



Article Gaze Behavior and Positioning of Referee Teams during Three-Point Shots in Basketball

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Featured Application: Even though this study focuses on referees in basketball, the approach we took can help to learn more about refereeing in other team sports, considering that, at least in professional team sports, there are usually teams of referees adjudicating a game. This is probably due to the sheer number of highly dynamic aspects of and around game action that have to be perceived to allow a high quality of referee decision making. Precision in such decisions cannot be accomplished by a single referee. However, the way in which the dynamics, rules, and conditions of other team sports affect how the team of referees is expected to behave in order to optimize their decision making, requires further research. In many sports (like soccer, American football), referees are assigned special responsibilities that might lead to certain patterns of gaze behavior different to what we observed in basketball. How far these patterns of gaze mean referees are able to perform high quality refereeing duties well as a team, has so far remained untested and unknown. Further research on this could have the practical applicability of incorporating better gaze strategies for high-quality decision making in team sports because referees are currently trained and advised to behave in a certain way without any basis for these instructions.

Abstract: This study looks at the visual scan patterns of high-class basketball referees. Using mobile eye-tracking devices, referees' gaze behavior was analyzed during the execution of three-point shots in the official pre-season games of Germany's men's professional basketball league. We evaluated the extent to which the referees fulfill the tasks assigned to them, where do they look, and to what extent does their gaze behavior overlap during a three-point shot. Results indicate that referees who are far away from the ball and are, therefore, not responsible for observing the actual shot, tend to comply with their areas of responsibility less often than referees standing nearer to the ball, i.e., they appear to observe the ball more than required (*ball watching*) at the expense of other areas that they are required to be observing at the beginning of the shooting process. However, referees spend a very small part of a three-point shot looking at the same areas of interest. This indicates that referee teams' allocation of gaze is rather effective, remaining in line with FIBA recommendations and is presumably not the main cause for errors in officiating.

Keywords: team sport; eye tracking; ball watching; officiating

1. Introduction

In recent years, a number of studies have explored the process of decision-making by different actors in various sports. The role of these actors becomes especially important in fast-paced team games, such as basketball, football, or handball, where not only teammates but also opponents need to be observed simultaneously, often in high-stress and time-sensitive circumstances. These challenges apply to athletes as well as referees, who are



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). expected to perceive different game situations accurately and make decisions in high-pressure situations [1–3].

The existing literature presents both efficient visual search strategies and optimally directed visual attention as important determinants of anticipation and decision-making performances in complex sports [4]. These cognitive abilities are not only relevant to players of various team sports but also to referees. In most game situations, the referees have to make their decisions based primarily on visual stimuli [5–7]. Referees are required, at all times, to observe the field markings, the ball, and the players actively involved, as well as the players who are not involved in any given game situation. Depending on their position and the position of the ball, the referees have continuously changing areas of responsibility. Moreover, they are expected to be able to anticipate game situations and procedures as best as possible in order to optimally adapt their gaze behavior. By means of a multitude of—primarily visually—perceived information, they should then, ideally, be able to correctly evaluate game situations and take appropriate decisions [8]. Simultaneously, they need to be able to communicate with their colleagues on overlapping areas of responsibility and/or disagreements. Therefore, optimum gaze behavior is of great significance for the overall performance of referees.

Gaze behavior and associated gaze strategies of referees have, so far, received insufficient attention in the literature. Primarily, analysis into the gaze behavior of multiple referees who have to work together in several games, has remained nearly obscure. Until now, only one case study [9] about two amateur-level handball referees has looked at gaze behavior and the coordination of gaze strategies of multiple sportspeople simultaneously. It was found that both the referees mostly fixated on the game actions with the ball (75%), while simultaneously neglecting actions without the ball. This current study evaluates the expert basketball referees' gaze behavior and their compliance to their primary area of responsibility. This investigative approach extends previous research by exploring the coordinated gaze behavior of three sportspeople (referees—"Three-Person Officiating System"; [10]), simultaneously, in specific basketball game situations (three-point shots). This approach is of particular interest, not only from a sport's practical point of view, but also from a scientific perspective, especially related to work in other areas of research on visual search behavior of more than one observer [11]. Moreover, the level of refereeing expertise of the participants in the current study is significantly higher than in the study by Fasold et al. [9]. Furthermore, while these authors [9] observed gaze patterns that seemed rather uncoordinated (i.e., gaze was often directed at the same areas of interest over and over again, neglecting other aspects of game actions which were away from the ball), it remains questionable whether the same patterns of gaze behavior can be found in a group of observers/referees with more experience.

