



Original research

Using 360° virtual reality as a decision-making assessment tool in sport

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ABSTRACT

Objectives: To examine the reliability, construct validity and ecological validity of 360° VR and match broadcast footage for off-field decision-making assessment in Australian football umpires.

Design: Validation assessments with test re-test reliability.

Methods: Two video-based tests of 60 clips each were developed to assess Australian football umpire decision-making, including 360° video of small-sided Australian football games and match broadcast footage of AFL games. Elite (n = 13) and amateur (n = 15) umpires participated in two testing sessions, in a randomised, counterbalanced design. Test re-test reliability was assessed using Cohen's Kappa for individual clips and Intraclass Correlation Coefficients for test scores. Video tests were assessed for construct validity. Ecological validity of the decision-making processes was assessed for each method.

Results: 31 clips met the minimum Kappa criteria for the 360° VR test and 28 clips for match broadcast. Results indicated strong reliability for the 360° VR (ICC = 0.89) and match broadcast (ICC = 0.89) tests. For both video modes, elite umpires performed significantly better in decision-making accuracy than amateur ($p < 0.05$). For ecological validity of the decision-making processes, 360° VR was rated significantly higher than match broadcast vision ($p < 0.05$) overall.

Conclusions: This is the first study to examine the reliability and validity of 360° VR footage as an off-field decision-making assessment tool in sport. As match broadcast vision is commonly used to assess decision-making in athletes and officials, results suggest that 360° VR is also an appropriate assessment tool. Although both video modes demonstrate similar reliability and construct validity, 360° VR was considered more specific to in-game decision-making processes, suggesting stronger ecological validity.

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Practical implications

- 360° VR is a reliable and valid assessment tool for perceptual-cognitive skills such as decision-making and has potential to be explored in a range of sporting environments.
- 360° VR is considered to represent more game-like decision-making processes than footage sourced from a broadcast perspective, suggesting 360° VR to be a more ecologically valid decision-making tool.
- Future studies should compare the effectiveness of both 360° VR and traditional broadcast methods in developing decision-making.

1. Introduction

Decision-making is a key perceptual-cognitive skill in sport, defined as the ability to perceive and correctly interpret game-related information to select an appropriate sport-specific response.¹ There has been extensive research investigating decision-making processes of athletes.^{1,2} Importantly, decision-making skill can differentiate between skilled and less-skilled performers in sport.^{3,4} Sporting officials have emerged as a key group to examine this skill as decision-making is the most important skill for successful performance.^{5,6} It has been acknowledged that to develop decision-making, the best form of practice is in-game performance.⁷ There are only a finite amount of games with inherent physical loads, which has led to the development of additional methods to investigate decision-making. To investigate and assess decision-making, video-based methods are commonly used as they provide a controlled off-field environment for testing and

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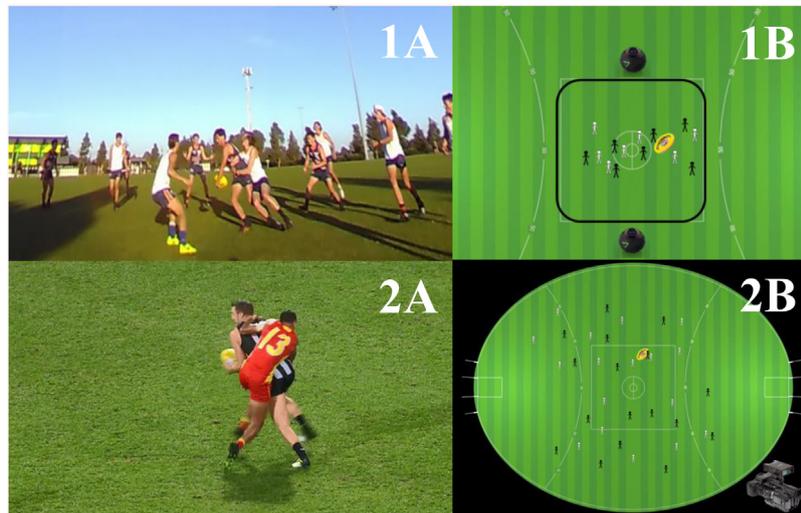


Fig. 1. An example of the (1A) 360° VR decision-making test footage, (1B) 360° VR filming design, (2A) match broadcast decision-making test footage and (2B) match broadcast filming design.

training both athletes⁸ and officials.⁹ Due to the high variability of match decision-making, video-based assessments provide a reliable and valid measure of decision-making performance.

