Human Kinetics

CASE STUDY

Using Mobile 360° Video as a Tool for Enhancing Sport Referee Performance: A Case Study

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Many new video-based technologies (e.g., eye trackers, point-of-view camera) have been integrated into sport referee performance monitoring and training. Mobile 360° video (an omnidirectional video capture tool affixed on the referee during their performance using a chest harness) provides moving images recorded from a first-person perspective. This case study explored rugby union referees' and referee coaches' engagement with mobile 360° video during a viewing situation of another referee's performance. An analysis of the referees' and referee coaches' cognitive activity (interests, concerns, noticing, and knowledge) during a viewing of this mobile 360° video was elicited through an other-confrontation interview approach. Participants experienced heightened immersion in the situation as well as enhanced discovery and noticing behavior, and they constructed different types of embodied and corporeal knowledge. Using a rugby union setting, this occurred through enhanced perceptual involvement provided by mobile 360° video for reflection on referee positioning and movement, contextual inference about decisions, and sensitivity to player cues and interactions. This study provides preliminary evidence for the utility and acceptability of mobile 360° video as a pedagogical innovation in referee training to enhance referees' decision making, game management, and reflexivity. Limitations, challenges, and applications of immersive mobile 360° video as a pedagogical tool in rugby union refereeing and other sports are discussed.

Keywords: immersive experience, training, development, embodied knowledge

Sport officials (i.e., referees, umpires, judges) occupy a crucial role in the regulation and facilitation of sport games and competitions globally. Their decisions, actions, and communication impact on players' safety, performance, and other match outcomes. Much research has focused on higher order skills and characteristics of elite sport officials, with less also focusing on how to develop, practice, and apply these attributes (Cunningham et al., 2022; Hancock et al., 2021). With an abundance of research into superior performance attributes of athletes and understanding about broad methods to enhance their sport-specific performance skills (Schenk & Miltenberger, 2019), it is only within the past two decades that evidence-based training tools aimed to improve sport official performance have evolved. Officiating training environments are not "practice rich," with physical conditioning and technical learning activities and discussions often dominating practice hours for sport officials (e.g., football; McEwan et al., 2022). Deliberate practice hours could be enriched with virtual practice activities to develop knowledge and understanding to potentially transform and improve on-field/court officiating practice (Boyer et al., 2023; van Biemen et al., 2023). This case study evaluates the use of immersive video technologies by sport referees and referee coaches (RC) to develop recommendations for new approaches to strengthen off-field referee training practices and develop on-field psychological attributes and performance skills in this essential sport population.

Despite the challenges of training, monitoring, and evaluating sport referees' performance, their support mechanisms have evolved considerably with the advent of new technologies (Livingston et al., 2022). GPS and physical tracking systems have been used to understand sport referees' in-game physical movements (Emmonds et al., 2015), which has informed new ways for treating physical fitness and conditioning programming. Decision making is identified as one of the most important performance skills in sport referees (Morris & O'Connor, 2017; Nazarudin et al., 2015). As such, video-based approaches have become a common means to train and assess perceptual–cognitive skills (Kittel et al., 2019), and we have seen the use of eye-tracking technologies to understand expertise differences in visual gaze behavior (Hancock & Ste-Marie, 2013; Moore et al., 2019). Other studies have used two-dimensional (2D) video manipulations to provide off-field training tools to help sport officials develop better reasoning and intuitive responses to decision events (Larkin et al., 2018; Mascarenhas et al., 2005). To enhance the representativeness of off-field training to that of actual game conditions, Kittel et al. (2019) had Australian rules football umpires complete video-based decision tests under physical fatigue during high-intensity physical training sessions. Also, virtual reality options to video-based methods offer a computer-simulated decision scenario through three-dimensional video, which has been recently trialed to train football referees (Gulec et al., 2019; van Biemen et al., 2023). Establishing better ways to utilize existing video-based technologies to not only develop referee decision making but also to mentally prepare them for their performance, enhance psychological skills, and improve other key performance areas (i.e., law application, field positioning, communication, and game management) would be greatly welcomed by referees and RCs at different levels.

The Case

Recommendations provided by a review on sport official decision-making training research (Kittel et al., 2021) identified that