Three-Person Officiating System and Distribution of Tasks during Three-Point Shots

The Three-Person Officiating System divides basketball referees' areas of responsibility into three sections: (i) the Lead is located along the baseline, (ii) the Center stands across the court, near the free-throw line, usually on the weak-side (i.e., the side far away from the ball), (iii) the Trail is positioned on the same side of the court as the Lead, but between the players and the basket on the opposite side of the court. There are guidelines for each of these positions in order to evaluate a three-point shot, along with all other game situations in basketball (Figure 1).

In case of a shot attempt, basketball referees are required to position themselves as best as possible to optimally cover their designated area of responsibility and be able to assess the shot attempt with all associated actions. The referee closest to the player taking the shot (the shooter), is responsible for signaling the shot and identifying it as a two-point or three-point shot (by raising the hand with two or three fingers pointed, respectively). The Trail and the Center officials share responsibility around the area comprising the free-throw line and the free-throw circle. The Lead only takes over the responsibility for this area in fast break situations (fast attack), where the Trail and the Center are unable to follow the



fast break. In all other circumstances, the Lead's task is to observe the zone and the players in it.

Figure 1. Referees' positioning (L: Lead, C: Center, T: Trail) during a three-point shot on the side of the Center (modified according to [12]).

The referee (Trail or Center) located farthest from the shot attempt, is responsible for actions and events not involving the active ball. Referees should avoid engaging in so-called *ball watching*, i.e., tracking the ball and its trajectory with their eyes during a shot attempt. Ball watching carries the risk of referees neglecting their own areas of responsibility and fulfilling their tasks appropriately. This could also lead to rule violations going unpunished [12]. Instead of watching the ball, it is expected that referees will stay with the play until the end of an action, e.g., the referee closest to the ball should focus on the defender until the shooter has landed on his feet after taking the shot. For the other two referees, it is necessary to keep the focus off the ball because when a shot is taken that is the key moment for the players to fight for the best position in order to snatch the rebound. Focusing on the rebound after the ball hits the rim might be too late to call an obvious foul [12] (Table 1).

	Phase 1	Phase 2	Phase 3
Lead	- Active matchups in the zone	Players in the zone fighting for a rebound position	Rebound action
Center/Trail nearby	 Shooter and defender Signaling three-point shot attempt 	Shooter and defenderShot coverage	Signaling successful shotPerimeter rebounds
Center/Trail far away	- Active matchups in the zone	 Players in the zone fighting for a rebound position 	 Perimeter rebounds Goaltending (primary) Basket interference (primary)

Table 1. Responsibilities of the three referees—divided into "Lead", "Center/Trail nearby" and "Center/Trail far away"—during the three phases of a three-point shot in basketball.

As referees' decisions can strongly impact a game situation, and even a game's outcome [13,14], their decision making must be at a high level [14,15] to prevent referee teams from missing relevant aspects of game action. Therefore, the primary aim of this study was to evaluate the extent to which referees fulfil the tasks assigned to them in relation to their gaze behavior during a three-point shot in basketball. We investigated whether referees comply with their primary area of responsibility, as indicated by the referees' manual for basketball. In order to derive results as accurately as possible, not only was the trajectory of the shot divided into three phases (before, during, and after the shot) but also a clear distinction was made between referees standing close to the ball (responsible for observing the shot) and those standing far away from the ball. We also analyzed the places where the referees looked at during a three-point shot, depending on where they were positioned—nearby or far away from the ball—in order to observe their ball watching behavior.

Additionally, the overlapping gaze behavior of the referee team was calculated, that is, how often did at least two referees direct their foveal gaze at the same spot. To answer these questions and evaluate the gaze behavior of referee teams as a potential area of improvement in high quality referees, the referee crew was equipped with eye-tracking systems during pre-season games of the highest German basketball league.

