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Basketball referee's gaze behavior and stimulus selection in relation to visual angle perspective and officiating mechanics and expertise

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Abstract: This work aimed to describe the visual search behavior of basketball referees. Eight national and eight regional basketball referees took part in the study. The participants watched five projected gameplay video clips twice from different perspectives: lead and trail referee positions. Dependent variables were based on the extrinsic ocular motility (number of fixations, average fixation time, and total fixation time on the selected areas of interest), and the independent variables were expertise (expert vs novice) and visual angle (lead vs trail referee position). Most gaze behavior differences were found between the lead and trail positions (total fixation time: $F = 10.79$; $p < 0.01$; $\eta p^2 = 0.435$; average fixation time: $F = 16.23$; $p < 0.01$; $\eta p^2 = 0.537$). It was found that basketball referees mainly follow a target strategy on the attacking player with the ball and a visual pivot on the players' trunk. Expertise does not determine the number or time of fixations, but it does influence fixation location.

Keywords: visual scan patterns, perception, vision, decision-making, officiating

1. Introduction

The performance of sports referees is based on their perceptual-visual skills and decision-making ability (MacMahon et al., 2014). Refereeing is a task in which environmental conditions change constantly and decisions must be taken in a short period of time from information originating from unpredictable gameplay situations (Nakamoto & Mori, 2008). Vision is the most efficient channel for receiving information from the sports environment (Mann et al., 2021). However, it presents some limitations. Firstly, the human visual field extends slightly over 180° in the horizontal dimension and about 90° in the vertical dimension (Curcio & Allen, 1990). Secondly, the area of maximum visual acuity (e.g. fovea) only includes 5° of the visual field, and acuity decreases as we move away from the visual axis to the periphery (Green, 1970). In addition, peripheral vision also has limitations that make it difficult to perceive stimuli, known as the crowding effect and the binding problem (Wolfe, 2018). For these reasons, humans are required to use their visual system to search for information in the environment. A visual fixation is defined as the time in which the gaze remains in the same spatial location (Milazzo et al., 2016). The rapid eye movements between fixations are known as saccadic eye movements, and they are considered disruptive events in information processing due to the phenomenon of saccadic suppression (Idrees et al., 2020). Traditionally, it has been hypothesized that a strategy characterized by fewer fixations would reduce the time the eye is in a state of saccadic suppression. Thus, this situation would help extract valuable information from the environment (Mann et al., 2007). However, some opposite results have been found in the literature (Catteeuw et al., 2009; Moore et al., 2019), and it would be helpful to add more evidence in this regard within a specific field of study.

The referees' visual behavior in decision-making environments has been previously analyzed to discover which visual search behavior is more efficient in perceiving information (for a review, see Ziv et al., 2020). Some studies carried out with referees have focused on variables such as the distance from the target and the visual angle. Luis-del Campo et al. (2015) found that football assistant referees showed different visual search behaviors depending on the distance and the visual angle in offside situations. The referees performed a higher number of fixations and longer fixation time on the player with the ball when they observed the game with larger angles than when they observed it with smaller angles. In addition, they showed a higher number of fixations and longer fixation time on the last defender, and they reduced the number and time of fixations on the player receiving the ball when the game action took place close to the referee than when it took place at greater distances (Luis-del Campo et al., 2015). While there is not any similar research conducted on basketball referees, these results underline the importance of the referee's position. In addition, when more than one referee is on the court, it is necessary to consider the coordination of gaze behavior between referees, generally positioned on opposite sides of the court. For example, a study conducted in handball concluded that the two referees fixated most on the same area of the court, and this was usually where the action with the ball took place (Fasold et al., 2018). The authors suggested that coordination of gaze behavior was not optimal, and visual search performance could be improved through training.

In sports such as basketball, two-person refereeing mechanics is plausible for officiating matches (FIBA, 2010). Under these mechanics, there are two main zones in which referees should position themselves: (1) lead, ahead of the action, beyond the baseline; and (2) trail, behind the action, close to the center line. Each referee is positioned in each zone, and the game takes place between them. Two-person refereeing mechanics requires both referees to work together, one taking responsibility for gameplay near the ball and the other for play away from the ball. Depending on the situation of the ball, referees must make decisions about what happens in their zone of responsibility. To date, the guidelines provided by the International Basketball Federation (FIBA, 2010) determine basketball referees' fixation locations, but visual search behavior has not been studied (Ziv et al., 2020).

In this study, the visual search behavior of basketball referees was analyzed while viewing sport-specific video footage. An expert-novice paradigm was used, and the influence of the position of the referees on the court of play following two-person refereeing mechanics was evaluated (lead vs trail). The main hypothesis is that experts and novices will differ in their visual behavior due to better perceptual-cognitive skills related to expertise, mainly characterized by fewer fixations of longer duration (Mann et al., 2007). Additionally, experts are expected to spend more time directing their gaze to more informatively relevant stimuli than novices. Finally, differences in gaze behavior between lead and trail referee positions are expected due to the different attentional demands set by FIBA and the perceptive angle (FIBA, 2010; Luis-del Campo et al., 2015).