An advantage of video-based methods is they provide greater control and consistency of scenarios than in-game decision-making assessments.⁹ Video-based methods present a short game-based scenario where an athlete or official must make a sport-specific decision. Video-based measures have highlighted differences between skilled and less-skilled performers in a range of athletes such as Australian football players⁸ and Australian football umpires,^{9,10} suggesting strong validity of the video-based tasks. There are, however, inherent limitations associated with using video-based methods. For example, these methods typically use a broadcast or third-person (exocentric) perspective, which is filmed from an elevated position in the grandstand.¹¹ As a result, footage from an exocentric perspective does not replicate the position or the potential in-game perceptual-cognitive information required in the decision-making process of an umpire or athlete. Research has suggested the implementation of first-person (egocentric) viewpoints would increase the representativeness of decision-making tasks.¹² Further, traditional video-based methods also limit interactivity and representativeness of the task whereby video footage does not automatically update with visual changes from head movements.¹¹ This is critical in 360° sports such as soccer, basketball and Australian football as it could provide information regarding the ability to identify player movement patterns in all areas of the field. Despite a range of research using video-based methods, there is potential for researchers to create more representative tasks.

To address these limitations, virtual reality (VR) has been suggested as a more suitable and representative task to assess decision-making.^{11,13} VR is a term used to describe simulations of a real or imaginary environment, whereby a participant can both perceive and move (interact) within the environment.¹¹ Typically, VR has explored animated/virtual sporting environments presented on a large screen,¹⁴ or through a head mounted display (HMD).¹⁵ A key premise of using VR is to increase representativeness, suggesting real world footage may be a suitable alternative to animated footage when using this technology. 360° VR has emerged as a possible testing and training tool for decision-making in sport. A recent study examined the effectiveness of 360° VR on enhancing decision-making in basketball players.¹⁶ This study found large yet non-significant improvements following the intervention, suggesting more research is required to determine the effectiveness

of this technology. The reliability, construct validity and ecological validity of 360° video viewed through a HMD as a decision-making assessment tool, however, has not yet been examined in the literature. Therefore, the primary aim of this study is to examine both the reliability and construct validity of two different video-based methods to assess Australian football umpires' decision-making skill. These two video-based methods are 360° VR (i.e., egocentric viewpoint) and traditional match broadcast footage (i.e., exocentric viewpoint). A secondary aim will be to evaluate the level of ecological validity of each method through game-likeness ratings.

2. Methods

28 participants across two performance levels, elite and amateur, participated in this study. The elite group comprised of 13 Australian football umpires who officiate in the Australian Football League (AFL), with a mean age of 29.9 years ($SD=5.9$). The elite cohort had umpired for an average of 15.07 years, with an average of 7 years at the AFL competition level. At the time of this study, the average AFL matches officiated by this group was 118 ($SD=109$), with all umpires being on the elite list for at least one full season. The amateur group consisted of 15 Australian football umpires who officiate in an Australian football Metropolitan division one competition, with an average age of 27.8 years ($SD=12.0$). These participants had umpired Australian football for an average of 9.73 years, with none of this group having umpired at AFL level. Ethics approval was granted by the by the Victoria University Human Research Ethics Committee (approval number: HRE18-122) and all participants provided informed consent prior to participating in the study.

Two different video-based methods for decision-making skill of Australian football umpires were developed: 360° VR footage and match broadcast footage. For both tests, inclusion criteria for decisions were player contact scenarios, with decisions including: “play on”, “holding the ball”, “high tackle”, “push in the back” and “contact below the knees” as outlined by the “Decision-making heuristic for a tackling situation” in Australian football.¹⁷

360° VR footage was obtained from small-sided games and match simulations completed by high performance Under 18 Australian football players as part of their standard training procedures. This was filmed from the perspective of an umpire in match play using a 360° video camera (360fly 4k Camera, 360fly, Canonsburg, USA). The camera was positioned on a tripod 1.5 m above the ground. To optimise representativeness of the footage, the cam-

era was positioned approximately 15 m from the training drills, in a similar position to an umpire in-game. Fig. 1 presents a static example of this footage and a map of the setup.

For the match broadcast test, footage from the 2017 AFL Premiership Season was obtained from the AFL Umpiring Department. This footage was filmed from an elevated position in the grandstand. Videos were not included if the elite cohort had received group coaching on the particular scenario, or if the umpire's in-game decision was observable in the clip. Fig. 1 presents a static example of this footage and a map of the setup.

