

Ger J Exerc Sport Res
<https://doi.org/10.1007/s12662-024-00947-5>
 Received: 12 July 2023
 Accepted: 16 February 2024

© The Author(s) 2024



Christian Vater¹ · Urs Schnyder¹ · Daniel Müller²

¹Institute of Sport Science, University of Bern, Bern, Switzerland

²Department of Human Movement Sciences, Faculty of Behaviour and Movement Sciences, Amsterdam Movement Sciences and Institute Brain and Behavior Amsterdam (iBBA), Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

That was a foul! How viewing angles, viewing distances, and visualization methods influence football referees' decision-making

Introduction

Football referees must be able to make correct decisions under high time pressure (Plessner, Schweizer, Brand, & O'Hare, 2009). The time pressure forces the referees to pick up information from their environment and adjust their viewing distance and viewing angle based on the current situation (Avugos, MacMahon, Bar-Eli, & Raab, 2021; Hossner, Schnyder, Schmid, & Kredel, 2019; Mann, Farrow, Shuttleworth, Hopwood, & MacMahon, 2009). To date, no studies have tested the effect of different viewing perspectives and viewing distance for the same decision-making situations. Therefore, we will manipulate the viewing angle and distance to the same decision situations in virtual reality (VR) animations of real game scenarios. Moreover, we will test how different stimulus presentation (real videos, slow-motion videos, and animated virtual-reality videos) affect decision accuracy.

A major component for correct decision-making by referees is their perceptual–cognitive skills. These skills manifest in better anticipation and decision-making, facilitate the ability to process visual information, and help to execute task-related movements (Brams et al., 2019). Perceptual–cognitive skills also include the optimal use of situational probabilities and the use of advance cues

(Mann, Williams, Ward, & Janelle, 2007; Williams, Huys, Cañal-Bruland, & Hagemann, 2009). All of this is important for referees, who need to be aware of, among other things, the players, the ball position, and field markings (Helsen, Gilis, & Weston, 2006; Samuel, Tenenbaum, & Galily, 2021). The referees process the actions of the players with high accuracy (Spitz, Put, Wagemans, Williams, & Helsen, 2016) and use their acquired prior knowledge to make the most accurate decisions (Schweizer, Plessner, & MacMahon, 2023). Referees are able to process multiple cues in a very short time, allowing them to make decisions under high time pressure (Plessner et al., 2009). To process the visual information correctly, they must also be able to use their foveal and peripheral vision effectively (Klostermann, Vater, Kredel, & Hossner, 2020; Vater, Williams, & Hossner, 2020). This is especially the case when judging situations from different viewing distances, which leads to different demands for the visual system, which in turn emphasizes the importance of an optimal positioning. We frame decision-making as a perceptual–cognitive task where referees are challenged to detect fouls by picking up visual cues from their environment. In accordance with existing research on decision-making, it can be argued that the decision-making accuracy is moderated by the stimulus pre-

sentation (Travassos et al., 2013) as well as the viewpoint of the observer (Janssen, Müller, & Mann, 2023).

Current research indicates that a referee's positioning and gaze behavior are key to processing all relevant information (Schnyder & Hossner, 2016). To investigate the effect of positioning, De-Oliveira, Orbetelli, and Neto (2011) analyzed over 300 foul scenes from Brazilian U-20 matches and found best decision-making accuracies if the referee was positioned between 20 and 25 m from the decision event (81% correct; average for all distances: 72%). In a similar study, Mallo, Frutos, Juárez, and Navarro (2012) analyzed the distances of referees to foul situations in 15 games of the FIFA 2009 Confederations Cup. They found that the referee judged most situations from 11 to 15 m. At that distance, they also had the lowest error percentage (7%), which was lower than situations judged from smaller (11–12% at distances < 11 m) and greater distances (20–22% for distances of > 20 m). In a third study on this topic, where 64 matches (1527 potential foul situations) of the 2014 World Cup were analyzed, the overall error rate of referees was 6.9% and the most frequent position of referees relative to the foul was between 10 and 15 m. At this distance range, however, more “whistle errors” (i.e., the whistle was blown although it was not a foul) have been found; it was 2.58 times

more likely for referees to commit such an error at this distance compared to other distances (Hossner et al., 2019). In contrast to the distance, the viewing angle had no effect on their decision-making (Hossner et al., 2019). Regardless of the viewing angle, it seems most important for expert referees to view the fouling player and the contact zone of the foul (i.e., where the attacking player fouls the other player) to successfully judge foul situations (Spitz et al., 2016).

To improve decision-making skills, UEFA referees regularly watch video-recorded foul situations (e.g., Plessner et al., 2009) using a WebApp (<https://www.perception4perfection.eu/about-us>). These situations are often presented from a bird's-eye perspective (i.e., the perspective when watching football from a broadcasting perspective). Critically, none of the perspectives match the referee's viewing perspective (van Biemen, Müller, & Mann, 2023). Research has shown that decision-making accuracy is affected by the viewing perspective (Mann et al., 2009; Travassos et al., 2013). Given that referees train their perceptual-cognitive skills with video-recorded situations presented from artificial viewing angles, it can be questioned whether training effects transfer to a game situation. Previous research underlines the importance of a high similarity between test or training scenarios and the game situations to successfully transfer trained skills to the field (Broadbent, Causer, Williams, & Ford, 2015; Pinder, Davids, Renshaw, & Araújo, 2011; Vater, Gray, & Holcombe, 2021). Therefore, in this study, we tested whether different viewing perspectives affect referees' decision-making by comparing the real-time bird's-eye and slow-motion zoom-in perspective with a first-person perspective that was created by rebuilding video foul situations in virtual reality.

Slow-motion replay is a common video manipulation technique that is frequently used as a visual learning tool (Spitz, Wagemans, Memmert, Williams, & Helsen, 2021). Slow motion replay takes away the immediate time pressure and allows the observer to better pick up visual information, such as the intent of the actors in the video (Caruso, Burns, &

Converse, 2016). In the case of football referees, more experienced observers are seemingly better able to make accurate technical decisions when the stimulus is presented in slow-motion (Spitz, Put, Wagemans, Williams, & Helsen, 2017).

