Decision-making training in sporting officials: Past, present and future

Abstract

Objective: Decision-making has commonly been cited as the most important skill for successful performance in sports officials, however insight into how this critical skill is improved through off-field training has lagged. The overall aim of this paper is to provide a narrative review concerning the evolution of off-field decision-making training approaches in interactor sporting officials (i.e., those with high movement and perceptual demands). This paper will reconcile these past forms of training with theories and concepts discussed in the officiating and sporting literature, with subsequent recommendations for future investigations.

Design: Narrative review.

Method: 10 peer-reviewed studies on the development of decision-making in interactor sporting officials were comprehensively scrutinized.

Results: Decision-making training studies were found to use diverse methodological approaches and theoretical perspectives. There are several limitations in the decision-making training literature for officials, such as limited representativeness in training, leading to a more decontextualized approach.

Conclusions: Future studies should consider stronger representativeness by including more competition constraints into training decision-making, such as contextual factors. Reflective training and individualized approaches may be an appropriate training methodology to train officials for adequacy, rather than accuracy.

Keywords: sport officials; umpires; referees; decision-making; representative design; training

Introduction

Sports officials are key stakeholders within the sporting environment along with players, coaches and spectators. The main role of an official is to decide whether any infringements of the rules have occurred and to ensure the game is played in a fair and safe manner. There is increased scrutiny of officials' decisions as they have the potential to influence a game's outcome which may impact team/club performance and revenue (Larkin et al., 2011). Due to the high expectation for accuracy in officials' decisions from players, coaches, sporting organizations, and spectators, decision-making is commonly cited as the most important skill for sports officials (Kittel et al., 2019b; Morris & O'Connor, 2016). Anecdotally, officials develop decision-making in several ways, including competitive match experience, officiating their peers in simulated drills, reviewing and reflecting upon game footage, and completing structured video-based training. Most recently, as could be seen in UEFA TV series, Man in the Middle (UEFA, 2019), soccer referees also started to perform on-field decision-making training, under physical strain, to simulate on-field review with the video assistant referee system. Different approaches such as these are not always grounded in theory, can be spontaneously introduced and more empirical understanding is required for these innovations. Given the importance of this skill to officiating performance, there is a need for evidence-based and efficacious methods to train decision-making in this population (MacMahon et al., 2007b). Examples of deliberate practice programs show elite football referees use on-field simulation training up to 10% of their training hours (Samuel, 2017). While officiating decision-making has received increased research attention over the past three decades (Aragão e Pina et al., 2018; Hancock et al., 2020), the design and testing of theoretically-grounded, decision-making training tools for officials has only recently emerged in the past 15 years.

To inform training approach, numerous conceptual frameworks have been proposed to describe sport officials' decision-making. A social cognition perspective focuses on how social information (i.e., during a judgement situation) is perceived, encoded, transferred to and recalled from memory (Bless, 2004; Plessner & Harr, 2006). Another cognitivist approach, 'take-the-first' heuristic theory proposes probabilistic judgements in officials' use of perceptual information to make decisions (Johnson & Raab, 2003), including subjective thresholds officials may apply to their rule application

(Rabb et al., 2019, 2020). To account for time pressures in officials' decision making, naturalistic and recognition-primed paradigms suggests officials don't often generate and compare different options, but rather use prior experience and intuitive processes to rapidly categorise decision situations (Klein, 2008; Mascarenhas et al., 2005). Finally, ecological dynamics advances a non-representational approach suggesting perception and cognition are embedded and an embodied part of officials' decision-making in their practice environment (Araujo et al., 2007; Russell et al 2019). Together, these different theoretical assumptions provide foundations for interpreting how sport officials' decisions occur through myriads of perceptual-cognitive process and influences of external constraints on decision-making. As such, a conceptual debate has developed in the literature comparing more cognitivist, representational interpretations of sport officials' decisions (e.g., bias, underlying cognitive mechanisms) to more non-representational perspectives that emphasise deliberate game management aspects of decisions and accounting for broader affordances and ecological constraints acting on sport officials' rule application.

The complexity of decision-making demands for sporting officials can differ depending on the sport officiated. The unique decision-making constraints of particular sports may require different decision-making training approaches (and intersection of approaches) for different sporting officials. To help explain the differences in sporting officials' performance demands, MacMahon et al. (2014) classified officials by their respective movement, perceptual and competition interaction demands. This resulted in three specific groups of sports officials including, *monitors* (e.g., gymnastics judge), *reactors* (e.g., tennis line judge), and *interactors* (e.g., soccer referee) (MacMahon et al., 2014). Interactor sport officials have greater movement and fitness requirements (and changing physical workloads) and are required to process multiple decision cues and interact with greater numbers of players (most often team sport settings). For example, interactor officials' decisions are often made spontaneously and under strict time and information constraints (Mascarenhas et al., 2005a), require deep prior knowledge and efficiency in appraising and processing perceptual information (Raab et al., 2020), and involve a high degree of mental and physical fatigue (Bloß et al., 2020; Samuel et al.,

2019). Such decision-making demands are evident in the central official's responsibilities in soccer, Australian football, hockey, and other team-based, interactive ball-game sports.

The number of decisions made during gameplay for soccer referees is found to be extensive, with studies reporting the number of penalties/free kicks an official makes can range between 15 (Emmonds et al., 2015) to 44 per game (Elsworthy et al., 2014; Helsen & Bultynck, 2004). While the above numbers represent the number of penalties/free kicks awarded, officials may face upwards of 887 decision 'moments' per game (Neville et al., 2016). These moments include repeated instances throughout the match where an official does not say anything or make an observable decision; the official has consciously considered the play must continue uninterrupted. Notably, interactor officials are generally the main focus of sporting officials decision-making training research (MacMahon et al., 2014). While we acknowledge the different decision-making challenges associated with officiating any sport, this paper solely focuses on interactor officials who have high physical, perceptual, interaction and in-game decision-making demands. The inherent differences of officiating different interactor sports present certain constraints that should be addressed in decision-making training approach. For instance, there are three or four Australian football umpires officiating per game, whereas soccer and rugby involves one central referee with some decision-making assistance from the two assistant referees (Samuel et al., 2020).