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representative designs are generally absent (to build on traditional, passively engaged video-based approaches) as well as a lack of direct assessment of the transfer of skills derived from video training to actual on-field performance. 360° video offers an innovative tool to consider for training decision making and other performance enhancement aspects in sport officials. 360° videos, also called immersive videos or spherical videos (Kosko et al., 2021), are video recordings in which a view in every direction is recorded at the same time using a specific camera with a fish-eye lens (Wohl, 2019). 360° video has been used in different domains to provide a means for practitioners to immerse in an extended reality of their practice environments. This has led to new forms of video-based, reflective practices to improve teaching (Roche et al., 2021; Theelen et al., 2019), to enhance situation awareness in firefighters (Sarkar et al., 2022), to learn safety procedures in climbing (Gänsluckner et al., 2017), and to reduce fear of water and aquaphobia (Roche et al., 2022) and has recently extended into teaching motor skills in sport (Paraskevaidis & Fokides, 2020). The potential benefits shown to exist in other domains, such as improved classroom noticing skills in teachers (Kosko et al., 2021), suggest that 360° video has the potential to improve sport official decision making by enhancing their attention to key perceptual information, as one example. This is said to be due to 360° video's ability to offer an increased perceptual capacity by raising the user's awareness to a broader array of information in a scenario when compared with 2D video (Ferdig et al., 2020). As a consequence, a type of contextual noticing for relevant decision cues by sport officials[1] could be deemed a perceptual–cognitive skill in their decision making worth better training. 360° video studies have used different formats of viewing, such as laptop or head-mounted display (HMD); however, across different formats, participants acknowledge a heightened embodiment (i.e., feelings for bodily aspects or motor behavior) and immersive experience that cannot otherwise be gained from 2D video alone in their practice context (Ferdig & Kosko, 2020).

A few studies have now begun to investigate sport officials' use of 360° video. The first approach has been made by Kittel et al. (2021), who provided initial evidence for the ecological validity and relevance of this tool for improving decision making in isolated decision scenarios with Australian rules football umpires. 360° video cameras were situated on the perimeter of a playing area of small games to capture recordings and compare against 2D recordings from an alternative perspective (i.e., a raised, "broadcast view"). For the 360° video viewing group, HMD was used to project the video for the umpires to watch and decide on decision situations. Compared with a group of umpires receiving no training, the research found that 360° video significantly improved decision-making accuracy in umpires when measured 4 weeks following the training intervention. Furthermore, the 360° video training intervention demonstrated higher ratings from umpires in enjoyment, relevance, and video fidelity compared with 2D video (Kittel et al., 2021).

Although there has been a surge in the use of point-of-view cameras (POV) in sport officiating training, which allows mobile capture of the referee's performance, it can often provide only a narrow scope of view. It has been suggested that mobile approaches to 360° video capture could provide moving images that give a more unique perspective and better immersion in performance (Boyer et al., 2023; Kittel et al., 2022). Head- or body-mounted mobile approaches to capturing 360° video (where one or more 360° video cameras are affixed on the referee using a chest or head harness) to be used for training and reflective practices have yet to

be tested as a potential performance enhancement tool. The utility of using first-person viewpoints within video-based reflections on referee performance is supported by the original work of Rix-Lièvre (2010), who used head-mounted referee recordings within interview methods to help them relive their situated subjective perspective. More recently, Boyer et al. (2023) identified specific benefits of the mobile 360° video capture approach by harnessing cameras on a soccer referee and later using recorded video sequences in HMD-reflective protocols with officials from different sports (soccer, rugby, and handball). Interestingly, they discovered many benefits for officials' reflectivity skills when observing another official's performance through this viewing perspective, particularly an increase in "empathetic immersion" (p. 8) for the viewed soccer official's activity. The findings provide preliminary evidence for a more representative learning tool in mobile 360° video use in training.

The role of embodied cognition and construction of mental representations of performance is one underlying set of processes that underpin learning and reflection through mobile 360° video use. Embodied cognition challenges conventional notions about cognition on action (Raab & Araujo, 2019). Cognition is embodied (in a body) and embedded (in a context) so that environmental information related to spatiotemporal characteristics helps to define goal-directed action (Richardson et al., 2008). A dominant view of embodied cognition considers a perception–action coupling in which "mental representations in various bodily formats have an important causal role in cognition" (Goldman & de Vignemont, 2009, p. 2). Therefore, the benefits that mobile 360° video might offer recognize the visual experiences through an immersive tool that could strengthen this bidirectional link for action–environment interactions (for a more comprehensive discussion in sport officiating, see Pizzera, 2015). The importance of embodied cognition and mental representation in officiating performance suggests that the unique, immersive auditory and visual experience that 360° video offers provides a suitable framework to investigate these factors above that of 2D video.

Given the training utility that 360° video is found to provide for improving professional practices in other contexts (e.g., medicine; Bruening et al., 2022) and building on initial evidence for enhancing sport officials' decision-making (Kittel et al., 2021) and reflectivity skills (Boyer et al., 2023), this case study aimed to provide initial groundwork on testing referees' subjective experiences with mobile 360° video formats to identify their potential value to officiating performance enhancement more broadly. This case study approach (Starke, 2005) sought to qualitatively investigate the cognitive activity of rugby union referees and RCs while observing and engaging with mobile 360° video of another referee's performance in their sport. This involved a case analysis in a rugby union context focusing on the participants' video-viewing activities (what they observe, notice, and understand, and what types of knowledge they construct and use during a mobile 360° video-viewing situation). Within the case setting of rugby union, a second aim was to identify performance factors emphasized through mobile 360° video and within reflective practice and training activities for rugby union referees. The case findings can be extrapolated and tested in other football codes, developing similar protocol for study of referee–coach interactions in training periods and more generally to other sport official populations to enrich their training and improve their deliberate practices.