2. Materials and Methods

Participants - Sixteen basketball (15 male,1 female) referees took part in the study, distributed into two groups. One group of non-professional experienced basketball referees from the Spanish national 4th EBA Division (n = 8, all male; age = 27.5 ± 5.04 years; experience = 9.25 ± 5.03 years) and one group of novice referees with experience in regional competition (n = 8, seven male; age = 22.8 ± 1.88 years; experience = 2.00 ± 1.06 years). The participants were all dwelled in the same region as the hosting institution. Before their participation, all subjects were informed of the objectives and requirements of the experimental situations, giving their agreement through a voluntary participation consent form. The postulates of the Nuremberg Code and the Declaration of Helsinki were considered in the design and collection of the experimental data.

Instruments- Two cameras (DSR-200P-DVCam, Sony Group Corporation, Tokyo, Japan) were used to film 5x5 game situations, one to film the gameplay situations from the trail position and one from the lead position. The position of the two cameras in the court can be found in Figure 1.

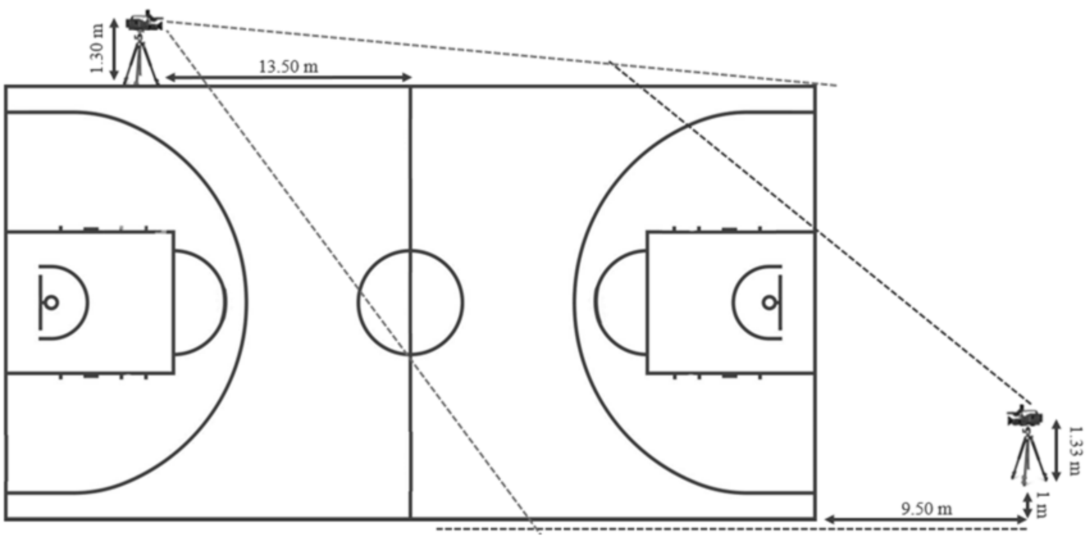

Figure 1. Details of the location of the two cameras filming the gameplay of the basketball team.

For the projection of the 5x5 gameplay situations, a Hitachi CP-S310W LCD (Hitachi Ldt., Tokyo, Japan) projector was used. The projection was shown on a 5x3 m projection screen. The ASL SE5000 Gaze Tracking System (Applied Sciences Laboratories Inc., Washington, USA) was used to record the visual behavior of the referees. This is a video-based monocular system that measures the perceiver's point of gaze through an infrared eye camera and a scene camera when observing video images. The eye camera records displacement data from the left pupil and cornea at 50 Hz, and the result is a specific point of gaze on the scene image.

Video Footage Recording - Five 5x5 positional plays were selected and executed by 10 Spanish first-category (i.e., ACB League) players during a training session. The session was recorded by two cameras that were placed, as shown in Figure 1, to simulate the view of the lead and the trail referee (Figure 2). The criteria for the selection of the five plays were: (1) all the players had to be inside the recording frame from both positions, while (2) an ambiguous action that required a referee decision took place (e.g., contact between players, illegal use of arms, etc.). Two international FIBA referees decided on the suitability of the clips. Only those clips on which there was full agreement were selected. The duration of each play was adjusted to a duration of 5 s.

Figure 2. Lead (left) and trail (right) point of view.

Procedure - The participants watched five 5x5 positional gameplay situations of a senior ACB basketball team recorded from the lead and the trail referee position, which were projected on a laboratory projection screen. The participants watched ten clips with an eye-tracker device on their heads. The viewing order of one perspective or the other was counterbalanced between subjects. The participants stood behind a line that was at a 4m distance from the 5x3m screen, trying to simulate the actual visual field size during basketball refereeing.

Data Analysis - The visual search behavior of the 16 participants was analyzed during five gameplay visualizations from the lead and the trail referee position, with a duration of 5 s each. Therefore, 160 gameplay situations were analyzed, resulting in an 800s analysis time.

The design involves an independent between-group variable (expertise: expert-novice) and an independent within-group variable (viewing position: lead - trail). The dependent variables were based on the study of Extrinsic Ocular Motility (EOM): the number of fixations (NF), average fixation time (AFT), and total fixation time (TFT). A fixation was considered when the subject maintained their gaze on a location for at least 60 ms (Reina et al., 2007; Trabulsi et al., 2021). The maximum TFT for each referee is 25 s for each referee position.