There is conjecture in the literature whether interactor officials' decisions should be made in isolation, or with consideration given to previous judgements and contextual factors such as score, time and position on the playing area (Corrigan et al., 2018; Kittel et al., 2019d; Morris & O'Connor, 2016). Research has suggested there are a number of 'unwritten rules' interactor officials consider when making decisions, implying contextual judgements and conscious, game management strategies are often at the forefront of their decision-making process (Mascarenhas et al., 2002; Samuel et al., 2020). Interactor officials may consider the behaviour of players over a longer match periods, such as aggressive behaviours (Jones et al., 2002) and verbal interactions (Cunningham et al., 2018; Cunningham et al., 2015). Due to the unique constraints on officiating decisions in interactor sports, officials may deviate from isolated rule application. Russell et al. (2019) describe decision-making for officials as an 'emergent process' that requires an ongoing balance of certain game imperatives in

their decision-making, such as fairness, game control, and entertainment. Through this, the official's decision-making allows them to maintain control and preserve integrity of the match.

It has been acknowledged that direct participation in sport, whether playing or officiating, is the ideal mode of developing sport-specific decision-making skill (MacMahon et al., 2007a). For athletes and officials alike, there are only a finite amount of competitive games available to participate in, with each game causing high physical loads (Weston et al., 2012). Therefore, there is a need to develop off-field methods to develop decision-making skill. Outside of competition, small-sided games are a common training modality incorporating decision-making, tactical, technical and physical elements present in a competitive game (O'Connor et al., 2017). Although beneficial for athletes, officials cannot commonly use this as a training modality due to logistical and pragmatic issues of bringing in players to role-play and create realistic decision-making scenarios. Due to these limitations, officials are generally not privy to the same deliberate practice hours as athletes. One method to potentially overcome this limitation is video-based decision-making training methods. These programs have the potential to accelerate deliberate practice hours in keeping with Ericsson et al. (1993)'s seminal concept of 10,000 hours or 10 years of deliberate practice to attaining expertise. Under the 10,000 hour rule, officials would need to officiate an unattainable number of 5,000 games to become experts (Larkin et al., 2017). As most studies aiming to develop decision-making in officials investigate non-elite participants (Kittel et al., 2020b; Larkin et al., 2017; Schweizer et al., 2011), this is to accelerate expertise in these cohorts to that of elite decision-makers.

Anecdotally, current teaching methods in both domestic and international federations include the implementation of on field teaching scenarios that utilize players whom replicate in-game scenarios. Sessions are designed to incorporate a physical demand such as a sprinting action and subsequently a decision will end each repetition. These types of scenarios are controlled in nature as they are focused on a specific topic. The environment presents limitations as there are no fans, the players typically do not replicate a high speed of play, and the singular topic reflects a fabricated scenario where a decision is required. Classroom training, on the other hand, is often a review of recent games and situations where decision, positioning, player management errors are highlighted with the intention for the individual or group to learn from. To provide a training stimulus for

decision-making skill similar to classroom training described above, video-based training has emerged as a means to enhance decision-making skill for both athletes and officials (Larkin et al., 2015). A key theoretical rationale of video-based training is to develop representative tasks with similar constraints to competition (Pinder et al., 2011). Therefore, the key aim of a video-based training program, is to present video of a representative game situations promoting a perceptual-cognitive response in relation to the decision event (Larkin et al., 2015; Mascarenhas et al., 2005b). Representative learning design has been used in the sport literature to design tasks which are more similar to competition by including constraints that are experienced in games (Hadlow et al., 2018; Pinder et al., 2015). Mascarenhas et al. (2002) highlighted this by suggesting training programs can be more representative by emphasizing the extreme time pressures experienced by official's in-game within the training environment. Similar to high representativeness, it is imperative for video-based training approaches to be ecologically valid by having similar perceptual cues to that of competition (Araujo et al., 2007). As discussed by O'Brien and Rynne (2020), existing video-based training have limited representativeness by isolating decision-making, rather than incorporating constraints of competition.

Crucially, O'Brien and Rynne (2020) argue that training tools aimed to improve officials' performance can tend to be too narrow and passive pedagogies and often neglecting to account for officials' prior knowledge and sociocultural context. Incorporating more holistic and constructivist perspectives of officiating performance development (recognising environmental influences and individual constraints) is recommended to create contextually appropriate training stimulus. Socio-cultural constructivist views would consider how sport officials' decision-making training is situated and constructed within the specific performance environment. Learning designs within these perspectives would promote collaborative, personal and contextualised approaches in which training avoid prescribing decision problems that reflect a more deficit-based approach (O'Brien & Rynne, 2020). Another limitation of video-based training is the view that there is one putative correct decision for every scenario (O'Brien & Rynne, 2020). When the putative decision is subjective in nature, it can be difficult to definitively determine whether the reference decision is correct or lead to conjecture on the 'correct decision' for different scenarios. Sometimes, these decisions need to be

adequate rather than accurate, taking into account certain contextual factors (Helsen et al., 2019; Schweizer & Plessner, 2016). Bordner (2019) recommends accuracy is often unattainable, and simpler with more refined criteria (e.g., adjudicating the 'forward pass' in Rugby) should be established in officials' training and assessment to overcome these challenges. This translates to aspects of officiating practice that contribute to how accuracy is observed, such as training officials' to how they craft rule application and incorporate values in their decisions (fairness, game flow). Further, to account for broader social and cultural values that underpin perceptions of what is 'accurate', working to find alignment between stakeholder's perspectives (players, coaches, and officials) should be sought as a source for training design. This notion of adequacy in decision-making contradicts every scenario having a correct decision, which may enable officials to maintain control and preserve integrity of the match (Russell et al., 2019). For a practical example, Raab et al. (2020) explain how when a referee approaches a subjective middle ground between foul/no foul, they adjust their decision in how they believe it would more appropriately manage the game.

