest that the top-down process stimulates the eyes to make more (macro-) movements with respect to the bottom-up condition. It could be explained by the fact that during the top-down condition, athletes do not have an "eyehold” that stimulates their attention. Moreover, during the top-down condition, athletes had to shift their attention to both sides before making the pass, resulting in their eyes being more “hesitant” with respect to the situation in which they are peripherally stimulated. As suggested by Vater, Williams, and Hossner (2019) and confirmed with these results, an ideal combination of bottom-up processing and top-down monitoring of peripheral information seems to be crucial for highly skilled players.

CRediT authorship contribution statement

Alessandro Piras: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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