An enactive cultural anthropology perspective was adopted that draws on a "course-of-action" approach (Theureau, 2015). This perspective aims to understand participants' enaction and embodied cognition of lived experience in a situation as a means for transforming training methods that has empirical (aimed at

knowledge construction) and technological facets (aimed at ongoing coconstruction via a video-based artifact; Leblanc, 2018). Within this vein, this preliminary exploration, therefore, sought to understand how referees and RCs engage with and organize their activity with a technology aid (360° video) and their attitudes toward mobile 360° video technologies' benefits, challenges, and potential as a training tool. Combined, this case study provides an initial step and informational basis for the future development and integration of 360° video as a pedagogical innovation for sport official training programs, educational curriculum (particularly extended reality video training, an umbrella term for immersive technologies including augmented, virtual, and mixed reality), and reflective practices. Two research questions were, therefore, posed.

Research Questions

1. How do rugby union referees and RCs engage with mobile 360° video as a tool for performance review?
2. What are aspects of rugby union referee performance that mobile 360° video can emphasize over other viewing perspectives?

Methods

Participants

Referees with a range of experience levels were selected after consultation with a national panel RC to account for a range of expertise and refereeing, playing, and referee coaching backgrounds. This included three rugby union referees (one with referee coaching experience) and a full-time, national RC (see Table 1 for participant information). Kittel et al.'s (2019) categorization of officiating experience levels helped to identify the level each referee was currently refereeing, including amateur (R1), subelite (R2), and elite (R3; RC). All participants were provided with a letter of information outlining the aims of the study before providing their written informed consent.

Procedures

The 360° video used for the interview was captured during an actual rugby union match (national competition) through a mobile approach (cameras on the referee). The referee was an "advancing" referee operating at development level, the competition level below national premier league. A chest harness was equipped on the referee that housed two Kodak SP360 4K cameras (see Figure 1). One was affixed on the referee's chest just above the sternum using one chest harness, and the second was placed on the referee's upper back in line with the front camera using a second chest harness (see Figure 2). The chest harnesses and cameras were fitted on the referee in a private changing room prior to the start of the match.

The referee was given an opportunity to simulate common arm movements, rotate his body different directions, and jog around with the cameras on to ensure they would not disturb their refereeing activity. Postgame conversations confirmed that the equipment did not inhibit the referee's on-field performance.

The first 15 min of the match were captured and later "stitched" into one whole 360°picture using Kodak software, which resulted in a 12-min section of video after editing. This software coordinated the timing of both videos and provided a 360° video that was then uploaded to a private YouTube channel (see Figure 3). The video included a variety of phases of rugby union play, including the initial kick-off, tackles, rucks,[2] changes of possessions, a team score, and lineouts. It was, therefore, anticipated that the 360° video segment provided to participants in the interview offered a sufficient range of performance-related information about the referee's activity to engage with and reflect on. Participants were interviewed in person in a quiet location to allow for full engagement in the 360° video. Prior to the interview, a 360° video of a physical education teaching session (6 min 30 s; recorded from a fixed position in a classroom) was sent to the participants to provide a nonrefereeing familiarization task. The participants were asked to watch the 360° video of the physical education session and (a) observe or pay attention to the variety of teacher and student activity and (b) experiment with the functionality tools (zoom, pause, and rotating the camera) to prepare for engaging with the rugby union refereeing 360° video during the interview.

Referees were informed that they could manipulate the video to their liking and were shown the available functionality of the video use once more: to pause, change angle (by panning around the image), and zoom while the video was playing.

Case Data Collection

An other-confrontation interview method (Leblanc, 2018), originally inspired by Mollo & Falzon's (2004) "allo-confrontation"

Figure 1 — Kodak PIXPRO SP360 4K.

Table 1   Participant Demographics and Rugby Union Experience (Refereeing, Playing, and Referee Coaching)

Participant	Age (years)	Referee experience (years)	Playing experience (years)	Referee coaching experience (years)
Referee 1 (R1)	19	2	0	0
Referee 2 (R2)	35	12	3	2
Referee 3 (R3)	29	7	0	0
Referee coach	49	12	10	15

Figure 2 — Mobile 360° video apparatus (front and rear camera affixed on referee's chest and back).

Figure 3 — 360° video presented in interview via laptop computer viewing (with appended examples of rotated images for illustration).