Research so far shows that referee decision-making depends on the positioning relative to the foul situation. There are, however, mixed effects on the optimal position (distance and angle) from which a referee should make decisions. Furthermore, variations of viewing distances seem not to be considered for referee training, where they use artificial viewing perspectives (bird's-eye view) or artificial spatiotemporal dynamics (zoomed-in slow-motion video). Therefore, the first aim of this study was to compare referees' decision-making when viewing the same situations from different viewing angles and distances. To have the same situations judged from all perspectives, we recreated foul situations with animated avatars in VR. In terms of optimal distance, the existing studies suggest the decision-making accuracy to be best between 11–15 m (Mallo et al., 2012) and 20–25 m (Hossner et al., 2019). To cover this range, we compared decision-making when viewing the foul situations from a distance of 5 m, 15 m, and 25 m. Based on previous findings, we predicted that decision-making accuracy would be better at 15-m (Mallo et al., 2012) and 25-m (Hossner et al., 2019) compared to 5-m distance. We also presented the situations from three viewing angles, but, based on Hossner et al. (2019), expected no differences. If, however, the ecological validity of the viewing perspective matters, best performance should be observed from the “view between players.”

Our second aim was to compare the three visualization methods, i.e., the two video perspectives used in referee training (bird's-eye and slow-motion close-up view) and animated VR scenes rendered from a first-person perspective. Based on findings from Spitz et al. (2017), we hypothesized that slow-motion videos can be judged best, because it is easier to see whether there was a contact between players or not, but that first-person visualizations would lead to better decision-

making accuracies than those presented from bird's-eye perspective because of the more representative viewing perspective.

Method

Participants

Ten male amateur referees (age: $M = 25.50$, $SD = 2.46$ years, range: 22–29 years), with refereeing experience of $M = 8.4$ years ($SD = 3.14$ years, range: 3–14 years) in national leagues (between fifth highest and second highest league) took part in this study. They had normal or corrected-to-normal visual acuities. Ethics approval was obtained by the local ethics committee of the university.

Stimuli

Video scenes. Scenes from the FIFA 2014 World Cup in Brazil and the UEFA Champions League season 2013/2014 were used as video stimuli. These scenes were used because they were also part of the official set of training scene of FIFA referees (an a priori agreement to use these scenes was obtained from FIFA). In total we selected 18 scenes, with three scenes each where the referee in the game judged foul and red card, foul and yellow card, foul and no card, or no foul but diving (attacker acts as being fouled but was not), and six scenes with play-on decisions. The selection of scenes was made together with an expert referee of the Swiss National Football league. All video scenes were presented from the bird's-eye perspective (regular TV perspective; see [Fig. 1](#)) and from a close-up perspective (the camera zoomed closer to the foul and the video is presented in slow-motion).

Animated scenes. For each of the scenes, a VR animation was created. For this, we selected the player in ball possession, the foul-committing player, and the fouled player as well as further players who are close to the situation (in total between four and seven animated players in each scene). The animation of scenes was made in Autodesk 3dsMax. All motions but the foul itself were animated by hand, using existing motion files (.bip) downloaded from Turbosquid (New Orleans,

C. Vater · U. Schnyder · D. Müller

That was a foul! How viewing angles, viewing distances, and visualization methods influence football referees' decision-making

Abstract

A football referee must choose the right position on the field in order to perceive a foul accurately. In previous research, decision-making for foul calls was compared across different situations within a match or even across different matches, which questions the comparability of decisions that often depend on the situational context. In this study, we experimentally controlled this situational context to investigate the effect of viewing distance and viewing angle on referees' decision-making. We recreated real-life decision-making situations using markerless tracking devices and virtual reality (VR) animation processes to render first-person situations. We compared the decision-making

accuracy of ten experienced football referees when judging situations from three different viewing angles and distances. Furthermore, we compared their decision-making accuracy in VR scenes with accuracy when viewing the same scenes from a bird's eye and slow-motion perspective, i.e., with the perspectives used in official referee training. We found that decision accuracy is not affected by viewing angles and distances, but that the referee's decision certainty is lower when viewing the foul situation from a greater distance. The visualization of the situations had an impact on the referee's decision-making but only for detecting a simulation (i.e., a player acts like they have been fouled). Slow-motion

scenes led to higher decision-making accuracy than VR scenes. Our study suggests a way to recreate VR situations for experimental studies, allowing researchers to control the context of each situation. Our findings help to disentangle the mixed findings of previous studies on distance and viewing angle effects on decision accuracies. Finally, we propose potential avenues to improve VR animation processes in future studies.

Keywords

Virtual reality · Soccer · Animation · Sport · Perception · Cognition

Das war ein Foul! Wie Blickwinkel, Betrachtungsdistanzen und Visualisierungsmethoden die Entscheidungen von Fußballschiedsrichtern beeinflussen

Zusammenfassung

Ein*e Fußballschiedsrichter*in muss die richtige Position auf dem Spielfeld wählen, um ein Foul korrekt wahrzunehmen. In früheren Studien wurde die Entscheidungsfindung für eine Foulentscheidung über verschiedene Situationen innerhalb eines Spiels oder sogar zwischen verschiedenen Spielen verglichen, was die Vergleichbarkeit der Entscheidungssituationen infrage stellt, da die Situationen vom jeweiligen Kontext abhängen. In der vorliegenden Studie wurde der Kontext jeder Entscheidungssituation experimentell kontrolliert, um die Auswirkungen der Betrachtungsdistanz und des Blickwinkels auf die Entscheidungsrichtigkeit von Schiedsrichtern zu untersuchen. Dazu wurden reale Entscheidungssituationen mithilfe von markerlosem Tracking und Virtual-Reality(VR)-Animationsverfahren nachgestellt, um Situationen in der Egoperspektive

darzustellen. Die Entscheidungsrichtigkeiten von 10 erfahrenen Schiedsrichtern bei der Beurteilung der Situationen aus 3 unterschiedlichen Betrachtungswinkeln und -distanzen wurden verglichen. Außerdem erfolgte ein Vergleich der Entscheidungsrichtigkeiten in VR-Szenen mit den gleichen Szenen aus der Vogelperspektive und in Zeitlupe (den beiden in der offiziellen Schiedsrichterausbildung verwendeten Perspektiven). Dabei stellte sich heraus, dass die Entscheidungsrichtigkeiten nicht durch Betrachtungswinkel- und -distanz beeinflusst werden, aber dass die Sicherheit der Schiedsrichterentscheidung geringer ist, wenn die Foulsituation aus einer größeren Entfernung betrachtet wird. Die Visualisierung der Situationen hatte ebenfalls einen Einfluss auf die Schiedsrichterentscheidung, jedoch nur für die Erkennung einer Simulation (d. h., Situationen in denen ein Spieler nur so tut,

als ob er gefoult worden wäre). Bei Szenen in Zeitlupe wurde eine höhere Entscheidungsrichtigkeit erkannt als in VR-Szenen. In dieser Arbeit wird vorgeschlagen, wie VR-Situationen für experimentelle Untersuchungen nachgestellt werden können und dabei den Kontext der einzelnen Situationen zu kontrollieren. Die vorliegenden Ergebnisse tragen dazu bei, die gemischten Ergebnisse vorheriger Studien zum Einfluss der Betrachtungsdistanz und des Blickwinkels auf die Entscheidungsrichtigkeit besser zu verstehen. Schließlich werden mögliche Wege zur Verbesserung von VR-Animationsprozessen in zukünftigen Studien vorgeschlagen.