The overall aim of this paper is to provide a narrative review concerning the evolution of off-field decision-making training approaches in interactor sporting officials (i.e., with high movement and perceptual demands). This paper will reconcile these past forms of training with theories and concepts discussed in the officiating and sporting literature, with subsequent recommendations for future investigations. These recommendations are grounded in key theoretical concepts such as representative learning design and ecological dynamics. While more scoping systematic reviews of sport official research are available (Aragão e Pina et al., 2018; Hancock et al., 2020), our goal here is to focus on a small subset of these studies (i.e., decision-making training interventions) that were identified based on these reviews and other data resources. An outline of past approaches and their theoretical explanations for improving interactor officials' in-game decision-making is provided in this paper (as a way to compare and transfer learnings between interactor sports), with a particular emphasis on how new technological tools may help supplement more general officiating education and development of decision-making skills. As a result, this review of the decision-making training in sport officiating research provides a summary and synthesis of approaches for strengthening future

decision-making training structures and practices, particularly as sports officials adopt training protocols from other sporting codes.

Method

A narrative review was the preferred approach for two reasons: (i) collectively, the authors have published several studies on decision-making and training in sport officials to support a sound understanding of this literature base, and b) considering the narrow representation of decision-making training studies in sport official research as documented in recent systematic reviews (Aragão e Pina et al., 2018; Hancock et al., 2020) and primary readings in sport official science (Livingston et al., 2020; MacMahon et al., 2014), we drew on referencing records informed by these research compilations initially.

As defined in the introduction, those categorised as 'interactor' officials were included in this review (MacMahon et al., 2014). This included studies that involved decision-making where there was a direct infringement between two players of opposing teams. This has also been labeled as 'one on one' decision-making in several studies, to distinguish between offside decision-making which has commonly been examined (Aragão e Pina et al., 2018; Boyer et al., 2020). As such, studies including offside decision-making were not included.

Based on the relevance of study titles, we collated an original list from these primary sources and then conducted a secondary manual search of several databases (Web of Science, SportDiscus, and PsycInfo). Using key terms for interactor sport officials ('referee', 'umpire', 'sport official') AND 'training', 'decisions', and 'decision-making', combinations resulted in one additional study for inclusion.

Full articles (n = 10) were shared among the authors to adjudge if they meet our narrative inclusion: studies where interactor sport officials were the primary participants and a training intervention has been employed that assessed changes overtime in a decision-making performance variables. MacMahon et al. (2007b) was included because of study design and training implications. This formal process helped reduce researchers' bias for the current narrative review by: a) relying on other more larger scoping reviews as a basis for article selection and expert conclusions about

decision-making training intervention in interactor sport officials; and b) allowing the researchers' to establish inter-group consensus concerning article inclusion.

Results

Studies are noted in-text if they are not explicitly a training intervention (identified with an asterisk *). Figure 1 provides a brief illustration of past approaches for decision-making training and its evolution over time, and how these approaches have begun to be more representative over time.

***** Insert figure 1 (timeline) around here*****

First video-based training. One of the first pioneering investigations in this area examined the effectiveness of video-based training on rugby union referees decision-making performance (Mascarenhas et al., 2005b). This intervention utilised 25 video clips from a first-person perspective (recorded by mobile sideline camera, level to play) with the aim of developing referees' decision-making accuracy and shared consistency. Viewing perspective from a first-, rather than third-person perspective (similar to research conducted in athletes (Farrow, 2007)) theoretically affords stronger representative design (Petit & Ripoll, 2008). Referee decision-making accuracy was assessed before and after an intervention involving a set of training clips accompanied by a senior, high-performing referee's interpretation of the decision situations. This interpretation included the decision, rule-based reasoning, and explanation of underlying cues used to reach the decision. Referees were asked to make an immediate decision in order to attempt to better represent the naturalistic conditions of how actual match decision-making for the referee. Results suggested the training intervention was effective for lower ranked officials, but not higher ranked officials, implying experience level is an important factor to consider when developing decision-making training programs. This training process is said to help orientate officials' attentional focus, reduce mental workload, and improve decision accuracy (Mascarenhas et al., 2005b).

Information priming strategies*. Directing officials to essential decision information prior to making decisions is another approach, described as information priming. MacMahon et al. (2007b) developed a video-based infraction detection task for basketball referees. Prior to testing referees' accuracy to detect fouls and basketball violations, referees were engaged in different priming

strategies (i.e., either knowledge-priming by completing a rules test, or infraction-priming by watching a video of defensive fouls) to improve decision cue recognition. The results suggested priming strategies as a mode of training didn't demonstrate clear improvements in referees' infraction detection, however the researchers discovered that infraction detection did improve based on aspects of video clip difficulty and format of sequencing. The authors suggest decision-making training tools for referees should focus on increasing perceptual difficulty from on-ball to off-ball infractions.

Multiple-cue learning. Interactor officials must attend to numerous decision cues in their decision-making which has been the focus of some training studies. Plessner et al. (2009) draw on Brunswik (1955)'s multiple-cue learning framework (or, probabilistic functionalism) that suggests how learning occurs through repeated exposure to probabilistic information. It proposed that soccer officials' decision-making is mainly intuitive or automatic compared to deliberate (i.e., integrating rule-based knowledge in a serial manner (Schweizer et al., 2011)), and requires multiple cues rather than a single decision cue. Therefore, the quality of officials' decisions may be improved through training that helps officials acquire links between multiple cues and the decision criteria through automatic learning process and immediate feedback. Schweizer et al. (2011) developed a web-based, decision-making training tool (SET; *S*chiedsrichter-*E*ntscheidungs-*T*raining) aiming to improve soccer officials' intuitive decision-making processes. A database of video sequences of foul situations (i.e., physical contact between opposing players) was developed (144 clips in total) and matched with the correct decision provided by soccer league senior refereeing administrators (i.e., expert modelled feedback). The authors emphasize such decision-making training tools should be predicated on single and immediate feedback in order to reinforce relationships between decision cues and criteria for isolated decision situations. This is seen as vital in categorization tasks for enhancing intuitive processing as opposed to more deliberate processing of decision situations.

Implicit learning approach. Feedback to support learning is a common feature of video-based training programs in sports officials (Kittel et al., 2019a; Schweizer et al., 2011). An alternative approach is an implicit one where officials receive no instruction or feedback while undertaking the video-based training. Receiving less instruction and feedback during training has been reported to lead to performance improvements in stressful environments (i.e., competitive games) (Raab, 2003).