2. Method

This study is a part of a larger research project investigating the gaze behavior of referee teams in basketball wherein a new method has been developed to analyze the synchronized gaze behavior of more than two individuals working together in a team [16]. The current study focuses on the gaze behavior of basketball referee teams during three-point shots.

2.1. Participants

In total, nine male basketball referees took part in the experiment. All nine of them regularly officiated matches in the second German basketball league while six of them did so in the first German basketball league during the 2018/19 basketball season. Their ages ranged from 27 to 42 years (M = 33.6 years, SD = 4.5 years), they were, on average, 1.8 m tall (SD = 0.1 m) and weighed 81.8 kg (SD = 7.0 kg). One of the nine referees' data had to be excluded as his eye-tracking footage could not be evaluated due to technical problems. At the time of the study, all the participants indicated they had been active as referees for 16.2 years on average (SD = 5.0 years), with 7.9 years of this time in competitive sports on average (SD = 4.7 years). Four participants reported that they had refereed at international level, too. Apart from their referee tasks, all participants had experience in playing basketball (M = 17.6 years, SD = 8.1 years); three of them were still active as players at the time of the study, in addition to refereeing at the highest performance level. All subjects reported normal or corrected-to-normal vision (with contact lenses, n = 2). The experiment was carried out in accordance with the Helsinki Declaration of 1975, and the participants signed a consent form approved by the local ethics committee (ethics proposal number: 141/2018).

2.2. Materials

The gaze behavior of each referee was recorded using a mobile eye-tracking system (Pupil Core binocular, Pupil Labs GmbH, Berlin, Germany, weight: 23 g). The pupil core headset was connected to a Motorola Moto Z2 or Z3 Play (weight: 145 g and 156 g). The front camera of the eye-tracking system was adjusted so that the entire visual field of the referee was recorded (120 frames per second). The gaze information of both eyes was recorded at 200 Hz and matched with a simultaneously captured scene video recorded at 30 Hz.

2.3. Procedure

Figure 2 represents a flowchart of the working process. The gaze data were collected during three normal pre-season games of the men's highest German basketball league. First, referees filled out a questionnaire regarding their general experience as a basketball referee. Prior to testing, the referees were informed about the procedure and the functioning

and handling of the eye-tracking devices was explained to them. One hour before the game, the eye-tracking headsets were placed on the participants' heads, adjusted, and the participants had time to familiarize with the equipment. The participants were informed beforehand of the focus of the study being their communication strategies after a call in order to minimize the potential of them changing their normal gaze behavior prior to and during on-court decision making due to the eye tracker [17]. After all the participants were tested, the true purpose of the study was disclosed (single blind study).



Figure 2. Working process to analyze the gaze coordination of the three referees (modified from [9]).

After that, the referees performed their normal pre-game warm-up without the eyetracking system, until five minutes before the tip-off. Afterwards, the eye-tracking systems were returned to the referees and were calibrated using the *Manual Marker Calibration* [18]. For this, the referees stood on the free-throw line, looking towards the basket. One of the examiners held a Pupil Calibration Marker v0.4 in his/her hand while standing one meter in front of the referees. The referees were told to not move their heads and to follow the route of the marker only with their eyes. The route started at a sideline of the zone one meter in front of the referees. Then, the examiner walked sideways to the other end of the zone while holding the marker at an angle of 90 degree to the referees. At the sidelines and in the middle of the zone, the examiner moved the marker up and down and from side to side. As the examiner reached the other sideline, he/she moved one more meter back and followed the same route before the calibration was finally done.

During the halftime breaks of the games, the recordings were stopped and five minutes before the start of the second half, the same calibration procedure was performed. All videos were saved on an SD card and calibrated offline afterwards.

2.4. Data Analysis

There were different stages in analyzing the data, starting with offline calibration and mapping of the video footage of the three eye-tracking systems used in order to monitor the point of gaze of each referee. Then, all three-point shot attempts were selected from the video footage of the three recorded games. A manual frame-by-frame analysis was used to analyze the referees' gaze behavior. By replaying the "gaze overlay video" frame-by-frame, two independent raters manually decided when a fixation or saccade started and/or ended and identified the areas of interest within which the fixation took place ([19,20] for a more

detailed description of this procedure). This method has been used successfully by several researchers in previous studies [21,22].