Visual fixations (number and duration) are performed on a series of spatial locations, which are assumed to be indices that the referee considers most informative. Fixation location was studied based on three categories. The first category consisted of the refereeing technique set by the FIBA Referees' Manual (FIBA, 2010), which divides each half of the court into six zones. As shown in Figure 3, each referee must pay attention to one (or more) of these areas, grouping them into zone of full responsibility (FR), zone of shared responsibility (SR), and zone of non-responsibility (NR). The FR are those areas in which a referee is solely responsible for assessing the rule violations that occur in them, and SR are areas where both referees can make decisions. The FR of the trail referee are the NR of the lead referee, and vice versa.

The second category is based on the spatial location of play, establishing the following zones: attacking player with the ball (AWB) or without the ball (AWOB), defender against the player with the ball (DWB) or a player without the ball (DWOB), the window between the attacking player and his defender (WIN), hoop (HO), the ball while in the air (BA), and free space (FSP).

Finally, the third category was also established based on the body part: head (HEAD), arm (ARM), trunk (TRUNK), pelvis (PELVIS), legs (LEG), feet (FEET), ball in the hands of a player (BALL), and no fixation on a player (NP).

SPSS Statistics package version 24.0 was used (IBM Corp., Armonk, NY). The normality of the variables was evaluated using the Kolmogorov-Smirnov test. A two-way mixed Analysis of Variance ANOVA was carried out. The intragroup factor was the position on the court (lead and trail), and the intergroup factor was the participants' experience group (expert or novice). Because three EOM parameters were used to assess gaze behavior performance, statistical significance was adjusted following Bonferroni criteria. Thus, statistical significance was set at $p < 0.016$.

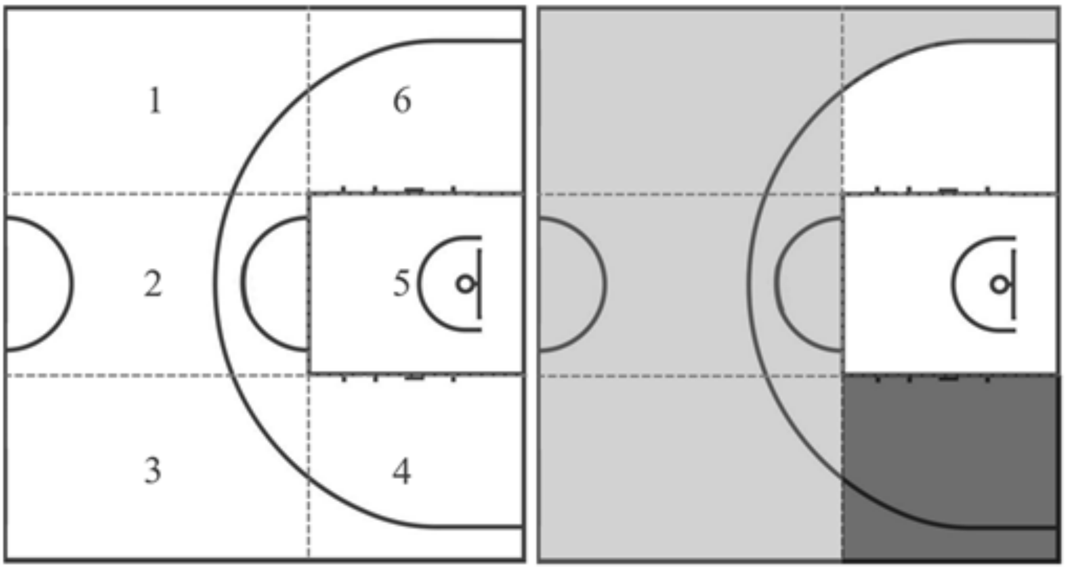

Figure 3. Division of the court into numbered rectangles and responsibility zones (FIBA, 2010). White: zone of shared responsibility; Dark grey: lead referee's zone of full responsibility; Light grey: trail referee's zone of full responsibility.

3. Results

Table 1 shows the mean and standard deviation obtained for the total number of fixations, the average fixation time, and the total fixation time in all the gameplay situations for both experimental groups: experts and novices, in lead and in trail positions. No differences were found between the number of fixations in the lead and trail positions. However, the referees spent slightly more total fixation time and more average fixation time in the trail position than in the lead position [TFT: F1.14

= 10.79; $p = 0.005$; $\eta p^2 = 0.435$; AFT: $F_{1.14} = 16.23$; $p = 0.001$; $\eta p^2 = 0.537$]. No statistically significant differences were found between the expert and novice groups in any of the three variables.

Table 1. Visual search behavior of the referees depending on position and expertise.

	Trail			Lead		
	Experts	Novices	Total	Experts	Novices	Total
NF	53.63 ± 7.41	54.75 ± 8.38	54.19 ± 7.66	55.88 ± 8.72	57.88 ± 7.08	56.88 ± 7.75
AFT	0.33 ± 0.05#	0.34 ± 0.03#	0.33 ± 0.04#	0.30 ± 0.05	0.30 ± 0.05	0.30 ± 0.05
TFT	17.54 ± 1.87#	18.27 ± 2.12#	17.90 ± 1.97#	16.34 ± 1.72	17.12 ± 2.10	16.73 ± 1.90

NF: number of fixations; AFT: average fixation time (s); TFT: total fixation time (s) out of 25 s. #: statistically different (p < 0.016) with lead.