When deliberating over a more explicit (i.e., feedback and/or instruction) or implicit approach, there is a trade-off that must be considered for the duration of the training program. Explicit instruction can lead to more rapid performance gains, yet lower retention of knowledge and decreased competitive performance (Raab, 2003; Smeeton et al., 2005). For video-based training, this means existing explicit approaches use short video-based training programs with less clips. Larkin et al. (2017) investigated an implicit approach using a significantly greater amount of decision-making scenarios from a match broadcast perspective in training Australian football umpires (1,040 total clips over 12 weeks). While the results demonstrated there were improvements for participants within the training group, there were greater improvements for the less experienced participants. The results indicated the significant differences between the less experienced and experienced group prior to the intervention, but over time the two groups converged, with the less experienced umpires performing to a similar level on the video-based test as the experienced umpires following the training program. Therefore, the authors suggested observation of match play decision-making situations may hasten skill development in less experienced umpires; however, experienced umpires are less susceptible to change with this mode of training. Therefore, it may be experienced umpires may require more representative training programs for skill development.

Visual search strategies*. Visual attention is sometimes regarded as a component skill to judgement and decision-making in sport, with researchers suggesting a better understanding of referee gaze behaviour can improve training and education of visual search patterns, and in-turn decision-making (Abernethy & Russell, 1987; Hancock & Ste-Marie, 2013). A challenge is most studies that compare elite and non-elite referees use eye movement recorders with pre-recorded video clip compromising the representativeness (Spitz et al., 2016), and sometimes showing no differences between experienced and less experienced officials (Hancock & Ste-Marie, 2013). Also, using visual search patterns alone as a proxy for novice-expert decision-making differences can neglect to account for underlying meaning attributed to such visual cues in decision-making. No studies to date have attempted to design training to enhance referee gaze and visual search strategies, but some newer approaches that record officials' gaze behaviour during their performance using mobile eye tracking devices might be a first step.

Blurred video training. Research has suggested incorrect decisions are often made by sports officials when there is missing information leading to a breakdown of the decision-making process (MacMahon & Mildenhall, 2012). van Biemen et al. (2018) removed key perceptual information by contrasting blurred and normal video footage in a video-based training intervention, with 70 clips per condition. Results demonstrated the blurred video training group experienced greater training adaptations than the normal group, which the authors attributed to being more effective identifying key kinematic information that relates to a foul, rather than focusing on superficial information. Approaches such as blurred training may assist officials with removing irrelevant information to the decision-making process, and focus on more relevant cues.

Physical exertion simulations. Given the high physical loads officials experience within games (Blair et al., 2018; Elsworthy et al., 2014), researchers have investigated the influence of decision-making under high physical stress in off-field settings. Studies in Australian football suggest decision-making is not negatively impacted under physical exertion, whether that be during the quarter breaks of a game (Larkin et al., 2014) or after repeat maximal intensity 300m running efforts (Paradis et al., 2016). To further this area of knowledge, Kittel et al. (2019a) examined whether incorporating video-based training into high intensity interval training is a more beneficial approach for developing decision-making than at rest. The authors concluded this training method had no additional benefit to standard video-based training in the development of decision-making. Although physical exertion is a key constraint of in-game officiating, there may be more representative methods as this not appear to negatively impact decision-making.

Samuel et al. (2019) introduced one of the first representative approaches to off-field decision-making training through a simulator strategy. Officials were required to exert physical effort (i.e., running on a treadmill at varying paces) while making decisions on two condensed video recordings (each 30 minutes) of a full soccer match (90 minutes). Officials were required to make decisions in either a mixed order or the actual order they occurred in the match. Assessment of the soccer referees' decision accuracy differed depending on the observed decision event. In assessing officials' decision-making after the training, for less complex decisions (i.e., 'out of play') officials were 74% accurate, for 'careless fouls' 63% accurate, and for decisions deeming a yellow or red card

officials were 26% accurate. Accuracy of yellow or red card decisions were slightly less accurate when video situations were mixed (21%) compared to decision events in context (29%), and finally, decisions were less accurate during final stages of the match. While officials' felt the training was moderately representative of their actual performance, the authors suggest a simulator approach can be an innovative way to train sequential decision-making and manage influences of fatigue on decision-making.

3D virtual training environments. More recent digital technology advancements use 3D virtual environments in officials' training to provide opportunities for increased experience to actual real-world officiating settings. It is suggested that immersion in computerized environments similar to the real stadium atmosphere can help soccer referees experience challenging decision situations to decrease decision error and become better accustomed to spectator presence they may encounter during actual performance (Gulec et al., 2019). Gulec et al. (2019) used this form of training proposing in their study it allows for the learner to experiment in a safe practice environment prior to the risks and difficulties that come from real-world decision situations. While enhancing decision accuracy was not an explicit purpose of the training and therefore not considered an intervention similar to other studies outlined, participating officials identify the utility of first-person training experience and game likeness. In the future, studies of the impact virtual environments have on the transfer of learning and decision-making skill needs to be evaluated further to prove benefits and utility of such modalities.

360°VR training. With technology developing, virtual reality has emerged as a tool to develop perceptual-cognitive skills for athletes (see Faure et al. (2020) for a review). VR has been acknowledged as an expensive tool (Düking et al., 2018), however, leading to technology such as 360°VR which is a 'middle ground' between VR and the screen-based approaches described throughout (Fadde & Zaichkowsky, 2018). A training intervention examining 360°VR and the previously used match broadcast video as training groups, in addition to control (i.e., no training) was examined over five weeks in Australian football umpires (Kittel et al., 2020b). Although no significant results were evident immediately post training, the 360°VR scored significantly higher decision-making accuracy than the control five weeks following training in a retention test. No

differences were observed for match broadcast video between the control and 360°VR groups. Further, participants rated the 360°VR video to be more relevant and enjoyable than match broadcast video, with no differences observed for concentration and effort. Authors attributed the positive finding for 360°VR compared to control to the greater ecological validity (i.e., how similar to game decision-making) of this video mode (Kittel et al., 2020b). Further research may need to investigate this technology in sports officials.