An original software, written for the purpose of this study, enabled the simultaneous playback of all four video recordings of the scenes from the same game, i.e., the recordings from the perspective of the three referees and from the camera outside the court. This software was developed with Delphi XE3 and the PasLibVlc components as a 32-bit Windows GUI application. When designing the user interface of the software, the focus was on the simple and efficient collection of the relevant data of all three referees. Therefore, all possible data properties were listed in the selection fields. In this way, it was possible to index the position of each referee on the court (Lead, Center, Trail [10]), his positioning in relation to the ball (near the ball, far away from the ball) depending on the respective positions in the Three-Person Officiating System [10], and if the referees covered their areas of responsibility (by comparing actual gaze with referees' areas of responsibility) in a reasonable time. Moreover, fixation times at the areas of interest (ball, basket, shot clock, other referees, shooters, and other offensive and defensive players) were determined along with overlapping gazes (i.e., gaze of at least two referees at the same area of interest at the same time).

The shooting process was divided into three different phases: Phase 1 was defined as the period starting before the shot, until the ball left the shooter's hand. Phase 2 started at the time the ball left the hand, until it touched the ring or the backboard, or until the basket was scored. Phase 3 included the time after the shot, meaning after the ball touched the ring or the backboard, until the rebound. In case of a successful shot, this phase was understandably short since no rebound was noted here. The evaluation was carried out until the ball went completely through the net.

2.5. Statistical Analysis

The distribution of the referees' coverage of their primary area of responsibility was analyzed by means of a 3 (role: Lead, Center, Trail) \times 2 (relation to the ball: nearby, far away) \times 3 (time: phase 1, phase 2, phase 3) ANOVA with repeated measures and the coverage of the areas of responsibility in percentage as the dependent variable. Appropriate, post-hoc tests (Tukey HSD) were subsequently performed. In addition, the gaze fixation data were analyzed by means of a MANOVA using Pillai's Trace. A similar factor structure and the different areas of interest were the dependent variables (gaze durations at ball, basket, shot clock, other referees, shooters, and other offensive and defensive players). In case of any multivariate effects, subsequent univariate tests were conducted. Greenhouse–Geisser adjustment was used to correct for violations of sphericity (if necessary). Additionally, it was calculated how often the referees (two or all three) looked at the same aspect of the game action. For all tests, alpha level was set at 0.05 and for effect size estimation, *Cohen's f* was used.

3. Results

3.1. General Results

The collected data set comprising all video footage consisted of 10,813 frames out of which 8836 frames (81.2%) were included in the final data analysis. The other 2047 frames were excluded because they either did not show any visual foci, or no recording was available. Based on the available data, the referees' gaze behavior during 73 three-point shots (26 shots in game 1; 25 shots in game 2; 22 shots in game 3) was used for further analyses.

For the coverage of the primary area of responsibility in game 1, two shots for the Lead, one for the Center, and two for the Trail referee had to be excluded due to technical errors mentioned above. In the second game, one shot had to be excluded for the Lead and the Trail referee. Ten shots were removed for the Lead and the Trail referee, as well as nine for the Center in game 3. This resulted in 60 shots being analyzed for the Lead and Trail referee and 63 shots for the Center referee. The numbers, means, and standard deviations

as well as frequency distributions of the coverage of the primary areas of responsibility of vision in percent as a function of role, time, and relation to the ball, are shown in Table S1 and Figure S1 in the supplements.