Table 2. Visual search behavior of the referees regarding the zones of responsibility

		Trail			Lead		
		Experts	Novices	Total	Experts	Novices	Total
FR	NF	9.00 ± 3.07	8.00 ± 4.63	8.50 ± 3.83	5.88 ± 2.90	5.38 ± 3.16	5.63 ± 2.94
	AFT	0.31 ± 0.12	0.39 ± 0.13	0.35 ± 0.13	0.32 ± 0.09	0.32 ± 0.15	0.32 ± 0.12
	TFT	2.63 ± 0.79#	2.87 ± 1.55#	2.75 ± 1.20#	1.70 ± 0.45	1.58 ± 0.91	1.64 ± 0.69
SR	NF	40.38 ± 6.89	43.13 ± 7.95	41.72 ± 7.33	45.25 ± 6.39	48.25 ± 5.70	46.75 ± 6.05
	AFT	0.33 ± 0.05	0.33 ± 0.03	0.33 ± 0.04	0.30 ± 0.06	0.30 ± 0.05	0.30 ± 0.05
	TFT	13.04 ± 1.10	14.09 ± 3.02	13.57 ± 2.26	13.47 ± 1.44	14.24 ± 1.60	13.86 ± 1.52
NR	NF	4.25 ± 1.98	3.50 ± 2.33	3.88 ± 2.13	4.75 ± 3.45	4.25 ± 3.65	4.50 ± 3.45
	AFT	0.42 ± 0.18#	0.41 ± 0.24#	0.42 ± 0.21#	0.24 ± 0.07	0.25 ± 0.12	0.25 ± 0.09
	TFT	1.87 ± 1.43	1.29 ± 0.92	1.58 ± 1.20	1.17 ± 0.85	1.30 ± 1.23	1.24 ± 1.02

FR: zone of full responsibility; SR: zone of shared responsibility; NR: zone of no responsibility; NF: number of fixations; AFT: average fixation time (s); TFT: total fixation time (s) out of 25 s; #: statistically different (p < 0.016) with lead.

Concerning the visual behavior in the areas of responsibility, Table 2 shows that both expert and novice referees spent considerably more time in the areas of shared responsibility than in the areas of full or no responsibility. When the referees were in the lead position, they reduced the total fixation time in their areas of full responsibility. Within the areas of shared responsibility, no differences in the number of fixations or the fixation time were found between trail and lead. Additionally, referees showed shorter average fixation time in non-responsibility zones in the lead position compared with the trail position. No differences were found according to experience.

According to the spatial locations of play (Table 3, Figure 4), all the referees showed a greater number of fixations and total fixation time on the attacking player with the ball compared to other AOI. Novice referees showed longer fixation time [$F_{1.14} = 8.76$; $p = 0.010$; $\eta p^2 = 0.385$] on the defensive player of the ball than experts. It is also noteworthy that novice referees dedicated more fixations to the ball's flight than experts, especially in the trail position. Concerning the referee's court position, the greatest differences have been found on the defender against the player with the ball. Referees made more fixations and more fixation time (average and total) in the trail position than in the lead position to the window between the attacking player and his defender. Furthermore, when the referees were in the trail position, they dedicated more fixations with a longer total duration to the hoop than when they were in the lead position.

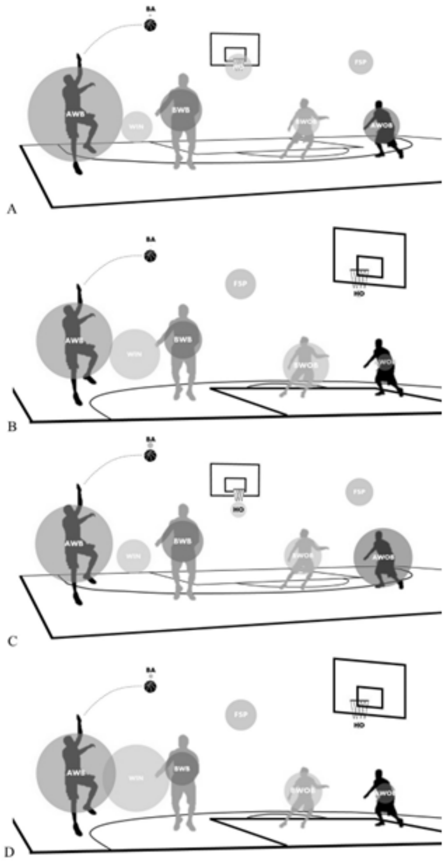

Figure 4. Referees' visual search behavior as a function of spatial game locations. (**a**) Experts' trail visual behavior; (**b**) Experts' lead visual behavior; (**c**) Novices' trail visual behavior; (**d**) Novices' lead visual behavior.