For each mode, clips were edited into short (3–12 s) individual clips presenting a possible infringement (i.e., free kick), as per previous methods implementing a video-based decision-making task.¹⁸ Clips were excluded if there was a poor/distant camera angle. 100 clips from each video mode were presented to subject matter experts: full-time AFL umpire coaches ($n = 2$). The two coaches had on average 10 years' experience coaching at the elite AFL level. The coaches assessed the face validity (i.e., whether there was a potential decision-making scenario) and the correct response for each clip. If the coaches did not agree, a discussion on the correct decision occurred until they came to a consensus decision. At this stage, videos were removed if there was no clear decision, per coaches' feedback. The coaches and the authors discussed the final selection of clips to be used in both decision-making tests. To ensure consistency between tests, there was an identical number of each individual decision type (i.e., "play on", "holding the ball", "high tackle", "push in the back" and "contact below the knees") within each test. "Play on" decisions, which were situations where no free kicks were awarded but still required a deliberate "no" decision from the umpire¹⁸ were also included within the tests.

For both tests, a three second period was presented before each clip indicating the clip number in white text on a black screen. For the 360° VR condition, this period also included arrows pointing to where the clip number was, to enable the participants to orientate themselves within the 360° space. This was followed by the presentation of a static image of the first frame of the clip for two seconds to provide context, immediately followed by the clip. At the conclusion of each clip, a static image of the final frame appeared for 0.5 s. This was followed by a six second period where a black screen was presented, with white text stating "make your decision" per previous methods.⁹ This sequence was repeated for all clips. Audio was removed from all clips in both conditions. Final clips were rendered in 4k video (3840 × 1920 pixels) for 360° VR condition and Full HD (1920 × 1080 pixels) for match broadcast video using ADOBE Premiere Pro CS4 video editing package.

Participants completed the decision-making tests two weeks apart at the beginning of a scheduled training session, prior to any physical activity. Standardised conditions were followed for both testing sessions. Each testing session included the 360° VR decision-making task (60 clips) and the match broadcast decision-making task (60 clips), with the sequence of test administration randomised for each participant. Both modes included three practice clips prior to the test to familiarise the participants with the process. These clips were not repeated in the test battery. The 360° VR decision-making task was presented on an Oculus Go HMD (Oculus Go, Oculus, California, USA). For the 360° VR task, participants were seated in a swivel chair to allow the participants to freely and safely view the 360° vision. Participants were required to verbalise their decision for the 360° VR task as they would in a game, with their responses recorded by the research team. The match broadcast test was presented on iPads in a quiet room (Apple iPad Air 2, Apple Inc., Cupertino, USA) as per previous methods.¹⁸ Participants provided written responses on an answer sheet (i.e., "play on", "holding the ball", "high tackle", "push in the back" and "contact below the knees").⁹ For both tests, clip order was randomised between participants and testing sessions.

Test re-test reliability of the individual video-based clip responses was examined by Cohen's Kappa, as per previous research.⁹ Kappa values were categorised as poor agreement (<0.00), slight agreement (0.00–0.20), fair agreement (0.21–0.40), moderate agreement (0.41–0.60), substantial agreement (0.61–0.80), almost perfect agreement (0.81–1.00).¹⁹ Values greater than 0.40 (moderate agreement) were deemed reliable, providing a stronger assessment of reliability than previous research using 0.30 as the benchmark.⁹ Of the clips deemed reliable (i.e., kappa values >0.40), Intraclass Correlation Coefficients (ICC) were calculated for 360° VR and match broadcast video modes, by comparing the scores of each test across the two test sessions (i.e., comparing 360° VR test 1 to 360° VR test 2).²⁰ This was calculated through a widely available spreadsheet.²¹ ICC values were classified as the following: poor reliability (<0.50), moderate reliability (0.50–0.74), good reliability (0.75–0.89) and excellent reliability (≥ 0.90).²²

Decision-making accuracy was calculated by the number of clips with the correct decision response, as determined by subject matter experts. Decision-making differences were calculated only for the clips deemed reliable (kappa value >0.40). Decision-making accuracy differences between the two groups (elite vs. amateur) were assessed for each video mode, which is a form of construct validity by differentiating between known skill levels.²³ To assess decision-making differences between the two groups an independent samples *t*-test was performed for each video mode, with an alpha level of 0.05 deemed significant. Each video method was assessed for normality using the Shapiro-Wilks test. Effect sizes were calculated using Cohen's *d* statistic. Benchmarks for the effect sizes (*d*) were small (0.20–0.49), moderate (0.50–0.79) and large (≥ 0.80).²⁴

The ecological validity²⁵ of each video mode was determined by how closely each video mode replicated the decision-making processes of an umpire in-game. Following the second testing session, participants completed a visual analogue scale²⁶ for each video mode, determining how much the participants perceived each video mode (i.e., 360° VR and match broadcast) to be like in-game decision-making. Participants were asked to "make a dash on the line for how each method feels like your match decision-making process" using a 10 cm visual analogue scale ranging from "nothing like match decision-making", to "exactly like match decision-making". Differences in game-likeness ratings between the video modes were assessed using paired sample *t*-tests. This was analysed by skill level (i.e., elite and amateur), and for the participants overall.