3.2. Primary Areas of Responsibility

A 3 (Role: Lead, Center, Trail) \times 2 (Relation to the ball: nearby, far away) \times 3 (Time: phase 1, phase 2, phase 3) repeated measures ANOVA was conducted to compare the effects of the referees' role, relation to the ball and time covering the primary areas of responsibility. A main effect was found for the relation to the ball, F(1, 177) = 136.50, p < 0.001, Cohen's f = 0.435. A position near the ball (M = 0.89, SD = 0.26) was associated with higher coverage rates of the primary area of responsibility compared to a farther away position (M = 0.51, SD = 0.41). There was no effect of the factor role, F(2, 177) = 2.50, p = 0.085, but the interaction between these factors (relation to ball * role) revealed a significant effect, F(2, 177) = 17.06, p < 0.001, Cohen's f = 0.422. Post-hoc Tukey HSD tests found a significantly higher percentage of covering the primary areas of responsibility when the Center or the Trail referee were near the ball compared to percentages of covering the primary areas of responsibility from a position farther away from the ball, regardless of the referee's role (all ps < 0.001). The Lead referee covered the primary areas of responsibility more often when being positioned near the ball, in comparison to a Center and/or Trail referee farther away from the ball (all *ps* < 0.001). All other post-hoc comparison showed no significant differences (all ps > 0.05).

The ANOVA also showed an effect of time, F(2, 354) = 5.57, p = 0.004, *Cohen's* f = 0.16. Post-hoc Tukey HSD tests showed no difference between phase 1 and phase 3 (p = 0.24) as well as phase 2 and phase 3 (p = 0.20). A significantly better coverage of the primary visual field was observed for phase 2 compared to phase 1 (p = 0.003) though. No significant interaction was found for time and role, F(4, 354) = 1.83, p = 0.122, or time, relation to the ball and role, F(4, 354) = 0.293, p = 0.883, whereas the interaction between time and relation was significant, F(2, 354) = 10.06, p < 0.001, *Cohen's* f = 0.225. Subsequent univariate analyses showed that being positioned far away from the ball in phase 1 was associated with worse coverage of the primary areas of responsibility by a referee than all other positions and phases combinations. Moreover, the coverage of the primary area of responsibility was significantly worse in phase 1 compared to phase 2 and 3 for a far-away position (all ps < 0.001, Figure 3).



Figure 3. Mean coverage (error bars indicating standard errors) of the areas of responsibilities as a function of phase of the basketball shot and distance to the ball.

3.3. Gaze at the Areas of Interest

For the distribution of gaze fixations at the areas of interest (ball, basket, players, referees, shooter), additional shots had to be excluded, resulting in 52 shots being analyzed for each position (nearby: n = 72; far away: n = 84). Figure 4 shows the relative distribution of the referees' fixations of the areas of interest as a function of (a) time, (b) the role, and (c) relation to the ball.



Figure 4. Mean distribution (and standard errors) of fixations of the areas of interest for all referees as a function of (**a**) time, (**b**) the role, and (**c**) relation to the ball.

A 3 (Role: Lead, Center, Trail) \times 2 (Relation to the ball: nearby, far away) \times 3 (Time: phase 1, phase 2, phase 3) was conducted with fixation times towards the different areas of interest as dependent variables.

Multivariate analyses showed a main effect of *role*, V = 0.344; F(18, 286) = 3.30, p < 0.001, *Cohen's* f = 0.368, relation to the ball, V = 0.161; F(9, 142) = 3.03, p = 0.002, *Cohen's* f = 0.347, and time, V = 0.764; F(18, 133) = 23.86, p < 0.001, *Cohen's* f = 1.645. Interactions between time and role, V = 0.522; F(36, 268) = 2.63, p < 0.001, *Cohen's* f = 0.439, and between time and relation to the ball, V = 0.225; F(18, 133) = 2.15, p = 0.007, *Cohen's* f = 0.369, showed significant effects, too. Interactions between relation to the ball and role, V = 0.081; F(18, 286) = 0.67, p = 0.84, as well as between time*role*relation to the ball, V = 0.184; F(36, 268) = 0.75, p = 0.85, were not significant.

Subsequent univariate analyses of variance showed that the referees' role had an influence on the gaze at the basket, F(2, 150) = 17.52, p < 0.001, *Cohen's* f = 0.464, the offense F(2, 150) = 4.29, p = 0.015, *Cohen's* f = 0.207, and the zone, F(2, 150) = 4.89, p = 0.009, *Cohen's* f = 0.225. Post-hoc pairwise comparison showed that the Lead referee looked at the basket (M = 4.59, SD = 13.85, p < 0.001) less often than the Center (M = 18.45, SD = 13.85) and the Trail referee (M = 18.75, SD = 14.28). In addition, fixation times at the zone were higher for the Lead referee (M = 12.96, SD = 13.85) compared to the Center (M = 5.26, SD = 13.85, p = 0.016) and the Trail referee (M = 5.90, SD = 14.28, p = 0.035). Furthermore, offensive players were looked at longer (p = 0.025) by the Lead referee (M = 25.903, SD = 26.75) compared to the Trail referee (M = 11.67, SD = 27.62).