Table 4 (as well as Figure 5) shows the referees' visual search behavior results by classifying the location of fixations according to the body area. The part of the body on which the referees fixate the most, regardless of their position and expertise, is the trunk area followed by the arms and the head. Referees also showed more visual fixation time (average and total) on the trunk from the trail position than from the lead position. Significant differences were also found between referee positions in fixations on the feet, both in the number of fixations and in total fixation time. In the trail position, visual fixations on the feet were practically non-existent. Similarly, the low relevance of visual fixation on the feet is reproduced in the visual fixations on the legs, especially in experts. Novice referees do perform longer fixations on the legs than expert referees in both refereeing positions.

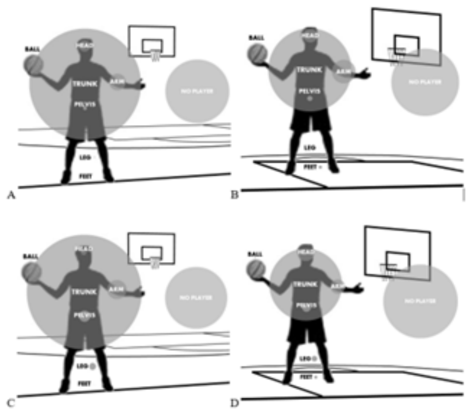

Figure 5. Referees' visual search behavior regarding the body area. (**a**) Experts' trail visual behavior; (**b**) Experts' lead visual behavior; (**c**) Novices' trail visual behavior; (**d**) Novices' lead visual behavior

4. Discussion

This work aimed to study the visual search behavior of basketball referees while watching 5x5 positional gameplay clips in a laboratory setting, with two independent variables: expertise and visual angle.

The visual behavior analysis found no differences in the number of fixations as a function of the referee's position regardless of fixation location. However, the referees showed more total fixation time and longer average fixation times in the trail position than in the lead position. This may be due to the different demands of each position. From the lead position, the basket and players are closer and perceived as bigger due to the

Table 3. Referees' visual search behavior regarding the spatial game locations.

		Trail			Lead		
		Experts	**Novices**	**Total**	**Experts**	**Novices**	**Total**
AWB	NF	11.00 ± 2.33	9.75 ± 3.99	10.38 ± 3.22	11.00 ± 4.11	12.00 ± 4.44	11.50 ± 4.16
	AFT	0.53 ± 0.19	0.50 ± 0.10	0.51 ± 0.15	0.44 ± 0.14	0.40 ± 0.11	0.42 ± 0.12
	TFT	5.78 ± 2.25	4.72 ± 1.68	5.26 ± 2.00	4.63 ± 1.65	4.83 ± 2.14	4.73 ± 1.85
AWOB	NF	9.00 ± 2.73	8.50 ± 3.96	8.75 ± 3.30	9.38 ± 4.17	7.38 ± 3.34	8.38 ± 3.80
	AFT	0.29 ± 0.09	0.30 ± 0.10	0.29 ± 0.09	0.26 ± 0.04	0.27 ± 0.06	0.26 ± 0.05
	TFT	2.56 ± 0.82	2.51 ± 1.24	2.53 ± 1.01	2.30 ± 0.95	2.04 ± 1.04	2.17 ± 0.97
DWB	NF	6.38 ± 2.50#	9.38 ± 3.54#	7.88 ± 3.34#	4.25 ± 2.31	5.50 ± 2.33	4.88 ± 2.347
	AFT	0.33 ± 0.15#	0.41 ± 0.10#	0.37 ± 0.13#	0.23 ± 0.08	0.23 ± 0.08	0.23 ± 0.08
	TFT	2.22 ± 1.47*#	3.59 ± 0.93#	2.90 ± 1.38#	1.01 ± 0.57*	1.24 ± 0.58	1.12 ± 0.57
DWOB	NF	7.25 ± 3.58#	7.00 ± 2.93#	7.13 ± 3.16#	11.63 ± 3.66	10.13 ± 3.83	10.88 ± 3.70
	AFT	0.24 ± 0.06	0.30 ± 0.15	0.27 ± 0.11	0.24 ± 0.09	0.23 ± 0.06	0.23 ± 0.07
	TFT	1.64 ± 0.85	2.28 ± 1.49	1.96 ± 1.22	2.82 ± 1.27	2.33 ± 0.96	2.57 ± 1.12
WIN	NF	7.00 ± 2.39#	6.63 ± 2.72#	6.81 ± 2.48#	8.50 ± 3.02	10.63 ± 2.67	9.56 ± 2.97
	AFT	0.26 ± 0.11	0.32 ± 0.11	0.29 ± 0.11	0.38 ± 0.17	0.38 ± 0.11	0.38 ± 0.14
	TFT	1.91 ± 1.08#	2.08 ± 1.00#	1.99 ± 1.01#	3.08 ± 1.28	4.08 ± 1.44	3.58 ± 1.42
FSP	NF	8.25 ± 1.75	9.38 ± 3.62	8.81 ± 2.81	8.88 ± 3.36	10.00 ± 2.27	9.44 ± 2.83
	AFT	0.19 ± 0.04	0.18 ± 0.03	0.18 ± 0.03	0.20 ± 0.06	0.19 ± 0.04	0.20 ± 0.05
	TFT	1.50 ± 0.34	1.69 ± 0.85	1.59 ± 0.63	1.86 ± 1.20	1.91 ± 0.71	1.88 ± 0.95
BA	NF	0.25 ± 0.46*	1.38 ± 0.52	0.81 ± 0.75	0.38 ± 0.52*	0.75 ± 1.04	0.56 ± 0.81
	AFT	0.17 ± 0.31	0.23 ± 0.12	0.20 ± 0.23	0.05 ± 0.08	0.13 ± 0.18	0.09 ± 0.14
	TFT	0.17 ± 0.31	0.37 ± 0.30	0.27 ± 0.31	0.05 ± 0.08	0.25 ± 0.49	0.15 ± 0.35
HO	NF	3.50 ± 1.60#	2.50 ± 1.41#	3.00 ± 1.55#	1.38 ± 1.30	1.50 ± 1.60	1.44 ± 1.41
	AFT	0.42 ± 0.29	0.37 ± 0.15	0.40 ± 0.22	0.31 ± 0.25	0.28 ± 0.25	0.30 ± 0.24
	TFT	1.62 ± 1.05#	0.95 ± 0.60#	1.29 ± 0.89#	0.52 ± 0.41	0.45 ± 0.36	0.48 ± 0.38