Schlüsselwörter

Virtuelle Realität · Fußball · Animation · Sport · Wahrnehmung · Kognition

Louisiana, USA, www.turbosquid.com) or Mixamo (San Francisco, California, USA, www.mixamo.com). The foul itself was captured with a five-camera markerless motion-capture system (PlayStation Eye; frame rate: 60 Hz, resolution: 640 × 480 px), connected with two laptops (ASUS X556). The recordings were triggered through the iPi Recorder software (iPi Soft LLC, www.ipisoft.com).

It was ensured that at least three cameras captured all parts of the 7 m × 7 m area. In this area, two actors with long football experience played each of the 18 foul scenes until the foul mimicked the video scenario. It was emphasized to the actors that the speed and the (no) contact of the foul were the most important quality criteria. After the fouls were captured, they were imported to iPi

Mocap studio (iPi Soft LLC, Poway, California, USA, www.ipisoft.com) for post-processing, which included the filtering out of missing data and the cutting of the animation to the foul sequence. This foul sequence was then imported to 3dsMax and blended with the running motions, to create realistic animations (Fig. 2, left). After that, three different camera tracks were used to present the foul situa-



Fig. 1 ▲ Video example scene in bird's-eye view (a), slow-motion close-up view (b) and virtual reality view from 15 m with the view between players (c)

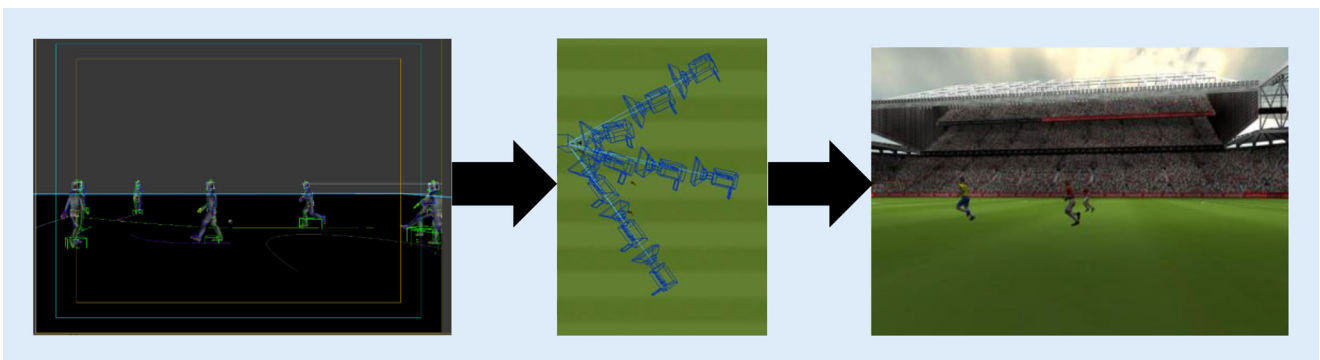


Fig. 2 ▲ Creation of virtual reality (VR) situations in 3dsMax. First, virtual players' movements were animated according to the real-life situations (*left image*). Second, three viewing angles and three viewing distances were animated while every camera perspective always focused on the foul situation (top-view perspective on the virtual camera positions; *middle image*). Third, rendering of VR scenes from all camera perspectives (*right image*)

tion from three different viewing angles. One viewing angle, which was considered optimal to judge scenes, is the one where the referee stands between both players involved in the foul (c.f., Hossner et al., 2019; Johansen & Erikstad, 2020; Schnyder & Hossner, 2016). We contrasted this “natural viewing angle” (view between players) with a perspective rotated 45° toward the defender making the foul (defender perspective) or 45° to the attacker who is fouled (attacker perspective). Furthermore, to test whether the distance to the foul matters, we used three different distances of the referee's viewing position to the foul (5 m, 15 m, or 25 m; see **Fig. 2**, middle). With this procedure, we created a total of 162 different scenes (18 situations × 3 viewing angles × 3 distances). Animations were rendered as video stimuli with a field of

view of 120° from the referee's perspective (**Fig. 2**, right). To reduce the recognizability between scenes, we randomly varied the color of the players' clothes, the virtual stadium, and the virtual weather conditions.

Procedure

After signing informed consent, participants were positioned 1.2 m from the screen to read the projected task instructions. The instructions and video stimuli were back-projected (projector: InFocus IN5110, Portland, USA) onto a large back-projection screen (height: 1.87 m; width: 3.01 m). Their task was to judge the scenes according to the officiating rules (no penalty, direct free kick, indirect free kick, penalty kick) and give personal penalties (no card, yellow card,

or red card). The 162 scenes were presented to participants in a randomized order in nine video blocks, each containing 18 video scenes. Participants' verbal responses were recorded in writing by the experimenter. After judging the VR situations, participants judged the bird's-eye and slow-motion perspective scenes, which were presented in randomized order. Participants made their decision by crossing their response on a paper-and-pencil questionnaire. The whole experiment lasted between 75 and 90 min per participant. Afterward, participants were thanked and debriefed.

Analyses

Decision accuracy was calculated as the number of correct responses for the following three decision-making categories:

foul decisions, play-on decisions, and simulation decisions (the player acts as being fouled and should be sanctioned with a yellow card). The number of correct decisions was then multiplied by 100 and divided by the number of scenes for the respective decision category (i.e., 162 animated scenes with 81 fouls, 54 play-on decisions, and 27 simulations or, for the second test, the 18 bird's-eye and 18 slow-motion videos which consisted of 9 foul situations, 6 play-on situations, and 3 simulations). While each of the animated situations was different (viewing angle and/or distance), we decided to not repeat the bird's-view and slow-motion videos so as to avoid learning effects. Consequently, the variance for the latter results can be expected to be much greater and results need to be interpreted with caution. To better understand whether personal penalties awarded were different in the match, we calculated the percentage of decisions for all possible decisions (play-on, simulation, foul no card, foul yellow card, foul red card).

Decision certainty was assessed for the VR situations. After every VR scene, participants indicated their decision certainty on a 6-point Likert scale ranging from 1 (*not certain at all*) to 6 (*fully certain*). We calculated the average decision certainty for the factors viewing angle and viewing distance.