approach was used to elicit descriptions of the participant's lived experience (cognitions, emotions, and knowledge constructed and used) while engaging with 360° video of another referee's activity. The purpose of the interview was to report on the on-field referee's activity during a 360° video-viewing situation: what they perceived about the refereeing situation, what they understood, and on which aspects of the viewed referee's activity they focused. Adopting this other-confrontation approach (Leblanc, 2018; i.e., when one is confronted about an activity, they normally perform but that is performed by another) involved the interviewer–researcher utilizing both simultaneous and interrupted verbalizations to encourage the participant to describe their activity when they viewed the 360° video but not to direct their thinking. During the other-confrontation interview, the researcher asked the participant to describe (flexibly across the viewing situation) why they were interacting with the video in a certain way (e.g., What are you zooming in on there? Why are you rotating the camera at this moment?); perceptions (e.g., What are you paying attention to? What do you notice?); concerns (e.g., What are you trying to perceive about the moment? What do you understand from this moment in the video?); emotions (e.g., What do you feel about the events in the video at this moment?); and knowledge (e.g., What type of knowledge have you constructed about the referee or the game up to this point? Is there any new knowledge you have gained from the video up to now?). This investigative confrontation of the participant's video-viewing activity, therefore, helped guide the participant to analyze the referee's practices shown in the video, which in turn, could be remobilized to analyze one's own ways of refereeing or those of one's refereeing peers and (a) allowed for a pronounced cognitive, emotional, and motivational engagement triggered by a familiar visual experience (Leblanc, 2018). Considering the research questions, this, therefore, allowed the participant's engagement with the video to be elicited and studied to understand more common information extracted by them from the video sequence based on this juxtaposition or posture in the viewing situation. Interviews lasted from 45 to 75 min. Two categories of data were collected, as follows: (a) the referee's verbalization during the viewing situation and (b) researcher observations of the participant's viewing behavior while observing a particular match situation on the pitch, as described by their orientation of the video and facial expressions.

Data Analysis

Data analysis took place in two stages: First, a temporal *description* of the referee's activity while engaging with the video based on their verbalizations and, then, *analysis* of their activity during the viewing situation. This information was arranged in four columns (see Table 2): The first column indicated the timecode of the viewing situation; the second highlighted the researcher's observation of the participant's viewing actions during the viewed match situation (e.g., stop the video, zoom in on a video detail, rotate the camera, point at the video screen); the third column transcribed the participant's verbalizations during the interview; and the fourth column provided an open coding, which included the researcher's interpretation of the participant's course of experience (Theureau, 2015) while observing the video. This was based on three assumptions founded in empirical phenomenology and semiotics of cognition in practice in terms of enaction and experience. These included (a) activity as a mechanism of self-production and expression of a coupling between actors and their environment or artifact (in this study, 360° video); (b) activity that gives rise to first-person lived experience (i.e., the stream of actions, thoughts, emotions, and perceptions that occur in a given moment while performing an activity, of which the actors are aware in the moment or are made aware of at a later point in time; Cahour et al., 2016); and (c) activity that occurs as sensing making, a permanent creation, and appreciation of meaning. As a result, verbatim transcriptions were produced that resulted in 28 pages of single-line, single-spaced 12 font data. This course of experience was analyzed inductively and independently by two of the researchers. First, raw codes were developed based on the meaning within each participant's course of experience while engaging with the 360° video (cognitions, knowledge constructed about the viewed situation, or knowledge used from past refereeing experiences). Second, raw codes were clustered into meaningful categories that provided descriptive themes for the research questions. The two researchers then discussed their emergent themes in search of deeper meaning to develop a coherent set of themes. Following this, to ensure trustworthiness, the main themes that outlined answers to the research questions were forwarded to the referees and RC following the interviews as a member-checking exercise. Participants were asked to add or change any aspects of the theme descriptions or labels. No significant amendments were recommended.

Table 2 Example of Data Analysis

Time code of the viewing situation	R2's use of 360° video during viewing situation	R2's verbalizations during the interview	R2's course of experience (Poizat et al., 2022) during the viewing situation
7'35: following a ruck, open play	Pauses the video and first rotates to the right 90°–180°. He rotates back to the scrum, unpauses the video and zooms in, points at players in scrum front-facing position of the referee.	I: What are you paying attention to? What are you observing? R2: I'm trying to look for errors here, and listen to what and how he communicates scrum instructions to the players. I: Why is that important for you here? R2: At this scrum, I notice the low player position here close up and the 360 video lets me see where players are positioned on the flank when the ball comes out. I work hard set up the scrum not just from a restart perspective but also for safety perspective because there is always a moment of doubt in your head, of you know if somebody goes down, at a scrum, you know and you're kind of feeling it I've got pins and needles and then you are responsible.	Uses and constructs procedural knowledge about the scrum phase. Scrum safety and illegal position of players outside the scrum. Identifying the usual elements (body position, referee communication cues) to evaluate scrum quality and the referee's scrum instructions.

Note. I = interviewer; R2 = Referee 2.

Findings

This case study sought to understand rugby union referees' and RCs' use of a mobile 360° video tool and their activity (cognitions, emotions, actions, and knowledge constructed) while observing mobile 360° video of another referee's performance to make recommendations for types of extended reality training for sport officials. An analysis of activity approach allowed for psycho phenomenological data to be gathered from participants to describe and explain the participants' concerns, interests, and cognitive activity while engaging with mobile 360° video to understand its potential benefits as a referee education and performance enhancement tool. The case study's research questions are restated, and thematic categories are presented with quotes to support the emergent categories.

RQ1: How do rugby union referees and RCs engage with mobile 360° video as a tool for performance review?