*NF: number of fixations; AFT: average fixation time (s); TFT: total fixation time (s) out of 25 s; #: statistically different ($p < 0.016$) with lead; *: statistically different ($p < 0.016$) with novices.*

visual angle available. In such situations, observers make more fixations and therefore more time is spent on saccadic eye movements and less on fixations (Al-Abood et al., 2002). Since referees have a larger visual angle in the lead position, the search for possible fouls and rule infringements may have led referees to conduct more saccadic movements and, consequently, reduce fixation time. The comparison between experts and novices in the general analysis did not show any significant difference, so we could not confirm the hypothesis that expert referees have a visual search behavior with fewer fixations and longer fixation duration. Other works in other sports also found no differences between expertise levels (Bard et al., 1980; Catteeuw et al., 2009;

Hancock & Ste-Marie, 2013; Schnyder et al., 2017; Spitz et al., 2016). For example, Catteeuw et al. (2009) found no differences in scan patterns (percentage viewing time in each area of interest) between international and national soccer assistant referees during offside video simulations, although international level assistant referees were more accurate in their decisions. However, other studies which reported results supporting our first hypothesis have been found (e.g., softball: Millslagle et al., 2013; rugby: Moore et al., 2019; gimnastics: Pizzera et al., 2018). For example, Moore et al. (2019) found that the time spent on some areas of interest, as well as stationary gaze entropy, were significant predictors of decision-making accuracy in rugby referees and players. In any case, a comparison of results across studies should be made with caution as these are highly dependent on the characteristics of the tasks analyzed (Frank & Schack, 2016).

Regarding the visual behavior of the referees according to the refereeing technique, it should be noted that in both refereeing positions, the areas of shared responsibility are those to which the referees pay the most attention. Some of the most relevant actions related to the game score take place on shared locations (e.g., penetrations, shots, etc.), so it is reasonable that both referees spend more time focusing on shared locations. Moreover, the information perceived by the refereeing team is complementary as each referee observes the actions from different visual angles. However, stimuli in other areas should not go unnoticed. The FIBA referee’s manual instructs the trail and lead referees to pay attention to different areas in the field of play, in order to avoid attentional redundancy and to control the maximum space (FIBA, 2010). However, visual fixations in the present study have been shown to coincide in the zone of share responsibility. Interpreting the game and coordinating with the partner so as not to overlap zones of fixation is one of the difficulties in referee training. Therefore, implementing cooperative gaze behavior protocols could be positive to increase team performance (Brennan et al., 2008; Neider et al., 2010). The aforementioned studies concluded that two people searching for the same target perform better when they receive information from the visual search behavior of the partner rather than verbal communication. Coordinated search behavior may be better improved by implementing knowledge of the gaze strategy of the other observer rather than verbal communication between both observers.

Non-responsibility zones received fewer visual fixations in both referee positions. However, when a referee perceives a stimulus peripherally from a non-responsibility zone (e.g., an abrupt movement against an opponent), a common strategy might be to make quick fixations to extract information from these zones to analyze its possible relevance and, subsequently, to fixate again on their areas of responsibility (Vater et al., 2017). This is reflected in the lead position, as shorter average fixation durations have been found for fixations on non-responsibility areas.

Regarding the referees' visual search behavior based on spatial locations, the referee manual states that referees should continuously search for the window between opposing players to judge illegal contact if it exists by either of the two players involved (FIBA, 2010). These instructions may lead referees to follow a ‘fixate center’ search strategy, which consists of fixing their gaze between two relevant stimuli to obtain information from both (Hüttermann et al., 2013). This strategy has been reported to show better perceptual performance when

Table 4. Visual search behavior of the referees regarding the body area.