We used repeated-measures ANOVAs for the two dependent variables (decision accuracy, decision certainty) using visualization (bird's-eye, slow-motion and animated), distance (5 m, 15 m, 25 m) and viewing angle (view attacker, view between, view defender) as within-subject factors in three separate ANOVAs and set the significance level to 0.05. For all data analyses and statistics, we used the R "afex" package (Singmann, Bolker, Westfall, Aust, & Ben-Shachar, 2023) for the repeated-measures ANOVAs and the "emmeans" package (Russell, 2019) for post hoc contrasts. We adjusted p values with the Holm method and, if the sphericity assumption was violated, Greenhouse-Geiser corrections were applied. Post hoc comparisons were Bonferroni adjusted. Effect sizes were calculated as partial eta squares. Due to

our predictions, we only tested post hoc differences for the same decision-making categories (e.g., fouls at 5 and 15 m) or within the same viewing angles or distances (e.g., foul at 5 m vs. simulation at 5 m). For plotting the data, we used the "papaja" (Aust & Barth, 2020), "bookdown" (Xie, 2020) and "rmarkdown" package (Allaire et al., 2020). Plots show the individual participant data, the mean of all participants, and the 95% within-subject confidence intervals.

Results

Distance

There was a significant main effect for the decision category, $F(1.73, 15.55) = 67.99$, $p < 0.001$, $\widehat{\eta}_p^2 = 0.883$, indicating better decision accuracies for fouls than for play-on and simulation situations. There was no main effect for distance, $F(1.52, 13.64) = 1.63$, $p = 0.230$, $\widehat{\eta}_p^2 = 0.153$, but a significant interaction between the decision category and the distance, $F(2.55, 22.94) = 8.79$, $p = 0.001$, $\widehat{\eta}_p^2 = 0.494$. The results show that accuracy was higher when judging fouls at 5 m compared to simulations, and that fouls viewed from a 15-m distance were judged more accurately than play-on situations and simulations. Moreover, at a 25-m viewing distance, fouls were better judged than play-on situations and simulations, and play-on situations were better judged than simulations (all significant post hoc contrasts within the same decision category or for the same distance are shown in [Fig. 3a](#)).

There were significant decision certainty main effects for the decision category, $F(1.49, 13.37) = 9.47$, $p = 0.005$, $\widehat{\eta}_p^2 = 0.513$, and for the distance, $F(1.17, 10.53) = 55.85$, $p < 0.001$, $\widehat{\eta}_p^2 = 0.861$. These main effects are overwritten by a significant interaction effect between the two factors, $F(2.86, 25.75) = 3.76$, $p = 0.025$, $\widehat{\eta}_p^2 = 0.295$. The interaction shows that the certainty of all decision situations was significantly higher at 5 and 15 m compared to 25 m. Moreover, judgment certainty was significantly higher for foul situations compared to play-on at 15-m viewing distance only and play-

on decisions were significantly more accurate at 5-m distance compared to 15-m distance (all significant post hoc contrasts within the same decision category or for the same distance are shown in [Fig. 3b](#)).

Viewing angle

There was a significant main effect for the decision category, $F(1.73, 15.55) = 67.99$, $p < 0.001$, $\widehat{\eta}_p^2 = 0.883$. Post-hoc analyses revealed that from all viewing angles, fouls were judged significantly more accurately than play on situations $t(9) = 6.76$, $p_{\text{Bonferroni}(3)} < 0.001$, and that foul situations were judged significantly more accurate compared to simulations $t(9) = 5.40$, $p_{\text{Bonferroni}(3)} = 0.001$. However, decision accuracy for play-on situations was not different than decision accuracy for simulations $t(9) = 1.96$, $p_{\text{Bonferroni}(3)} = 0.244$. There was neither an effect for viewing angle, $F(1.85, 16.66) = 0.26$, $p = 0.760$, $\widehat{\eta}_p^2 = 0.028$, nor an interaction between decision category and viewing angle, $F(2.61, 23.50) = 1.15$, $p = 0.346$, $\widehat{\eta}_p^2 = 0.113$ (see [Fig. 4a](#)).

There was a significant decision certainty main effect for the decision category, $F(1.49, 13.37) = 9.47$, $p = 0.005$, $\widehat{\eta}_p^2 = 0.513$. Participants showed a significantly higher decision certainty when judging foul situations than play-on situations, $t(9) = 3.27$, $p_{\text{Bonferroni}(3)} = 0.029$ and when judging simulations compared to play-on situations, $t(9) = 3.41$, $p_{\text{Bonferroni}(3)} = 0.023$. There were no certainty differences between fouls and simulations, $t(9) = 0.61$, $p_{\text{Bonferroni}(3)} > 0.999$. There was no main effect for viewing angle, $F(1.68, 15.09) = 1.22$, $p = 0.315$, $\widehat{\eta}_p^2 = 0.119$, but a significant interaction, $F(2.30, 20.67) = 5.99$, $p = 0.007$, $\widehat{\eta}_p^2 = 0.399$. The interaction shows that decision certainty was significantly higher for fouls than for play-on situations when referees view situations from the direction of the defender (see [Fig. 4b](#)).

In additional post hoc analyses, participants' overall decision accuracy across all viewing angles and distances was correlated with decision certainty. The results show that incorrect decisions are asso-

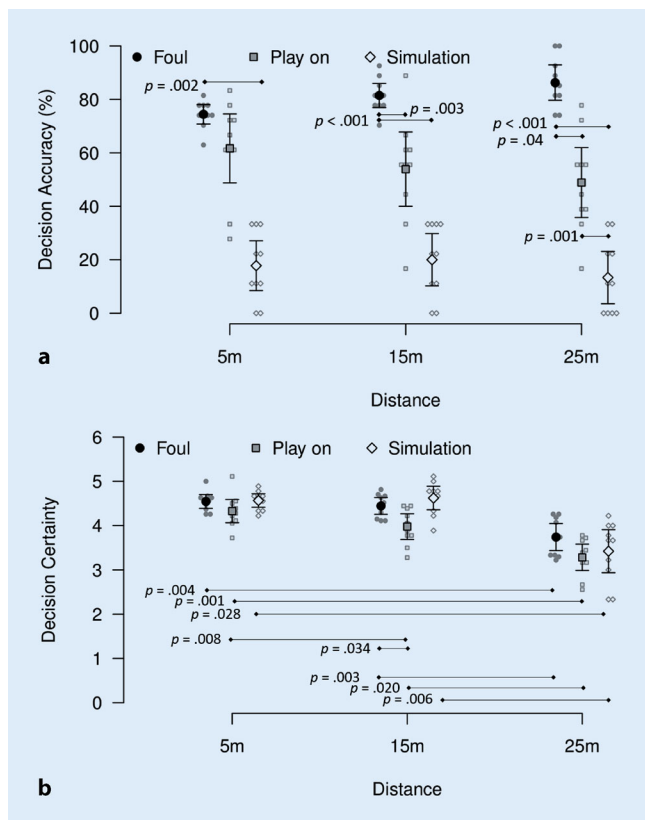


Fig. 3 ▲ a Decision accuracy for the three viewing distances and separately for the three different decision categories. b Decision certainty for the three viewing distances