Univariate analyses of variance showed that the distance to the ball had an influence on the gaze at the shooter, F(1, 150) = 11.83, p < 0.001, *Cohen's* f = 0.267, and the other referees, F(1, 150) = 4.79, p = 0.03, *Cohen's* f = 0.158. Post-hoc pairwise comparison for the distance to the ball revealed that the referees fixated at the shooter (p = 0.001) more often if they were in a position farther away from the ball (M = 17.03, SD = 14.95) than in a position near the ball (M = 8.15, SD = 17.41). In contrast, another referee (p = 0.03) was looked at longer from a position near the ball (M = 1.94, SD = 3.92) compared to a farther away position (M = 0.67, SD = 3.31).

Univariate analyses of variance showed that different phases of observation had different effects on the referees' gaze at the basket, F(1.41, 211.55) = 51.02, p < 0.001, *Cohen's* f = 0.574; shooter, F(1.24, 185.46) = 55.24, p < 0.001, *Cohen's* f = 0.599; offense, F(1.35, 202.95) = 5.14, p = 0.015, Cohen's f = 0.165; defense, F(1.68, 252.06) = 6.4, p = 0.003,*Cohen's f* = 0.189; the zone, *F*(1.6, 239.86) = 9.17, *p* < 0.001, *Cohen's f* = 0.232; other referees, F(1.71, 257.06) = 10.03, p < 0.001, Cohen's f = 0.244; the three-point line, F(1.1, 165.57) = 11.034, p = 0.001, Cohen's f = 0.257. Post-hoc pairwise comparisons showed that in phase 1, the basket (*M* = 0.00, *SD* = 0.00), defense (*M* = 7.05, *SD* = 12.19), and zone (*M* = 2.99, *SD* = 7.93) were less fixated on than in phase 2 ($M_{basket} = 17.61$, $SD_{basket} = 10.67$; $M_{defense} = 14.30$, $SD_{defense} = 13.99; M_{zone} = 8.54, SD_{zone} = 16.95$ and phase 3 ($M_{basket} = 29.37, SD_{basket} = 20.05$; $M_{defense} = 17.77$, $SD_{defense} = 19.25$; $M_{zone} = 12.59$, $SD_{zone} = 16.95$; all ps < 0.01). Moreover, in phase 1, the three-point line (M = 6.36, SD = 13.41) was looked at more than in phase 2 (M = 0.36, SD = 3.32, p = 0.002) and 3 (M = 0.22, SD = 1.15, p = 0.004). The shooter was fixated on for longer in phase 1 (M = 29.36, SD = 24.37) than in phase 2 (M = 8.27, SD = 9.66, p < 0.001) and 3 (M = 0.15, SD = 1.01, p < 0.001). Additionally, in phase 2, the fixation duration on the shooter was longer than in phase 3 (p < 0.001). In phase 2 (M = 22.98, SD = 22.57), the offense was fixated on more than in phase 1 (M = 11.99, SD = 21.49, p = 0.02) and 3 (M = 16.08, SD = 19.76, p = 0.001). Moreover, the referees looked at each other more in phase 2 (M = 2.90, SD = 4.18), compared to phase 3 (M = 0.00, SD = 0.00, p < 0.001).