***** Insert table 1 around here*****

Discussion

As evident in this review, video-based training has emerged for different interactor officials, with a particular focus on both soccer and Australian football officials. Most studies have isolated decision-making which may limit the representative of such training, and has been described as a more 'decontextualised' approach (O'Brien & Rynne, 2020). Further, the ecological validity has not been optimal in existing training which commonly uses match broadcast video to present video that may not have similar perceptual cues to competition. Most studies included in this review have examined decision-making interventions in non-elite officials, subsequently limiting the ability reliably assess in-game decision-making changes following the interventions. No studies in sports officials have examined whether reflective learning may be an appropriate intervention approach for sports officiating, as has been conducted using video-based training for decision-making accuracy.

Most of the studies in this review were not representative of in-game decision-making, as most trained in a decontextualized manner, without consideration of the constraints surrounding the official in-game (O'Brien & Rynne, 2020; Russell et al., 2019). This suggests research may need to shift from isolated decision-making approaches, to incorporating specific constraints of the environment (i.e., a more representative approach) (Pinder et al., 2015). Table 1 illustrates the number of studies in this area which have integrated game constraints (e.g. context, fatigue) for a more representative training tool. The non-shaded boxes represents where no studies have incorporated the constraints listed. Evidently, there is scope for future research to combine more constraints into

decision-making training using more ecologically valid technologies. Samuel et al. (2019) is an example of incorporating constraints such as physical exertion and contextual judgement into a decision-making training protocol. It is important to tailor the constraints to the specific needs of the unique officiating population. There are, however, several other factors which may influence decision-making in-game, and need to be managed by the official. These include position on the field (Corrigan et al., 2018); crowd noise (Balmer et al., 2007); physical exertion (Bloß et al., 2020); managing interactions with players (Cunningham et al., 2018); communicating with other match officials (e.g. assistant referees, VAR) (Spitz et al., 2020); contextual judgements (Burnett et al., 2017); and sources of stress (Anshel et al., 2013). Each of the above are examples of constraints officials must manage in competition to effectively apply the laws of the game (i.e., decision-making) and manage unfolding game activities. Including one, or multiple constraints would therefore lead to a more representative approach (Pinder et al., 2015). It is important to consider, how constraints introduced in training can have implications on the ecological validity and representativeness of training as dictated by development period. For example, it may not be beneficial to initially include all constraints or expose officials' to more complex context, dilemmas and constraints. Subsequently, a more representative approach that appeals to the development level would theoretically lead to stronger transfer to the field (Hadlow et al., 2018). Such methods would be less 'decontextualised' (O'Brien & Rynne, 2020; Russell et al., 2019), and overcome limitations of previous approaches.

As highlighted throughout this paper, match broadcast video has been a common method to present sport-specific decision-making training in officials. This is due to the ease of capture and minimal financial implications of using this viewpoint. Samuel et al. (2019) highlight virtual reality or first person videos can be costly and time-intensive to develop, leading to the common use of match broadcast. This technology lacks ecological validity due to the different perceptual information to what is received in-game (Kittel et al., 2019c). As such, 360°VR emerges as a more ecologically valid training tool for officials (Kittel et al., 2020b) and athletes (Pagé et al., 2019; Panchuk et al., 2018), researchers must consider whether the extra financial costs associated are worth creating a more representative training tool. This type of technology may also be a tool where new decision scenarios from recent games are included to present current sporting tendencies. Panchuk et al. (2018) and

Kittel et al. (2020a) discuss how 360°VR is commercially available at affordable prices, which may lead to this tool being more widely used. As discussed with a SWOT analysis by Kittel et al. (2020a), 360°VR has greater ecological validity and behavioral correspondence through the head movements afforded. This allows opportunities to officials to scan and proactively search for possible infringements. A current limitation of this technology is that it has only been investigated using a stationary perspective, yet there is opportunity to develop moving 360°VR as technology develops (Kittel et al., 2020a).

First-person video has been utilized in studies developing interventions for offside decision-making in assistant soccer referees (Catteeuw et al., 2010a; Catteeuw et al., 2010b; Put et al., 2013; Put et al., 2016; Put et al., 2015). This is appropriate for simulating tasks such as offside due to the minimal injury risks posed to the players being filmed. However, filming simulated tackles in soccer, rugby union or Australian football would either pose an injury risk to players or not be realistic. Therefore to achieve ecological validity in video-based tasks, researchers and practitioners must consider using first-person video filmed from small-sided games (Kittel et al., 2019c) or competitive games (Mascarenhas et al., 2005b). Given the call for less decontextualized approaches (O'Brien & Rynne, 2020), first-person game footage may be the optimal method.

Most commonly, training approaches are historically aimed to foster officials' ability to identify the correct decision outcome (Larkin et al., 2017; Schweizer et al., 2011; van Biemen et al., 2018). To determine the correct decision for a game, video test or training intervention researchers use several subject matter experts (i.e., elite referee/umpire coaches) engaging in a discussion (Corrigan et al., 2018). This highlights one difficulty of identifying the correct decision outcome for referees and umpires in training studies. This quantitative approach (i.e., identifying the correct decision) has drawn debate from the qualitative research field (O'Brien & Rynne, 2020), outlining how existing research 'misses the mark' with decontextualized training approaches by only quantifying the accuracy and number of decisions, rather than qualitatively understanding the context around decisions. For example, two decision scenarios are not the exact same (how the infringement occurred, the time of the game, previous decisions made etc.). Therefore, using one putative correct decision may not be appropriate as officials need to develop the skill of differentiating their decisions

relative to its context. Only one study in this review used assessed the effect of contextual decision-making (Samuel et al. 2019). Raab et al. (2020) recognise the increased use of qualitative methods to understand context and constraints in officiating decision-making that has implications for training strategy (Boyer et al., 2019; Russell et al., 2019). Future research should shift towards assessing and training decision-making with consideration of context, to enable officials to manage their environment adequately through their decisions (Russell et al., 2019).