ciated with lower certainties ($r^2 = 0.42$) but that there is no correlation between correct decisions and decision certainty ($r^2 = 0.01$). This could indicate that referees notice when their decision may not have been correct and indicate this with a lower certainty. In general, certainty was higher for correct ($M = 4.25$, $SD = 0.21$) than for incorrect decisions ($M = 3.85$, $SD = 0.34$), which is significantly different when applying a one-sided paired t test ($p = 0.001$).

Visualization

There was a significant main effect for visualization, $F(1.83, 16.49) = 23.93$, $p < 0.001$, $\widehat{\eta}_p^2 = 0.727$, indicating significantly better decision accuracies for slow-motion videos than for animated and real videos. A main effect for the decision categories, $F(1.47, 13.26) = 22.94$, $p < 0.001$, $\widehat{\eta}_p^2 = 0.718$, shows that fouls were identified with a significantly higher accuracy than play-on and simulation sit-

uations. There was also a significant interaction between visualization and decision categories, $F(2.84, 25.56) = 9.24$, $p < 0.001$, $\widehat{\eta}_p^2 = 0.507$. While fouls were judged significantly more accurate than play-on situations in all three visualizations, fouls were judged with a significantly higher accuracy than simulations in the animated visualization only. Interestingly, simulations were identified significantly more accurately than the slow motion in the animated visualization, but simulations were not better identified in the real videos compared to the animated videos (all significant post hoc contrasts within the same visualization or for the same decision category are shown in **Fig. 5**).

For a better understanding of participants' technical and disciplinary decisions (c.f., Spitz et al., 2017), we created a decision matrix comparing participants' decisions in the simulated visualization and real-life decisions from the original match (columns) and the participants de-

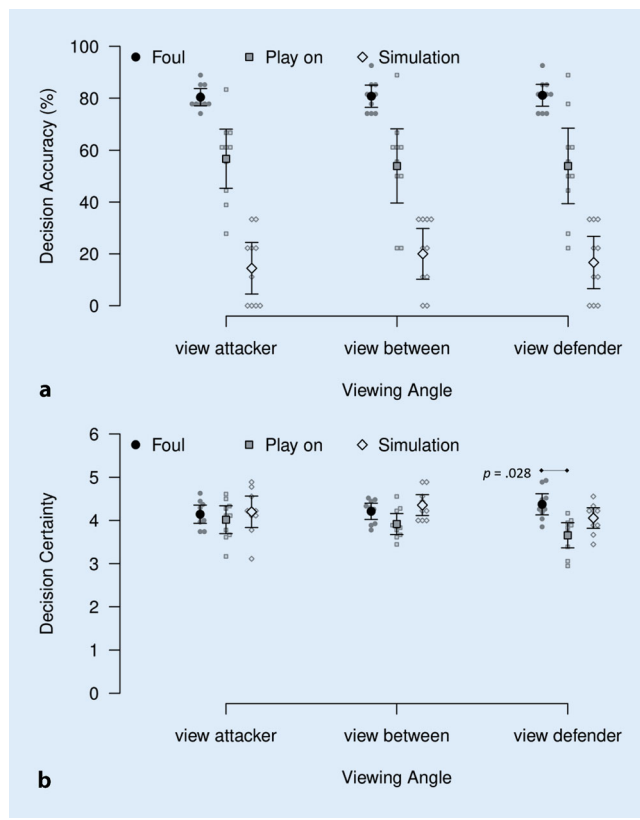


Fig. 4 ▲ a Decision accuracy (M, 95% confidence interval, individual data points) for the three viewing distances and separately for the three different decision categories. b Decision certainty (M, 95% confidence interval, individual data points) for the three viewing angles

cisions (lines) in **Table 1**. The personal penalties given for a foul deviated from the solution of the referee in the real match. For example, when the real referee decided that it was a foul but without giving a personal penalty, the same decision was only made in 27.41% of cases in VR. Instead, participants mostly decided that it was no foul and that the game should continue ("play-on"; 46.67%). Participants were more in line with the real-match decisions if a penalty was awarded (yellow or red card). For yellow card situations, participants made the same decision in VR in 61.11% of cases. Interestingly, in these yellow card scenarios, they gave a red card in 21.8% of cases, which indicates that fouls were judged as more serious in VR than in real matches. The opposite was the case for red card scenarios in real matches. Here, participants awarded a red card in 30.86% of all cases while they decided to give a yellow card in 62.83% of all cases. Most play-on scenarios in real matches were similarly

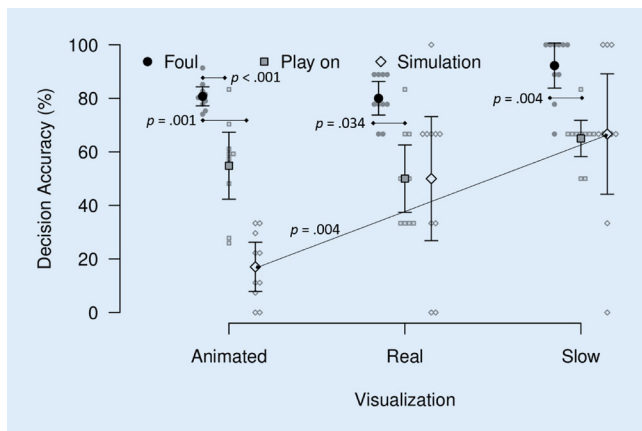


Fig. 5 ◀ Decision accuracy (M, 95% confidence interval, individual data points) for the three decision-making categories and the three visualization methods

judged in VR (54.56%). The greatest deviation from the actual decisions in real matches was observed for simulations. In only 16.73% of all cases, it was judged as a simulation in VR. In most of these scenarios, a play-on decision (38.29%) or a decision that it was a foul with no personal penalty (30.11%) was made.