Univariate analyses of variance of significant (and multivariate) interaction effects showed that there was an interaction effect of time and relation to the ball with respect to the gaze time of the referees on the shooter, F(1.24, 185.46) = 3.8, p = 0.040, *Cohen's* f = 0.136, and an interaction effect *of* time and referees' role with respect to the gaze time at the basket, F(2.82, 252.06) = 5.44, p = 0.001, *Cohen's* f = 0.221, and at the offense, F(2.7, 252.06) = 5.45, p = 0.002, *Cohen's* f = 0.217. Post-hoc analyses showed that fixation times on the shooter

decreased from phase 1 to phase 3 regardless of the relation to the ball. However, in phase 1 and phase 2, referees looked more at the shooter when in a far-away position compared to a position nearby the ball, whereas this was not the case in phase 3. Fixation times on the ball of Trail and Center referees increased more during the trajectory of the ball/shot than fixation times of the Lead referee. For the offense, no differences in the fixation times were observed for phase 1 and 2 between the referees' roles, but the fixations significantly increased for the Center role compared to the Trail and Lead referee. Furthermore, the referee/referees near the ball, spent more time looking at the basket in phase 3 in comparison to the referees in a position further away from the ball. When it came to the shooters, fixation times of the referees decreased during the trajectory of the ball/shot.

3.4. Gaze at the Same Areas of Interest

For the analysis of overlapping gaze, only three-point shots with all three referees available were used (n = 52). The analysis showed that the Center and the Trail referees looked at the same area of interest in 7.54% of all frames during a three-point shot. Visual foci of the Center and Trail referee overlapped in 3.45% and visual foci of Lead and Trail referee overlapped in 2.85%. In 2.97% of the frames, all three referees gazed at the same area of interest.

4. Discussion

A frame-by-frame analysis of expert basketball referees' gaze behavior during threepoint shots in pre-season games of the men's highest German basketball league was carried out. This was completed to determine the extent to which referees perform the tasks assigned to them and to generally describe their gaze behavior during a three-point shot (as an avenue for performance improvement). The results showed that while being positioned near the shot attempt, most of the time, the referees fulfilled their primary responsibilities, as defined by the federation (FIBA). When the referees were positioned away from the attempt and their primary areas of responsibility, their gaze deviated, and this deviation increased significantly the farther they were from the shot attempt (especially before the ball had left the hand of the three-point shooter). Moreover, in general, the gaze of the referees varied between phases of the shot as a function of distance to the ball as well as to the referee's incumbent role (Lead, Center, Trail). That is, the general gaze of the referees seems to be the most affected factor due to physical distance from the shot attempt during a three-point shot with the areas of their responsibility (according to FIBA guidelines).

The Lead referees were found to look less often at the basket (especially at the end of the shot), but more often at the players inside the shot zone, who may be trying to "outrebound" their opponent. Additionally, the movement of gaze from areas predominantly close to the shooter to areas closer to the basket and battles for a good rebound positioning, is in line with FIBA requirements. The fact that the referee (Center or Trail) closest to the shooter spent more time looking at the basket, means they were highly likely to observe shot outcome, goaltending, etc., and this exactly meets the FIBA guidelines for the referees closest to the shooter (watch the shooter/defender first, after which gaze should be directed at the basket area). According to our findings, the only pattern of gaze that did not correspond well with FIBA requirements was that of the referees who were farther away from the ball (Center or Trail), looking at the shooter most often, even though the focus of attention should have been on activities in the zone and on players getting in position for a potential rebound (active matchups). This increases the risk of missing out critical information on the game action happening away from the ball. One wouldn't perceive what one does not focus on/attend to [23] when not using peripheral vision [24]. Therefore, this does not seem to be a pattern of gaze behavior that seems beneficial for decision-making quality. Future research would need to analyze if this pattern of gaze leads to referee teams missing critical information. If so, it would support the claim that not only the knowledge and application (of the laws of the game), the judgements in the

context of game action, the fitness and positioning of the referees, and the personality and management skills of the referees are important for good officiating [15] but also the gaze (individually and as a team) predicts the quality of decision making of referee teams to a certain extent [14].

However, besides that, there were no clear indications that referees (Center or Trail), who were not directly responsible for observing the zone and players, spent more time looking at the actual shot and its outcome, i.e., ball watching (looking at the shooter in phase 1 and the ball/basket in phase 2 and 3). Although at first sight it appeared that the referees (Center or Trail) who were farther away from the ball spent more time looking at the actual shot rather than their primary areas of responsibility, it was only so at the beginning of the shot. During the remainder of the shot, the referees (Center or Trail) seemed to spend time watching other areas which were not a part of their responsibility when they were farther away from the ball (just in case they were not focusing on their actual required areas of interest). This may be related to the fact that standing farther away from the game action also means that a larger portion of the areas of interest of the current analysis could potentially catch the eye of the referee, hence, providing more sources of distraction from the actual areas of responsibility.