Enhanced Immersion Into the Refereeing Situation

The participants frequently acknowledged a unique experience derived from the video that brought them closer to the referee's activity, understanding about how the match was unfolding, and the referee's "relationship with the game" (RC):

I guess what I'm trying to say here is this technology is giving me a holistic view. A fuller experience of the situation for the referee and how he is reacting to it. (RC)

The participants identified an enhanced immersion into the situation, which as one referee termed a greater "atmospheric involvement" (R2). One referee described a "sense of inclusion" (R2) that enhanced an appreciation for finer details about the referee's activity, or approach or style to the match and characteristics of game play ("it feels like a kind of messy game"; R1). Such immersive qualities that the 360° video provided occurred in various forms. The RC identified concepts of *speed, space, and safety* as key national rugby learning principles for referee education to facilitate free-flowing games:

I can get a feel for where I am in space with the video and what is around me and responding to me. (R2)

Another referee described a particular "gut sense" (R3) that they were able to gain from the video that enriched their understanding about the game. This described an engagement with the video that elicited a deeper involvement with the viewed referee's experience in the situation when compared with 2D video viewing:

For me, it is almost just a duplication of the real image of being out there. I've got this sense of like, I'm inside the game. (R2)

The participants immersed themselves in such a way that they had the possibility to really choose their own orientation in the video. For example, participants said that they felt "presence" (RC) with the speed and movement of the referee in their environment and in relation to player movements from viewing the situation. Participants felt that these characteristics were more heightened from viewing 360° video compared with other video modalities.

Greater Discovery and Enhanced Noticing

When the participants viewed the video, they were not passive but, rather, active: They rotated the video and explored. This occurred through participants' use of all aspects of the functionality tools, such as zooming in and out, pausing the video, and rotating the image not only to follow play but also to discover or seek out other visual information (e.g., players' movements, off-the-ball activity). Participants verbalized their noticing of the referee's activity, the match environment, and perceptions of events in relation to their own declarative and procedural knowledge:

I'm just looking around here. He [the referee] is just standing there facing down the field. Why aren't the players out there yet? (R3)

The reason I focused in there was, especially at breakdown, one so I don't lose sight of the ball, and two, if there is any other infringement at all. (R2)

During one phase of rugby union play, the "ruck," the camera recording was frequently paused, zoomed in, and rotated to observe the "blindside":

I'm looking over the referee's shoulder here, if any players were offside. Having this view you can definitely see who is offside. Of course being at the ruck, the referee will not be able to look behind him necessarily but I'm interested to look over there. (R1)

With POV camera you are only getting one angle, but with the 360° video you get this front and the rear to play with. Did that player start from in front or was he already sprinting from well behind? It is a safety thing too to check that with the camera. (R2)

For the referees, 360° video provided an enhanced discovery for new perceptual cues that they would not have considered without the technology. As such, the technology could be a means through which referees may acquire greater visual experience that is suggested to be a key variable in sport official expertise development (Pizzera & Raab, 2012). This was further confirmed by the RC, who felt that directly experiencing the on-field referee's perspective gave a clearer idea of the cues that the referee was seeing and interpreting:

Mentoring a referee, I can be a bit more critical of what they are seeing with this view. It opens me up to their situation in the match. (RC)

The RC highlighted the value of the controllability of the 360° video in the video review process with referees. As a pedagogical innovation, the RC felt that the technology offered greater opportunity for a learner-centered approach during video review sessions:

You could give control of the computer and the video to the referee and they go, "OK, this is what I am looking at, this is what I was trying to achieve" and then I could say, "have you thought about this over here, look at this." The player is coming in from the side [rotating camera and pointing at the screen]. It gives power to them to show me what they are doing and for me to show different ways of doing it. Really changes the type of interaction between me and the referee in a good way. (RC)

Constructing Embodied Knowledge

Participants consistently described a type of embodied knowledge drawn from the 360° video-viewing situation. They frequently reflected about how they would position their own body because

they could observe some things that the referee in the video could not see. In its most fundamental form, the movement of the camera (shake, wobble, tilt, etc.) was a point of visual involvement and embodied knowledge reflecting in the movement of the referee to find an optimal viewing perspective to make a decision:

> I can tell he is behind play and sprinting there because the camera is all over the shop. (R3)

> When he starts off a sprint I can gather he sort of gets lower, tilts his body, like anyone would when they start accelerating . . . you can hear him panting as well. (R1)

The appearance of the referee's hands in the video (when signaling or pointing to players) offered other embodied knowledge for participants during communication and decision moments:

> Like here, I get a sense of the referee's feeling for the match by his hands. He is agitated and waving them around a lot there. I'd probably be more calm and just point to guide the player rather than react. (R3)

RQ2: What are aspects of rugby union referee performance that mobile 360° video can emphasize over other viewing perspectives?