Discussion

Football referees are required to anticipate fouls and position themselves at an optimal distance and angle. So far, researchers have compared the effects of viewing distance and viewing angle for different foul scenarios or even across different matches. In this study, we compared decision accuracies of football referees for the same situations from different viewing distances and angles using animated VR scenes and comparing decision accuracies between different visualizations (bird's-eye, slow-motion, and animated first-person perspective). Our results indicate that viewing distance and perspective did not affect decision-making accuracy in general, but that decision certainty is lower at large distances. When looking into the different decision categories (foul, play-on, simulation) for the different visualizations, foul decisions can be judged at similar accuracies from all three viewing perspectives. However, to accurately judge simulations, referees seem to need the close-up slow-motion view.

Previous research indicates that most foul situations are judged at a distance between 10 and 15 m (Hossner et al., 2019). There are, however, mixed results

on the optimal distances for a high decision accuracy. While one study shows that referees have the highest accuracies when viewing the situation from 11 to 15 m (Mallo et al., 2012), another reports an optimal distance between 20 and 25 m (DeOliveira et al., 2011). The study by Mallo et al. (2012) suggests that there is an optimal viewing distance and that a too-close positioning (i.e., < 11 m) and a too-far positioning (i.e., more than 20 m) leads to higher error rates. In previous studies, decision accuracy was compared for different foul situations even across games. Our study is the first to compare the same foul situations from different distances. Our results indicate that there is no general distance effect on decision accuracy but that it depends on the kind of decision-making scenarios. While there was no difference between foul and play-on decisions at 5-m distance, play-on decision accuracies were significantly lower than foul decision accuracies at 15 and 25 m. The lowest accuracies were observed for the detection of simulations, regardless of the viewing distance. These results indicate that closer distances might be beneficial to make correct play-on decisions (i.e., to judge whether there was a contact between the player who fouled and the one who was fouled).

For viewing distance, we also found that decision certainty is much lower at 25 m compared to 5 and 15 m, regardless of the decision situation. In a post hoc analysis we also found that decision certainty is higher for incorrect decisions than for correct decisions and that certainty is only correlated with incorrect de-

isions (i.e., the more incorrect decisions were made, the higher the uncertainty). Since decision certainty can be an important factor, especially given that decisions must be made under time and social pressure (Samuel et al., 2021), referees should be able to position themselves at up to 15 m from the critical decision event. One explanation for lower certainties could be that foveal vision cannot be used as much as it is needed because the foul itself is too far away and the details (i.e., if there was a contact between players or not; c.f. Spitz et al., 2016) are difficult to process foveally (Klostermann et al., 2020; Vater et al., 2020).

While referees are trained to have a perfect viewing angle (i.e., to look between players) when judging a foul situation, an empirical study indicates that the viewing angle has no effect on decision-making accuracies (Hossner et al., 2019). In our study, we assumed that the referees in real matches position themselves in an optimal manner and contrasted their natural viewing angle (view between players) with a perspective rotated 45° toward the defender making the foul (defender perspective) or 45° to the attacker who is fouled (attacker perspective). Our results showed that there is no decision accuracy difference and no meaningful decision certainty difference between the three viewing angles. Thus, our results are in line with the study by Hossner et al. (2019) and suggest that referees are able to judge foul scenarios from different viewing perspectives. As for the viewing distance, decision accuracies were higher for foul decisions than for play-on decisions and higher for play-on decisions than for simulation decisions at all viewing angles.

So far, no study has compared decision accuracies for the same situation visualized from a bird's-eye view, slow-motion, and animated first-person view. Our results show that decision accuracy is similar for VR scenes and real (bird's-eye view) scenes, but that slow-motion scenes were judged more accurately than the other two visualizations. Previous research on decision-making in football players indicated that different visual information is processed from an aerial (bird's-eye view) perspective compared

Table 1 Cumulated decisions (*columns*) for each of the five manipulated scenarios (*rows*)

	Play on	Simulation	Foul, no card	Foul, yellow card	Foul, red card
<i>Play-on</i>	293 (54.56%)	103 (38.29%)	126 (46.67%)	23 (8.52%)	4 (1.49%)
<i>Simulation</i>	4 (0.74%)	45 (16.73%)	1 (0.37%)	1 (0.37%)	0 (0%)
<i>Foul, no card</i>	118 (21.97%)	81 (30.11%)	74 (27.41%)	23 (8.52%)	13 (4.83%)
<i>Foul, yellow card</i>	107 (19.93%)	40 (14.87%)	61 (22.59%)	165 (61.11%)	169 (62.83%)
<i>Foul red card</i>	15 (2.79%)	0 (0%)	8 (2.96%)	58 (21.48%)	83 (30.86%)

Values in bold indicate when the real-life decision matched the VR decision

to a first-person perspective and that this can impact decision accuracy (Mann et al., 2009). Since this previous study found higher accuracies for their aerial view perspective, one could argue that this information would also be beneficial for referees in replay situations to improve their judgments. The findings are in line with the finding that slow-motion replay facilitates judgment calls between yellow and red cards (Mather & Breivik, 2020). In combination with close-up views, as often provided in broadcast footage, it can be assumed that referees are able to achieve higher decision accuracies compared to having only the real-time viewing condition (Spitz et al., 2017). This could potentially be explained by longer processing times of important visual cues (Mann et al., 2007).

That we do not find differences between the animated first-person VR and the real-life (bird's-eye view) videos could be interpreted as support for the ecological validity of VR scenes. However, one should be cautious with this because re-building the dynamics of players' movements in VR is technologically challenging. Future studies should use position data obtained from competitions (Thomas, Gade, Moeslund, Carr, & Hilton, 2017; van Biemen et al., 2023). Ideally, the positional data come in 3D format and include joint body positions. If 2D positional data are available, algorithmic solutions can help recreate natural movements in VR (e.g., by using "Distance Matching," "Motion Matching," "Speed Warping," and "Orientation Warping" techniques); however, the challenge of recreating the foul collisions realistically remains.

Nevertheless, if these difficulties can be overcome, VR animations can be a useful research and training tool because it is possible to keep the context of a decision situation the same but only change details of the foul (e.g., if there is a foul contact or not), if a player is in an offside position or not, or manipulate the "realness" of a simulation. Moreover, other factors such as crowd noise could be manipulated. For example, the crowd could be included when noise is present and removed in a silent condition to increase stimulus validity compared to previous studies (Nevill, Balmer, & Williams, 2002; Unkelbach & Memmert, 2010). Thus, this experimental control over the context of the situation cannot be achieved in real life.

Our results also show that referees are very accurate in judging whether there was a foul or not. However, the decision about personal penalties varied considerably. In cases where the referee in the real match awarded a red card, for example, our participants awarded a red card in 31% and a yellow card in 63% of the cases. A similar trend was observed for yellow cards. In the recreated VR scenes, 61% of the decisions were in line with the real-match decision while in 20% of decisions, a red card was given. That the personal penalties awarded by referees viewing fouls from bird's-eye view and in slow-motion are often different to the real decisions was reported in a previous study by Spitz et al. (2017). Our results extend this result to animated VR situations.