		Trail			Lead		
		Experts	**Novices**	**Total**	**Experts**	**Novices**	**Total**
HEAD	NF	2.63 ± 3.46	2.13 ± 2.03	2.38 ± 2.75	4.38 ± 3.74	3.88 ± 2.42	4.13 ± 3.05
	AFT	0.25 ± 0.25	0.18 ± 0.08	0.22 ± 0.18	0.29 ± 0.14	0.30 ± 0.21	0.30 ± 0.17
	TFT	0.97 ± 1.27	0.48 ± 0.52	0.71 ± 0.97	1.15 ± 0.93	1.49 ± 1.65	1.32 ± 1.31
ARM	NF	5.00 ± 1.85	4.88 ± 2.90	4.94 ± 2.35	7.13 ± 2.70	4.88 ± 2.36	6.00 ± 2.70
	AFT	0.28 ± 0.07	0.33 ± 0.07	0.31 ± 0.07	0.29 ± 0.10	0.26 ± 0.09	0.28 ± 0.09
	TFT	1.40 ± 0.66	1.59 ± 0.97	1.50 ± 0.81	1.96 ± 0.70	1.28 ± 0.71	1.62 ± 0.77
TRUNK	NF	23.38 ± 7.46	23.00 ± 5.32	23.19 ± 6.26	21.38 ± 9.07	20.63 ± 6.44	21.00 ± 7.61
	AFT	0.41 ± 0.11#	0.42 ± 0.05#	0.41 ± 0.08#	0.33 ± 0.08	0.31 ± 0.12	0.32 ± 0.10
	TFT	9.35 ± 3.24#	9.50 ± 2.17#	9.43 ± 2.66#	6.87 ± 2.37	6.29 ± 2.41	6.58 ± 2.33
PELVIS	NF	2.13 ± 1.25	2.63 ± 2.72	2.38 ± 2.06	1.88 ± 2.17	2.88 ± 3.04	2.38 ± 2.60
	AFT	0.17 ± 0.12	0.29 ± 0.26	0.23 ± 0.21	0.19 ± 0.17	0.14 ± 0.15	0.16 ± 0.16
	TFT	0.34 ± 0.25	0.92 ± 0.95	0.63 ± 0.74	0.43 ± 0.58	0.76 ± 1.10	0.59 ± 0.87
LEG	NF	0.38 ± 1.06	1.88 ± 2.70	1.13 ± 2.13	0.50 ± 0.76	2.38 ± 2.13	1.44 ± 1.83
	AFT	0.03 ± 0.08*	0.15 ± 0.22	0.09 ± 1.72	0.03 ± 0.45*	0.17 ± 0.11	0.10 ± 0.11
	TFT	0.08 ± 0.23	0.56 ± 0.91	0.32 ± 0.69	0.04 ± 0.06	0.50 ± 0.45	0.27 ± 0.39
FEET	NF	0.00 ± 0.00#	0.13 ± 0.35#	0.06 ± 0.25#	0.75 ± 0.89	0.50 ± 0.53	0.63 ± 0.72
	AFT	0.00 ± 0.00	0.01 ± 0.04	0.01 ± 0.03	0.16 ± 0.19	0.27 ± 0.38	0.21 ± 0.30
	TFT	0.00 ± 0.00#	0.01 ± 0.04#	0.01 ± 0.03#	0.26 ± 0.33	0.27 ± 0.38	0.26 ± 0.35
BAL	NF	0.13 ± 0.35	0.25 ± 0.46	0.19 ± 0.40	0.25 ± 0.71	0.25 ± 0.46	0.25 ± 0.58
	AFT	0.06 ± 0.18	0.10 ± 0.23	0.08 ± 0.20	0.03 ± 0.08	0.12 ± 0.29	0.07 ± 0.21
	TFT	0.06 ± 0.18	0.10 ± 0.23	0.08 ± 0.20	0.06 ± 0.17	0.12 ± 0.29	0.09 ± 0.23
NP	NF	20.00 ± 2.83	19.88 ± 5.14	19.94 ± 4.00	19.63 ± 4.57	22.50 ± 4.21	21.06 ± 4.49
	AFT	0.27 ± 0.07	0.26 ± 0.05	0.26 ± 0.06	0.29 ± 0.03	0.29 ± 0.05	0.29 ± 0.05
	TFT	5.33 ± 1.63	5.12 ± 1.83	5.23 ± 1.68	5.58 ± 1.41	6.44 ± 1.31	6.01 ± 1.39

*NF: number of fixations; AFT: average fixation time (s); TFT: total fixation time (s) out of 25 s; #: statistically different ($p < 0.016$) with lead; *: statistically different ($p < 0.016$) with novices.*

both stimuli have the same informative relevance (Hüttermann et al., 2013). Therefore, fixating on the window of space between the attacker with the ball and the defender against the player with the ball would allow information to be obtained from both stimuli. However, the results of this study show that referees fixate more on players than on spaces classified as non-players (Table 3), so players are not looking for information on the window location, contrary to the recommendation of the refereeing manual. Specifically, the referees gave more importance to the attacking player with the ball, which can be considered as a 'fixate target' strategy, which is characterized by positioning one stimulus in the fovea, while the second is in the periphery (Hüttermann et al., 2013). This strategy may be more effective when one of the stimuli has more informative relevance than the other. From these results, it is interpreted that the attacking player with the ball provides more valuable information than his defender. The comparison between experts and novices supports this hypothesis, as expert referees have shown shorter total fixation times on the spatial location of the defending player of the ball.