Bodily Positioning, Movement, and Sightlines

The 360° video allowed for observation and projection to where the referee was in space and inferences about appropriate sightlines based on visual information gathered from the recording. They also considered the referee's "routes of passage" (R2, RC) and make better adjustments during the match to select appropriate paths to reach an optimal view position to make a decision. Many participants identified the breakdown (when a tackle is completed) in what they termed the "chariot position"[3] that led to conclusions about the on-field referee's tactical position at this phase of play:

> He is a bit static for my liking. Not particularly mobile. The problem is this tends to be his "go-to" for most rucks . . . sitting there he is not able to manage his backline. (R3)

> He is sitting back in that position. Maybe that is "adding value" because he thinks I want to give the teams' more space to play. (R2)

The RC identified how the video helped to amplify a sense of the referee's on-pitch position and movement that would be valuable with a referee's reflection on their own performance to develop their "self-management" (RC). The participants often made comment about what the referee was looking at and, as such, saw the technology a tool for training awareness of visual sightlines. This was emphasized in the following quotes wherein the participants acknowledged the value of 360° video when referees do not have the luxury of assistant referees to support them:

> Without assistant referees the blind side would be difficult to pay attention to . . . when you do not have an assistant referee this would be really, really useful . . . . All this helps in post-match review massively. You can pick up on all the mistakes he has made. (R1)

> Because you have seen the ball being kicked but you have not seen the contact made by the player so if you are by yourself and do not have an assistant referee this would help. (R2)

It was felt that the naturalistic perspective of 360° video could enhance self-awareness in the referee's positioning in a way that broadcast images could not. 360° video offered more corporeal information about the referee that led participants to become immersed and capable of predicting more on the pitch events. This type of corporeal projection (i.e., assimilating with bodily aspects of the referee's activity) about the referee's position and movement in space that the 360° video helped provide information about their movement and sightlines between phases of play.

Decision Making in Match Context

Participants often stopped the video during decision moments and used the 360° video to scan the environment, focusing on surrounding players and checking the score and pitch location. One participant said they could gain information from cues about the referee's decision context that helped them adjudge them as a more "proactive referee" (R2) in their treatment of decisions. One core principle that all participants acknowledged was for the referee to "add value" to the game, which the RC described 360° video help better emphasize in referees' off-field learning:

> Adding value could be giving or not giving a decision based on how the game is going—it is totally individual . . . it might be giving 10 penalties in the whole game and letting them play and letting it flow but added value could also be giving 30 penalties because the game requires it. This technology helps me deliver that message to the referee more easily. (RC)

Although it was acknowledged that 2D video gave a broader view of decision moments, it was felt that the 360° video provided a better insider perspective of events as it captured the game through a range of modalities:

> This way of watching the referee does help me reflect deeper on the referee's decisions more broadly. We've only watched about 4 and half minutes during this passage but I can absorb his moment-to-moment decisions, how they connect while the match unfolds. (R3)

> It is amazing how you can go down to the referee's level and look around and just get a stronger sense of how the referee is making decisions in context. (R1)

Using 360° video to explore decision moments of another referee amplified an awareness of context that was gained from ways in which players reacted to the referee's perceived style: They observed visual information more holistically through extended observation.

Player Cues and Interaction

All participants identified the performance aspects of the referee's interaction with players and aspects that could be differentiated from other camera perspectives:

> POV cameras can give you an idea of where a player is looking but this is different. I can listen to what they're doing, if they're saying "got it," or coming back at him [the referee] by zooming in. With POV you are facing each other but here you're right there in the mix and I can rotate the camera to get a full feel for the situation. (RC)

> This is my opportunity to scan the field and go is there anyone that is going to cause me problems right now? Is there anybody

that's going to change my relationship with the game right now? (R3)

The capabilities of the video to help the viewer identify "finer details" (R2) in the interaction and "pick up on more social cues" (R1) about players were frequently identified. Referees identified a higher degree of empathy for players' responses to the referee and a closer connection to the referee's emotions in the match. Players' voices, behaviors, and other information gave insight into "future problems that could arise from the context of decisions" (R3) and how that could be better managed by the referee:

I mean the player doesn't do anything but the body language and face, visual image tells you. (R2)

What is amazing about this technology is here after this score. I can observe, are the players happy? How are they handling the pressure at this point? Are they standing under the posts for the conversion, running to get back to the halfway line for the kick? . . . that type of stuff. This is essential for the referee to know how the team is feeling, to help his relationship with the game. (RC)

All participants had noticed subtle cues about the referee embedded in the video with statements like "fidgeting . . . feel . . . and urgency" (R2) and "happy smiley" (RC). Participants said the 360° video gave richer information about the referee's voice tone, or "cadence of instructions at the scrum" (R3), that could be associated with other cues about players in the video (e.g., reactions, responses, etc.). This was reinforced by numerous references to the players' responses to the referee's communication, with one participant commenting on the "white noise" (R3) of the referee's instruction that seemed to have little influence on the players' behavior during unfolding play:

I don't care if he's right or wrong in his decisions . . . I'm more interested in how he went about saying that at that time. Was that the best way to say it or could he have said it in a different way or at a different time? (R2)

There's a fair bit of him saying stuff but not a lot of listening. It has been a bit of one way speaking almost like a commentary rather than a conversation. (R3)

The 360° video may be a solution to accessing players' cues and developing referees' sensitivity to such cues to develop more preferred responses to players.