Additionally, the gaze of at least two referees was almost never directed at the same aspect of game action, though, some areas of interest (e.g., the basket at the end of a shot) are commonly interpreted as more salient than others (e.g., players far away from the ball). This seems to show that expert referees are able to distribute their gaze as a team very well, and in a way that makes it possible to cover as much of the game action as possible. This also means that many critical decisions (e.g., has there been a goaltending violation) have to be made based on the observations of only one referee. However, this is in line with the federation's assignments that emphasize distribution of gaze over many game aspects instead of paying extra attention to seemingly more crucial aspects of game action. This also differs from previous work on coordinated gaze in team handball referees [9], in which two amateur referees spent the majority of the time focusing on the same aspect of the game action. This discrepancy, however, could be caused by differences in aspects of both the sports (e.g., possibly the more relevant and spatially separated aspects of game action occurring at the same time in basketball compared to team handball, as reflected by the need for three instead of two referees in basketball). The expertise level of the referees could also contribute to this inconsistency and is something which requires some development [9]. However, the amateurs in the study by Fasold et al. [9], and the current participants (at least from time to time), were used to refereeing together as part of a team. That is, participants in both studies knew each other quite well and had the chance to coordinate their behavior in many games before the actual study.

There are some limitations in the current study that need to be acknowledged and considered by follow-up studies. Although gaze behavior can be recorded by eye-tracking systems, no conclusions can yet be drawn on peripheral vision [25]. Consequently, it cannot be ruled out that the referees observed peripheral areas also during the experiment. In fact, it seems probable that the referees used peripheral vision for decision making because it was observed that they were focusing on a point in the zone which, in itself, did not seem to provide any direct useful information [26,27]. So, one can argue that concentrating on the central position of the zone made it an ideal gaze anchor for the referees [21]. Future studies could control for this aspect through additional questioning of the referees.

Another limitation of this study is that only the referees' gaze behavior, and not their performance, was analyzed. In order to draw inferences about whether and (if so) in which case, gazing at the same or different aspect of game action is effective, assessments of referees' performances by expert raters will be inevitable in future. Finally, though not necessarily a limitation, the expertise and the experience of the referees in the current study was relatively high and did not vary greatly between participants, leaving research on any differences between less and more experienced referees for future endeavors.

5. Conclusions

In conclusion, the current study, being the first to explore the gaze behavior of expert basketball referees during three-point shots, revealed some previously unknown insights. One of the biggest revelations was that referees do not appear to neglect their own areas of responsibility very often during three-point shots, especially when they are positioned close to the ball. Further studies with larger sample sizes, are needed to confirm and validate our findings and test whether such gaze behaviors actually lead to the referees missing rule violations or not and, if so, to what extent. Repeat studies would also help to analyze how efficient current refereeing guidelines are (also in other situations than the three-point shot) and if there is room for improvement with respect to efficient gaze behavior of a team of expert referees in team sports. However, considering the fact that we analyzed the behavior of well-respected and experienced referees, we would suggest most referees behave according to the FIBA central board [10], as almost all the referees did in the current study. This means that the referee closest to the shooting is responsible for the shot and the two players (offense and defense) involved in the shot. He/she must ensure that the shooter is not fouled during the execution of the shot and recognize whether the ball goes into the basket or not. The referee standing under the basket (Lead) is responsible for everything that happens under the basket, e.g., the position battle during the rebound.

The referee who is further away from the ball is also responsible for the actions under the basket and the off-ball action. Just like the Lead, he/she is not primarily responsible for indicating a successful shot, but to punish rule violations away from the shooting action.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10 .3390/app11146648/s1, Figure S1: Frequency distribution of the coverage of the primary areas of responsibility in percent as a function of role, time, and relation to the ball. Table S1: Numbers of three-point shots separated by distance to the ball and role, means of coverage the primary visual field, and corresponding standard deviations.

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