Standards for expertise in officiating performance, outside decision accuracy, will inevitably need to develop sport-specific definitions and emphasise individualized learning approaches. For example, newer recommendations on expertise development in high performance sport officials suggest a need for understanding how officials plan and orientate their complex modes of learning (O'Brien & Rynne, 2020). When determining expertise in officials, there is a need to shift from weakness-based approaches to more strength-based pedagogical approaches. This considers the multitude of 'strategies, tactics, techniques, and subtext sport officials use to navigate their craft' (O'Brien & Rynne, 2020; p.6). Further, it may also benefit to gain insight into the implicit standards and norms of observers/assessors when assessing expertise in officials' actual performance (Boyer et al., 2014).

This follows to another question researchers and practitioners must consider is whether it is possible to assess changes in decision-making skill. Although research has used on-field transfer tests using live training scenarios (Put et al., 2013), this remains a decontextualized approach without all the additional factors experienced in competition (O'Brien & Rynne, 2020). Video-based tests have often been the measure of decision-making changes following interventions in sport (Larkin et al., 2015). While these methods demonstrate some level of validity and reliability in sports officials (Kittel et al., 2019d), there are limitations which must be considered. Firstly, these methods may not represent the complex environment and interactions officials encounter within competition (O'Brien & Rynne, 2020; Russell et al., 2019). Indeed, there are indications that perceptual-cognitive training can be an ideal approach to improve decision-making factors in an isolated decision-making task (Larkin et al., 2017; Schweizer et al., 2011), but the degree to which such improvements can be transferred to actual competitive performance needs to be further evidenced, similar to such strategies

used with athletes (Farrow, 2013; Renshaw et al., 2018). Kittel et al. (2020c) assessed the relationship between decision-making in two video-based tasks (360°VR and match broadcast) and in-game decision-making. There was no significant relationship between the two video-based tests to in-game decision-making, which the authors attributed to key constraints missing in the video-based tests, hence limiting representativeness achieved. Future research should consider reliably assessing in-game decision-making changes following decision-making interventions. As evident in Table 1, few studies have attempted to provide constraints of in-game competition such as contextual decision-making (Samuel et al., 2019), communication (no studies) or psychological/emotional factors (no studies). Future studies may include some, or a combination of these constraints, to be more representative of in-game decisions. Studies may look for a more qualitative approach where there is individualized feedback during and post training, accompanied by qualitative assessment of the trainee's experience.

When training any skill, the length of an intervention or time to see an improvement is a consideration for coaches. As mentioned above, implicit approaches may lead to stronger retention of knowledge (Larkin et al., 2017). A key limitation of this method is the longer time periods required for a more self-guided approach. Studies in the sports officials literature have often completed short (i.e., one to five session) interventions (Kittel et al., 2020b; van Biemen et al., 2018), which lead to immediate improvements in a video-based test. The literature suggests more longitudinal perceptual-cognitive interventions are required rather than existing approaches (Farrow et al., 2018). In addition to longer programs, implementation of a skill acquisition framework (Farrow & Robertson, 2016) for officials, similar to athletes, may assist with stronger decision-making interventions which translate to the field. In particular, it would be beneficial for officials' development to systematically assess the combination off-field video-based and on-field naturalistic training programs.

Researchers must also consider the aim of a specific training program. As highlighted throughout, studies often have one putative decision for every scenario that the officials must learn (O'Brien & Rynne, 2020). When the putative decision is subjective in nature, it can be difficult to definitively determine whether the reference decision is correct or lead to conjecture on the 'correct decision' for different scenarios. For example, decision-making training for officials is often

493 measured on a criterion task such as a video-based test, where the correct decision is determined by a
494 coach (Larkin et al., 2017; Schweizer et al., 2011). This is due to the desirable decision-making
495 hierarchy from coaches to officials (Mascarenhas et al., 2005a) and because the accuracy of making
496 decisions is commonly cited as the most important performance attribute for officials (Kittel et al.,
497 2019b; Morris & O'Connor, 2016). The reflective learning approach described above on the other
498 hand may be a suitable compliment to other training with central aims of decision accuracy.
499 Reflective learning can be used to better understand the official's point of view during the match in
500 order to help them make an acceptable decision. This may overcome limitations outlined by O'Brien
501 and Rynne (2020) where decision-making training commonly focuses on the one correct decision.
502 This method may create a more implicit or self-guided approach for stronger retention of learning in
503 the absence of feedback or instruction (Masters, 1992; Raab, 2003).
504 Elite soccer referees identify self-reflection and being self-critical of decisions to be important
505 to develop and maintain officiating excellence (Slack et al., 2013). Off-field, reflective practices such
506 as self-analysis primarily aid interactor sport officials to supplement the conventional lack of
507 deliberate practice hours afforded to officiating learning environments (Samuel, 2017; MacMahon et
508 al., 2007a; Mascarenhas, et al., 2002). Stimulated recall (Lyle, 2003) can often be the main reflective
509 approach used by referees to improve decision-making. This involves reflecting on a decision
510 situation (whether a previous decision made by the referee or by another referee) and providing
511 decision reasoning or interpretation of perceptual and player cues. A focus to learn one correct
512 decision for any situation can be a limitation (O'Brien and Rynne (2020) where such isolated
513 situations devoid of context neglect other constraints and affordances on sport officials' decisions
514 (Russell et al., 2019; Samuel, 2017). Officials must also make decisions respective to unique
515 situations in a just and fair manner (Russell et al., 2019).
516 Other reflective learning approaches encourage the learner to re-experience context and
517 constraints underpinning their decision-making and activity. Based on phenomenological traditions
518 (Theureau, 2003; Vermersch, 2012), an elicitation (or evocation) approach dictates a 'reflection-on-
519 action' process with the objective to confront one's own or another's decision-making activity. This is
520 shown to help performers develop explicit procedural and tacit knowledge contributing to decision-

making. It enables understanding of spontaneous cognitive processes (e.g. what is the most significant for the individual) during a critical event or face an emergent problem in a particular context (Hauw, 2018). This allows the performer to access and make sense of their knowledge-in-action as a way to approach what is an 'acceptable' decision rather than what might be most 'accurate' such as the adequacy vs. accuracy debate (Helsen et al., 2019; Schweizer & Plessner, 2016). Applied within sport coaching (Mouchet & Maso, 2018) and athletic performance training (Mouchet, 2005), this approach has been recently trialed in sport officiating (Rix-Lièvre et al., 2015). Lessons from reflection is used to improve high-pressure decision-making in sport sometime focus on 'slower' and more 'deliberate' forms of reflection. This considers a feed-forward, 'reflection-for-action' design where, for example, sport team players use slow deliberation through team meetings and video review reflect to improve more rapid response and adaptivity to a variety of contextual situations. In developing decision-making of sport officials, this area should continue to be supported by research on players. For example, Richards et al. (2017) developed a framework to foster decision-making in a more naturalistic context (i.e., less isolated), with particular focus on situational factors such as pressure and teammates. Such approaches for officials could improve the contextual factors experienced in training. These approaches could benefit interactor sport officials' reflective practice to strengthen their anticipation for decision contexts and recognition for more novel decision events.