Discussion and Conclusions

This research case study aimed to explore rugby union referees' and RCs' engagement with a unique form of performance video capture. The usability and acceptability of integrating technology to match the external representations of learning has been deemed important (Tricot, 2007). Overall, our case analysis found that 360° video provided referees and RCs an increased immersive experience, expanded perceptual field, and perspective taking that was enhanced through a corporeal presence and noticing. The findings show that participants experienced a heightened involvement in the refereeing situation in which mobile 360° video offered a video artifact to understand how the referee responded to their performance environment. For our case setting of rugby union refereeing, the performance characteristics emphasized the technology's value in reflecting upon positioning, movement and sightlines, contextual

judgment in decisions, and heightened sensitivity to player cues and match interactions. This case study represents a response to Kittel et al.'s (2022) recommendation for testing mobile 360° video uses in a sport officiating context (compared with fixed 360° video on a tripod at the side of the pitch). It also extends previous isolated decision-focused aims (Kittel et al., 2019) of 360° video in sport official training and builds on Boyer et al.'s (2023) recent investigation into mobile 360° video use for reflectivity skills by focusing on sport-specific, performance enhancement benefits.

The naturalistic nature of a mobile 360° video gives an inherent richness to the refereeing environment that cannot be otherwise achieved from more traditional 2D video options (Kittel et al., 2022). A distinctly different lived experience is derived from a mobile 360° video-viewing situation to that of other video perspectives of referee performance (e.g., 2D video from a broadcast/gantry, or POV). The first-person perspective (McLennan & Omodei, 1996) is recognized as being a more favorable and naturalistic approach to decision training based on enhancing visual information about decision contexts. Explicitation of one's own first-person lived experience in which a situated subjective perspective is relived through video-assisted reimmersion reflects a next step to potentially better understand (Rix-Lièvre & Biache, 2004).

The limitations of this study are found in the current challenges in the capture of this video and its use within training practices and referee education. Although the movement of the camera was seen as an indicator of speed and stress in the referee, the stabilization of moving images provided by 360° video can be problematic (bouncing and erratic movement of the camera). Participants in our study similarly identified this as drawback while in the viewing situation; however, with technological innovations, there are likely to be opportunities for better image stabilization of such moving images. Second, as a first approach, we used laptop viewing within our study as it is more readily available in refereeing communities. It would be interesting to evaluate mobile 360° video within an HMD format, but it is also recognized that this can potentially exacerbate feelings of "motion sickness" for the viewer. Cognitive overload is another potential limitation of 360° video as enhanced concentration and effortful perceptual attention are required (Kavanagh et al., 2016). These video-viewing and capture limitations should be further tested and evaluated, particularly with respect to individual differences and implementation in other sport contexts.

Because of the approach, we took of having two cameras, one on the chest and one on the back of the referee, this resulted in a "stitch" wherein both images are integrated, revealing a boundary line in the video that, at times, was noticed by the participants. This can be potentially remedied by an affixed camera on the shoulder or the head of the referee using a different type of harness, but this is also not without its problems. Participants in our study did identify that the chest height of the camera might be the most pragmatic approach for capture, which raises the question about future ways to affix the technology on the referee using an alternative harness. These challenges should be interpreted as a source for future development. Future research directions might also consider the applications of 360° video in other dynamic, team sport contexts, for example, considering the movement demands of soccer referees, it would be interesting to investigate with similar experiences occur for referees.

Case Application: Practical Applications and Integrations

As an innovative technology and performance capture method, mobile 360° video can provide an adjunct to traditional forms of

video review and reflective practice to aid sport official training. Video review is commonplace in the off-field deliberate practices for sport officials (particularly at higher levels). The 360° video perspective has potential to be integrated into and scaffolded with other video perspectives to provide a more holistic viewpoint within officials' video review and talent identification and development. The fact that 360° video provides an enhanced visual correspondence to the "actual" image, therefore, highlights its potential benefit as a new representative learning tool (Pinder et al., 2013). Superior perceptual–cognitive skills that are suggested to contribute to judgment and decision making rely on embodied cognition that arises from greater bodily experiences in officiating environments (Pizzera, 2015). Mental representations in performance contexts and various bodily forms (or codes) are considered to have a crucial role in cognition (Goldman & de Vignemont, 2009), where 360° video helps emphasize in sport officials' practices and performance. This might particularly be a helpful tool to improve reflexivity in referee practices (Boyer et al., 2015) to develop more adaptive, on-pitch positioning at phases of play, "routes of passage," for example. Positioning is identified as a core performance area in rugby union referee performance (Mascarenhas et al., 2005) and is suggested to benefit decision-making accuracy based on viewing angle and distance to decision situations (Hossner et al., 2019; Mallo et al., 2012). Furthermore, making decisions to match context and preparing for more spontaneous and pressured communications with players also emerged as other key learning features of mobile 360° video use. An important area of officiating performance that is difficult to develop through current training approaches is contextual judgment (i.e., an appreciation of the tenor of the game and the referees' ability to alter their style of refereeing to suit the particular nuances of the game; Mascarenhas et al., 2005). A referee's ability to monitor game situation and players' emotional and behavioral cues is also considered a higher order skill in effective communication with players, which, historically, has been difficult to train (Płoszaj et al., 2021). 360° video is said to aid in better anticipation of and reflexivity to players' responses (Boyer et al., 2015; Cunningham et al., 2018; Firek et al., 2020). The more reflexive a sport official is can allow them to be better suited for the complexity of informational cues used during performance and, thus, better adapted to different performance situations.