Limitations

Using VR to recreate the foul situations also comes with limitations. First, it is very time consuming in the case of foul situations. In our case, the fouls had to be practiced and simulated in a sports hall. Capturing these movements and post-processing the recordings to export smooth movement trajectories also requires a considerable effort. It cannot be ruled out that the animated foul scenarios vary in some way (e.g., in terms of kinematic cues) from the real scenarios although they have been inspected by an experienced football referee. Another limitation comes with the manipulation of viewing perspectives. It must be clear that changing the viewing perspective may impact which visual information can be processed over time (e.g., there might be spatial occlusions by other players from one but not from another perspective or different effects of crowding; Strasburger, 2020). The very low decision accuracies for simulations should be interpreted cautiously. In a real game, the referee often has difficulties to identify a simulation because of the deceptive intent of the fouled player (van Biemen, Koedijker, Renden, & Mann, 2018). In our study, 38% of the simulations were judged with play-on and 30% with a foul (i.e., the referee believed the simulating player that it was a foul). To increase the detection of simulations, additional training with a specific focus on kinematic cues could increase decision-making accuracy (van Biemen et al., 2018). Additionally, referees must be able "to put themselves into the specific situation" (Pizzera & Raab, 2012). Another limitation of our study is the small sample size. We decided to only include referees with a decent level of experience and consequently accept a lower number of participants. Future studies should also counterbalance the different visualizations to control for learning effects (which we did not observe). We decided to always show the animations first, because we expected that participants could remember the slow-motion close-up view, which would give them an advantage for judging the animations. Moreover, future studies could use VR situations in a more

immersive way, for example, by using head-mounted displays (HMDs) instead of the large video projection used in this study (e.g., DeCouto, Fawver, Thomas, Williams, & Vater, 2024).

Conclusion

In conclusion, we showed that referees' decision-making is influenced by the viewing distance but not by the viewing angle onto critical decision-making situations. Our results also show that best decision accuracies can be achieved by presenting the referee with slow-motion videos. Using animated virtual reality (VR) situations is a promising approach for future decision-making studies because the same situation can be presented from a first-person perspective from different viewing angles and distances. Future studies could manipulate other factors that might impact decision-making in VR (crowd noise, visual blur, peripheral masking etc.) to better understand which factors impact the decision-making of referees.

Corresponding address



Prof. Dr. Christian Vater
Institute of Sport Science,
University of Bern
Bremgartenstrasse 145,
3012 Bern, Switzerland
christian.vater@unibe.ch

Author Contribution. All authors contributed to the study conception and design. Material preparation and data collection were performed by all authors. The data analysis was carried out by Dr. Christian Vater. The first draft of the manuscript was written by Dr. Christian Vater and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding. Open access funding provided by University of Bern

Declarations

Conflict of interest. C. Vater, U. Schnyder and D. Müller declare that they have no competing interests.

The study has been approved by the local ethics committee and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All persons gave their informed consent prior to their

inclusion in the study. Details that might disclose the identity of the subjects under study were omitted.

Open Access. This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Allaire, J. J., Xie, Y., McPherson, J., Luraschi, J., Ushey, K., Atkins, A., Wickham, H., Cheng, J., Chang, W., & Iannone, R. (2020). rmarkdown: Dynamic documents for R. <https://CRAN.R-project.org/package=rmarkdown>
- Aust, F., & Barth, M. (2020). papaja: Prepare reproducible APA journal articles with R Markdown. <https://github.com/crsh/papaja>
- Avugos, S., MacMahon, C., Bar-Eli, M., & Raab, M. (2021). Inter-individual differences in sport refereeing: A review of theory and practice. *Psychology of Sport and Exercise*, 55, 101926. <https://doi.org/10.1016/j.psychsport.2021.101926>
- Brams, S., Ziv, G., Levin, O., Spitz, J., Wagemans, J., Williams, A. M., & Helsen, W. F. (2019). The relationship between gaze behavior, expertise, and performance: A systematic review. *Psychological Bulletin*. <https://doi.org/10.1037/bul0000207>
- Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *European Journal of Sport Science*, 15(4), 322–331. <https://doi.org/10.1080/17461391.2014.957727>
- Caruso, E. M., Burns, Z. C., & Converse, B. A. (2016). Slow motion increases perceived intent. *Proceedings of the National Academy of Sciences of the United States of America*, 113(33), 9250–9255. <https://doi.org/10.1073/pnas.1603865113>
- DeCouto, B. S., Fawver, B., Thomas, J. L., Williams, A. M., & Vater, C. (2024). The role of peripheral vision during decision-making in dynamic viewing sequences. *Journal of Sports Sciences*, 41(20), 1852–1867. <https://doi.org/10.1080/02640414.2023.2301143>
- DeOliveira, M. C., Orbetelli, R., & Neto, T. L. D. B. (2011). Call accuracy and distance from the play: A study with Brazilian soccer referees. *International Journal of Exercise Science*, 4(1), 30–38.
- Helsen, W., Gilis, B., & Weston, M. (2006). Errors in judging "offside" in association football: Test of the optical error versus the perceptual flash-lag hypothesis. *Journal of Sports Sciences*, 24(5), 521–528. <https://doi.org/10.1080/02640410500298065>
- Hossner, E.-J., Schnyder, U., Schmid, J., & Kredel, R. (2019). The role of viewing distance and viewing angle on referees' decision-making performance during the FIFA World Cup 2014. *Journal of Sports Sciences*, 37(13), 1481–1489. <https://doi.org/10.1080/02640414.2019.1570898>
- Janssen, T., Müller, D., & Mann, D. L. (2023). From natural towards representative decision making in sports: a framework for decision making in virtual and augmented environments. *Sports Medicine*, 53(10), 1851–1864. <https://doi.org/10.1007/s40279-023-01884-3>
- Johansen, B. T., & Erikstad, M. K. (2020). A preliminary analysis of the importance of distance, angle, and insight when soccer referees make penalty decisions. *Frontiers in Sports and Active Living*, 2, 595703. <https://doi.org/10.3389/fspor.2020.595703>
- Klostermann, A., Vater, C., Kredel, R., & Hossner, E.-J. (2020). Perception and action in sports. On the functionality of foveal and peripheral vision. *Frontiers in Sports and Active Living*, 1, 66. <https://doi.org/10.3389/fspor.2019.00066>
- Mallo, J., Frutos, P. G., Juárez, D., & Navarro, E. (2012). Effect of positioning on the accuracy of decision making of association football top-class referees and assistant referees during competitive matches. *Journal of Sports Sciences*, 30(13), 1437–1445. <https://doi.org/10.1080/02640414.2012.711485>
- Mann, D. L., Farrow, D., Shuttleworth, R., Hopwood, M., & MacMahon, C. (2009). The influence of viewing perspective on decision-making and visual search behaviour in an invasive sport. *International Journal of Sport Psychology*, 40(4), 546–564.
- Mann, D. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, 29(4), 457–478. <https://doi.org/10.1123/jsep.29.4.457>
- Mather, G., & Breivik, S. (2020). Is the perception of intent by association football officials influenced by video playback speed? *Royal Society Open Science*, 7(6), 192026. <https://doi.org/10.1098/rsos.192026>
- Nevill, A., Balmer, N., & Williams, A. M. (2002). The influence of crowd noise and experience upon refereeing decisions in football. *Psychology of Sport and Exercise*, 3(4), 261–272. [https://doi.org/10.1016/S1469-0292\(01\)00033-4](https://doi.org/10.1016/S1469-0292(01)00033-4)
- Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology*, 33(1), 146–155. <https://doi.org/10.1123/jsep.33.1.146>
- Pizzera, A., & Raab, M. (2012). Perceptual judgments of sports officials are influenced by their motor and visual experience. *Journal of Applied Sport Psychology*, 24(1), 59–72. <https://doi.org/10.1080/10413200.2011.608412>
- Plessner, H., Schweizer, G., Brand, R., & O'Hare, D. (2009). A multiple-cue learning approach as the basis for understanding and improving soccer referees' decision making. In M. Raab, J. G. Johnson & H. R. Heekeren (Eds.), *Progress in brain research: mind and motion: the bidirectional link between thought and action* (Vol. 174, pp. 151–158). Elsevier. [https://doi.org/10.1016/S0079-6123\(09\)01313-2](https://doi.org/10.1016/S0079-6123(09)01313-2)
- Russell, L. V. (2019). emmeans: Estimated marginal means, aka least-squares means. <https://CRAN.R-project.org/package=emmeans>
- Samuel, R. D., Tenenbaum, G., & Gally, Y. (2021). An integrated conceptual framework of decision-making in soccer refereeing. *International Journal of Sport and Exercise Psychology*, 19(5),