360°VR has been examined as a potential training tool with some positive results in Australian football umpires (Kittel et al., 2020b). The immersive qualities of 360°VR have proved effective in teacher training that allow pre-service teachers to reflect on their own teaching practices through the multiple viewpoints afforded by the 360° video (Walshe & Driver, 2019). Such reflective training approaches may be an appropriate method to facilitate decision-making development in sporting officials, without always referring to one putatively correct decision. With such technology developing, it may be possible for officials to wear a 360°VR camera in-game to allow for immersive reflective practice through an ecologically valid tool (Kittel et al., 2019c). First person video captured in-game (Nazarudin et al., 2015) would allow for initial reflective approaches.

Various types of high-tech equipment are being gradually introduced into some sports to assist sport officiating processes. The introduction of VAR has demonstrated a 6% increase in the

accuracy of on-field decisions (Spitz et al. 2020). With the advent of VAR, it occupies one visible constraint and support for interactor sport officials decision-making processes considering indications that VAR helps reduce the number of penilisations (Han et al., 2020), but the amount of game play time increases due to these officiating decision processes (Carlos et al., 2019). This shared decision-making between the on-field official and video observer contributes to increased communication demands (Cunningham et al., 2015). Training communication processes between the VAR and on-field official related to decision standards and contextual interpretation are becoming a hieghtened need for improving officating processes (Spitz et al., 2020). It must be noted, however, that VAR is only available to elite populations in soccer. Therefore, methods such as video-based training must be used to accelerate expertise in officials of non-elite officials where VAR is not available to assist with on-field decisions. Other sports such as Australian football do not use any off-field technology such as VAR to assist with on-field 'one on one' decision-making included in this review. As a very small percentage of officials use technology such as VAR to assist decision-making, notwithstanding sports which do not employ VAR, this highlights the need for training methods to be optimised and accelerate expertise in officiating.

Conclusion

To summarise, this paper presents an outline of previous decision-making approaches in interactor sporting officials, with the aim to present recommendations for future research studies in this field. It is evident development approaches for sporting officials have grown (and accelerated) over the last two decades. Main features of different off-field decision-making training for interactor officials include watching a video stimulus of sport-specific decision-making scenarios. Identifying optimal methods to train this skill are imperative given its well-documented importance to overall performance. Different instructional approaches have been used included explicit and more implicit approaches, with a degree of variation in the length of stimulus. Similarly, there has been a range of technologies and different viewing angles used, where the most common approach in the literature has been match broadcast video. There are, however, several limitations of previous approaches such as a decontextualized approach and limited representativeness. This paper recommends the use of

theoretical frameworks such as representative learning, ecological validity to present more game-like decision-making protocols. Other suggestions for future studies include longer and more structured interventions, or further investigation into the efficacy of reflective learning approaches. Incorporating the concepts discussed throughout may theoretically lead to improvement of the most important skill used in sports officiating; decision-making accuracy.

Practical recommendations

1. The representativeness of officials' decision-making training should be increased by including constraints faced in competition such as match context, fatigue and the perspective used to make decisions.
2. When assessing the efficacy of decision-making training, coaches and researchers should consider the adequacy of decisions in relation to the wider context, rather than the accuracy of the decision without context.
3. Reflective learning approaches may be a suitable decision-making training technique that allows officials to reflect on their decisions with consideration to the wider context, rather than assessing the accuracy in comparison to one putative 'correct' decision.