This case study's findings about the opportunities and benefits of 360° video provide a foundation for emphasizing conceptual consequences on activity transformations from a training and reflection-on-practice perspective (Durand, 2008). Our study illustrates the RC-led opportunities present for officiating education and, therefore, the need for more expanded strategies to improve video training of sport officials (Nurcahya et al., 2022). Specifically, referees can be given opportunities to immerse their coaches in their interests, concerns, and rationale for their on-pitch activity as a learning point for coaches to impart alternative courses of action. As identified by the RC, this technology might also be effective in enhancing referee and RC interactions through more referee-centered coaching approaches. As such, our analysis here into the sociotechno engagement of referees with 360° video supports video-based match review and provides a starting point for developing new and more evaluative coaching practices.

The multimodal benefits of visual, auditory, and corporeal information derived from 360° video technology were highlighted by the findings. For example, audio cues associated with the observed referee's physical exertion, referee communication tone and pace, and the players' interactions with the referee and with one another were noticed by participants. Such proximity to the match day sounds could potentially influence the attentional focus of the 360° video viewer according to camera location (Boyer et al., 2023) and whether ambisonic or monophonic audio is provided (Ferdig et al., 2023). Potentially occluding, altering (e.g., ambisonic), or filtering sound in future training and research approaches can underpin other pedagogical strategies through manipulating immersion elements. This also translates to modalities in the referee's attention and decision making related to corporeal sensations. The referee's proximity to play and their movement in relation to players' field position, including angular speed and movement of players entering the referee's view and their positioning behind the referee, were spatiotemporal aspects observed by participants. Combined, these examples of the multimodal benefits of 360° video over 2D video emphasize the potential to add value to referee training, reflection, and performance monitoring.

Figure 4 — 360° video presented to the referee via laptop computer with image of the referee's hand movements.

One drawback of 360° video compared with other immersive technologies, such as VR training with referees (Gulec et al., 2019), is its limitations for interactivity. Newer advances in 360° video technology, however, now allow for the insertion of information artifacts within video content that can provide the viewer with information (i.e., pop-up windows, text, hyperlinks; Roche et al., 2021). This could create interesting developments for archives of refereeing scenarios wherein the viewer can access information about decisions, game context, and interaction consequences with players that could be a basis for new 360° video pedagogies in referee curriculum. Such technologies may consider what place extended reality tools (360° video, VR) can occupy in sport official education and extended reality training curricula. The training outcomes for 360° video use may appeal to help develop imagery skills (Bedir & Erhan, 2021) for sport officials, considering the realistic images and better correspondence to the actual perceptual environment of officiating. Numerous studies that used different formats of 360° video viewing (i.e., laptop, HMD) also identified this closer correspondence to the activity (Broeck et al., 2017), with sport officials rating 360° video higher than 2D video on enjoyment and relevance to their practices (Kittel et al., 2019). To enhance a greater behavioral correspondence (i.e., replication of human movement; Hadlow et al., 2018; Pinder et al., 2013), future research could explore the use of mobile 360° video review with HMD to see whether this further enhances the connectivity to the behaviors of the referee (signaling, bodily movements, and communicating to players). Other types of technology can also be paired with 360° video in HMD for referees, including eye-tracking technology to study gaze behavior during the technology's use.

Uniquely, 360° video can provide a potential performance assessment and talent identification tool if sport-specific evaluative criteria are developed to indicate skill or ability levels for assessment. For example, decision scenarios can represent testing information for decision accuracy using 360° video or evolve to evaluate interaction skills with players and game management competencies. Together, understanding the use and referees' engagement with the technology in this study allowed for understandings about aspects of new extended reality education curriculum for sport officials that can be self-directed and coach led, considering the capabilities and enriched perceptual capacity provided by 360° video. As a sport official performance enhancement tool, there is potential for it to help familiarize officials with decision situations and develop perceptual–cognitive and imagery skills related to contextual noticing and corporeal knowledge.

Notes

1.   Visual gaze studies show that expert sport officials generally observe perceptual cues different to nonexperts (Hancock & Ste-Marie, 2013).

2.   The ruck is a phase of rugby union play that occurs after a tackle is made when opposing players compete to gain possession of the ball and offside lines come into play.

3.   The chariot position refers to the referee's field position directly behind the phase of play where a tackle occurs.

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