- 738–760. <https://doi.org/10.1080/1612197X.2020.1766539>.
- Schnyder, U., & Hossner, E.-J. (2016). Psychological issues in football officiating: An interview study with top-level referees. *Current Issues in Sport Science*, 1, 4. https://doi.org/10.15203/CISS_2016.004.
- Schweizer, G., Plessner, H., & MacMahon, C. (2023). Judgment and decision-making. In J. Schüler, M. Wegner, H. Plessner & R. C. Eklund (Eds.), *Sport and exercise psychology* (pp. 93–115). Cham: Springer. https://doi.org/10.1007/978-3-031-03921-8_5.
- Singmann, H., Bolker, B., Westfall, J., Aust, F., & Ben-Shachar, M. S. (2023). afex: Analysis of Factorial Experiments. <https://CRAN.R-project.org/package=afex>
- Spitz, J., Put, K., Wagemans, J., Williams, A. M., & Helsen, W. F. (2016). Visual search behaviors of association football referees during assessment of foul play situations. *Cognitive Research: Principles and Implications*, 1(1), 12. <https://doi.org/10.1186/s41235-016-0013-8>.
- Spitz, J., Put, K., Wagemans, J., Williams, A. M., & Helsen, W. F. (2017). Does slow motion impact on the perception of foul play in football? *European Journal of Sport Science*, 17(6), 748–756. <https://doi.org/10.1080/17461391.2017.1304580>.
- Spitz, J., Wagemans, J., Memmert, D., Williams, A. M., & Helsen, W. F. (2021). Video assistant referees (VAR): The impact of technology on decision making in association football referees. *Journal of Sports Sciences*, 39(2), 147–153. <https://doi.org/10.1080/02640414.2020.1809163>.
- Strasburger, H. (2020). Seven myths on crowding and peripheral vision. *I-Perception*, 11(3), 1–46. <https://doi.org/10.1177/2041669520913052>.
- Thomas, G., Gade, R., Moeslund, T. B., Carr, P., & Hilton, A. (2017). Computer vision for sports: Current applications and research topics. *Computer Vision and Image Understanding*, 159, 3–18. <https://doi.org/10.1016/j.cviu.2017.04.011>.
- Travassos, B., Araújo, D., Davids, K., O'Hara, K., Leitão, J., & Cortinhas, A. (2013). Expertise effects on decision-making in sport are constrained by requisite response behaviours—A meta-analysis. *Psychology of Sport and Exercise*, 14(2), 211–219. <https://doi.org/10.1016/j.psychsport.2012.11.002>.
- Unkelbach, C., & Memmert, D. (2010). Crowd noise as a cue in referee decisions contributes to the home advantage. *Journal of Sport and Exercise Psychology*, 32(4), 483–498. <https://doi.org/10.1123/jsep.32.4.483>.
- van Biemen, T., Koedijker, J., Renden, P. G., & Mann, D. L. (2018). The effect of blurred perceptual training on the decision making of skilled football referees. *Frontiers in Psychology*, 9, 1803. <https://doi.org/10.3389/fpsyg.2018.01803>.
- van Biemen, T., Müller, D., & Mann, D. L. (2023). Virtual reality as a representative training environment for football referees. *Human Movement Science*, 89, 103091. <https://doi.org/10.1016/j.humov.2023.103091>.
- Vater, C., Williams, A. M., & Hossner, E.-J. (2020). What do we see out of the corner of our eye? The role of visual pivots and gaze anchors in sport. *International Review of Sport and Exercise Psychology*, 13(1), 81–103. <https://doi.org/10.1080/1750984X.2019.1582082>.
- Vater, C., Gray, R., & Holcombe, A. O. (2021). A critical systematic review of the Neurotracker perceptual-cognitive training tool. *Psychonomic Bulletin and Review*, 28(5), 1458–1483. <https://doi.org/10.3758/s13423-021-01892-2>.
- Williams, A. M., Huys, R., Cañal-Bruland, R., & Hagemann, N. (2009). The dynamical information underpinning anticipation skill. *Human Movement Science*, 28(3), 362–370. <https://doi.org/10.1016/j.humov.2008.10.006>.
- Xie, Y. (2020). bookdown: authoring books and technical documents with R markdown. <https://CRAN.R-project.org/package=bookdown>

Publisher's Note. Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.