Regarding the differences between referee positions concerning fixation location, the windows between players are less fixated in the trail position. This may be caused by the fact that the space between players in that area is usually wider. This information may support the idea that the closer two stimuli are to each other, the more possibilities for action there are; therefore, they are more perceptually relevant (Martínez de Quel & Bennett, 2019). This happens to a greater extent in the lead position, in which a higher number of fixations and longer fixation time have been found in the window location, representing greater compliance with the manual guidelines. Another characteristic element of the trail refereeing position is that from this position, there is a more significant number of fixations and a longer fixation time on the hoop. This could be justified because the trail referees' front view of the basket allows them to obtain more reliable information about the basket and to perceive and interpret possible illegal interceptions or infringements after rebounds in this area. On the contrary, from the lead position, it is more difficult to perceive all this information due to the visual angle and the backboard's obstruction of the field of vision.

The visual behavior of the referees as a function of spatial locations has reported some differences between the expert and novice groups. The expert referees showed a shorter total fixation time in the spatial location of the defending player of the ball. In addition, novice referees showed more fixations on the ball in flight, especially in the trail position. Expert basketball referees seemed to be more selective and showed fewer fixations on less informatively relevant stimuli (i.e., direct defender of the ball and ball in flight), which seems to indicate greater efficiency in the alerting, orienting, and attentional processes, as has been reported in athletes from other modalities (Meng et al., 2019).

Based on the data obtained from the analysis of the visual behavior of the referees according to the body area of the players, it was found that in the lead position, there are more fixations and total fixation time on the feet than in the trail position. This may be because the proximity of the players to the court boundaries increases the need for the referees to pay attention to that specific location in order to judge a possible illegal release (i.e., when the player in possession of the ball steps outside the court). It is also noted that the most important body category is the trunk. Apparently, by directing their gaze to the center of the body, basketball referees can receive information from all body zones using both central and peripheral vision. Thus, when specific actions occur in other body zones, these are perceived by the peripheral vision, and fixation shifts to this zone to position the newly emerging stimulus in the fovea. This strategy is called visual pivot (Vater et al., 2019), with the trunk being the attractor on which the referees focus their gaze to obtain information from the rest of the areas and identify the most relevant one depending on the game situation. Athletes in combat sports have shown similar strategies, especially taekwondo athletes, in whom the lower body is very relevant because it is the main area in which attacks are initiated (Martínez de Quel & Bennett, 2019). It seems that the lower body area is not as relevant for expert than it is for novice basketball referees since the expert group in the present study showed less average fixation time to the players' legs than the novices. Once again, we found that expert referees select different AOI, positioning those stimuli that are supposed to provide higher quality information to make decisions about the game in the fovea (Gegenfurtner et al., 2011). However, additional data is needed to state that those stimuli lead to better perceptual and decision-making performance. It can be hypothesized that after years of refereeing practice, referees have developed the ability to identify the locations of the game and players that best reveal the information needed to make correct decisions related to game infringements. In this context, selecting relevant stimuli would be a reliable indicator of basketball referees' perceptual expertise level (Mann et al., 2007).

One of the weaknesses of this study is the use of video footage. This methodology is commonly used to overcome the difficulties presented by field studies. However, some authors questioned the reliability of the results obtained in studies using these methodologies (Renshaw et al., 2019). To date, only a few studies have analyzed the visual search behaviors of sports referees on-field (Fasold et al., 2018; Schnyder et al., 2017). Therefore, more information is needed regarding the visual search behavior of sports referees in more ecological situations. The second limitation of this study is the use of training task instead of actual game task footage. This introduces uncertainty regarding the extent to which the selected training clips accurately replicate the competitive nature of the actions observed in real-game scenarios, including crucial factors such as playing intensity and motivation. Another limitation of the study is the limited sample size. Because eye-tracking data analysis is very time consuming, the studies in this field often have a reduced sample size. Future reviews and meta-analysis have the potential to enhance the statistical power of the analysis. The fourth limitation of this study is the lack of information on decision-making performance. This would be key when linking visual search behavior and refereeing performance. Collecting and reporting this type of data in future research is encouraged. Finally, the two-person refereeing mechanics paradigm has been used in this work to simplify the experimental design. However, professional basketball leagues use three-person mechanics involving a third (center) referee. In three-person mechanics, lead and trail referees maintain the same visual angle on the court, while major changes are found in areas of responsibility for both referees. Even though two-person officiating is still applied in non-professional divisions and youth competitions, it should be considered a limitation. Future studies could address similar objectives to those of this work to overcome the limitations presented.

5. Conclusions

In conclusion, from the results of this study, we could not identify a characteristic perceptual pattern of expert basketball referees in terms of the number of fixations, average fixation time, and total fixation time on the selected areas of interest. However, expert referees showed different identification and selection of relevant stimuli in the environment. A visual strategy was observed in referees characterized by more visual fixations on shared responsibility areas, in which the perceived information is complemented by the partner from a different perspective, and the performance of saccadic eye movements with shorter fixations on other areas of full responsibility. Regarding this point, coordinated search behavior training programs may be helpful to accomplish the FIBA guidelines that ask lead and trail referees to pay attention to different stimuli in the court. Besides, contrary to what the

FIBA manual demands, it has been found that expert and novice basketball referees mainly follow a visual 'target strategy', positioning the attacking player with the ball in the fovea. Finally, a visual pivot on the players' trunk has been observed, intending to obtain information from all body segments using both central and peripheral vision.

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