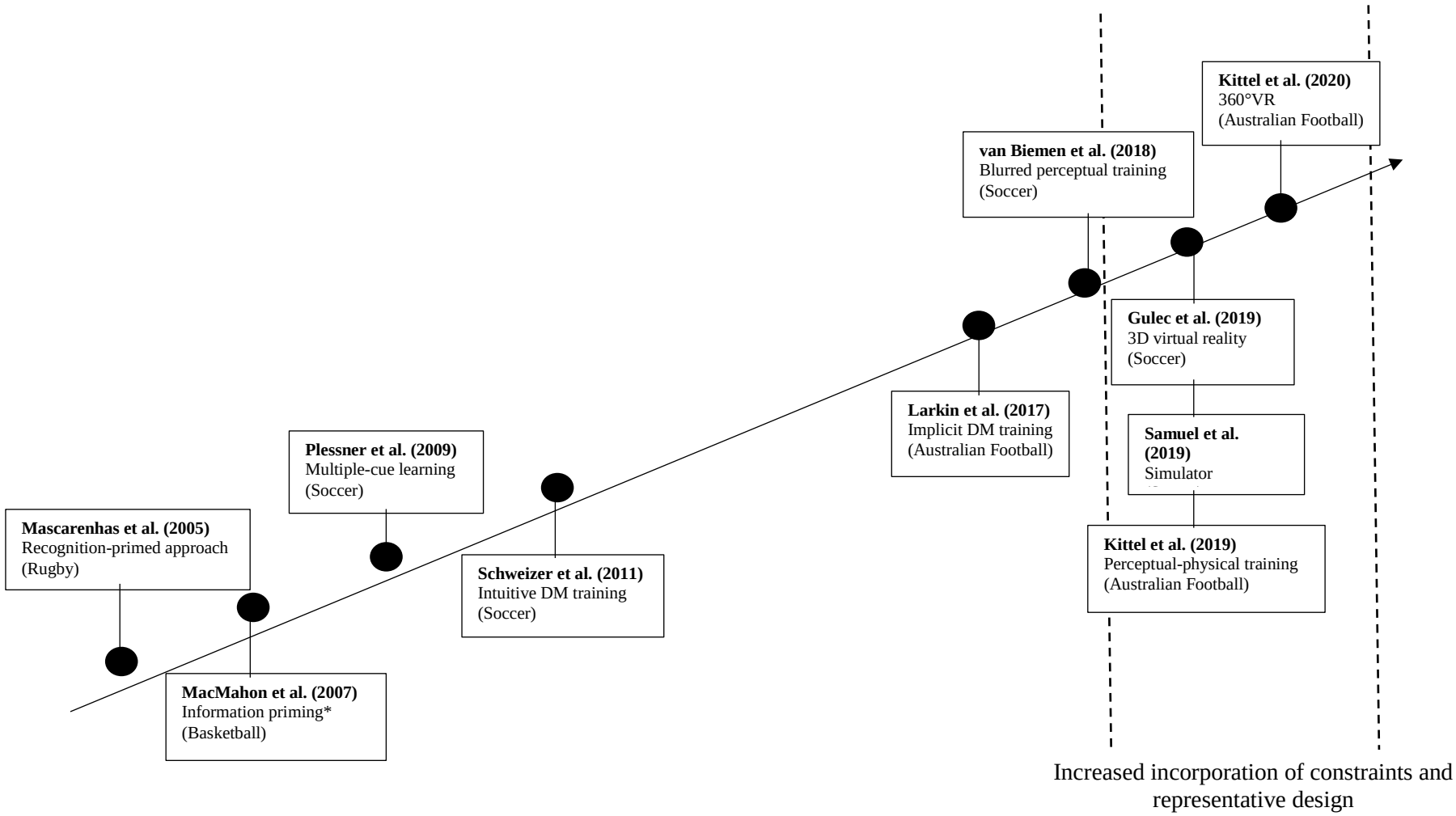
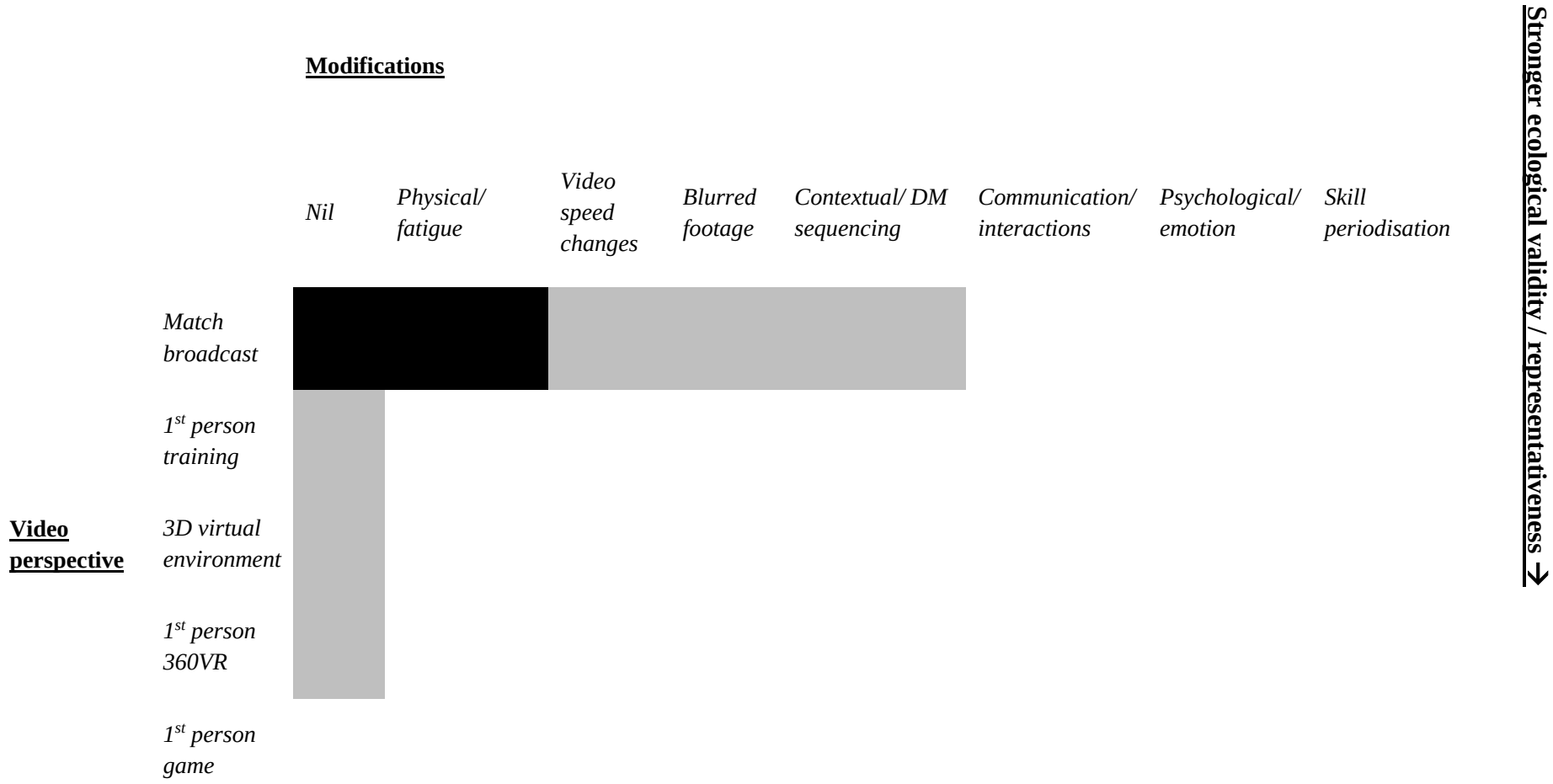


Figure 1: Progression of off-field decision-making approaches for interactor sports officials (only including central officials).

1 Table 1: Existing decision-making training studies in interactor officials



2

3 Note: Black boxes indicate 2+ studies, grey indicates 1 study, no shading indicates 0 studies.

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