3. Results

The set of 60 clips for each test were each individually analysed for test re-test reliability. For the 360° VR condition, results indicated that 31 clips were considered reliable (i.e., kappa values >0.40). There were 28 clips meeting the minimum reliability criteria (i.e., kappa values >0.40) in the match broadcast test. The ICC demonstrated good reliability for both the 360° VR test (ICC = 0.89) and the match broadcast decision-making test (ICC = 0.89), indicating consistent decision-making accuracy scores across the testing sessions.

The clips identified as reliable for both tests were assessed for construct validity. The average decision-making accuracy score (%) between the two testing sessions for each video mode was assessed for each participant (see Table 1). The elite umpires scored significantly higher than the amateur cohort in both the 360° VR test, $t(25) = 3.78$, $p < 0.01$ and the match broadcast test, $t(23) = 4.40$, $p < 0.01$. There were large effect sizes between groups for the 360° VR test ($d = 1.38$) and the match broadcast test ($d = 1.65$). Therefore,

Table 1
Mean percentage score for the 360° VR and match broadcast decision-making tests.

	Mean (SD)		F	p	Partial η^2
	Elite	Amateur			
360° VR (%)	75.18 (6.37)	65.21 (7.29)	1.13	0.001	0.36
Match broadcast (%)	71.75 (10.65)	50.51 (12.90)	0.66	0.000	0.46

Table 2
Ecological validity of the two video-based modes as assessed through game-likeness ratings.

	Mean (SD)		p	Effect size
	360° VR	Match broadcast		
All participants	6.50 (1.65)	5.00 (2.52)	0.03	0.59
Elite only	5.59 (1.26)	4.63 (2.55)	0.30	0.33
Amateur only	7.75 (1.28)	5.50 (2.56)	0.03	0.95

these results suggest strong construct validity of each assessment mode.

The results from the game-likeness questionnaire indicated that overall (see Table 2), participants rated 360° VR (6.50 ± 1.65) as significantly more game-like than match broadcast footage (5.00 ± 2.52), $t(18) = 2.41$, $p = 0.03$, $d = 0.59$. When considering the game-likeness ratings for the elite umpires only, there were no significant differences between the 360° VR (5.59 ± 1.26) and match broadcast footage (4.63 ± 2.55), $t(10) = 1.084$, $p = 0.30$, $d = 0.33$. The amateur umpires considered 360° VR (7.75 ± 1.28) to be significantly more game like than match broadcast footage (5.50 ± 2.56), $t(7) = 2.679$, $p = 0.03$, $d = 0.95$.

4. Discussion

Numerous studies have suggested VR to be a suitable tool to assess perceptual-cognitive skills such as decision-making,^{11,13} with 360° VR suggested to be an appropriate training tool.¹⁶ This is the first study to investigate the reliability and validity of 360° VR footage to assess sport-specific decision-making skill. Results indicated 360° VR demonstrates strong reliability and validity, similar to previous research examining match broadcast footage with Australian football umpires.⁹ Given the strong construct validity of each video mode, this infers 360° VR can be used as an alternative to traditional broadcast methods in assessing decision-making skill within sports officials.

In the literature, very few studies have examined test re-test reliability, in addition to the validity, of a video-based assessment tool.²⁷ It is integral that a test with strong validity must first have strong reliability, to ensure test differences are due to actual performance, rather than random test error.²³ Similar research in Australian football umpires examined the test re-test reliability of a battery of clips, to be used in future testing scenarios within practice and research.⁹ The strong reliability of the test overall, as evident by the ICC, demonstrate the reliability of using 360° VR as a decision-making assessment tool. Anecdotal results suggest that clips not deemed reliable were due to insufficient information presented in the clip, rather than the skill level of the participants. This study provides an updated battery of broadcast clips, in addition to 360° VR clips which are yet to be validated within the sporting literature.

This research contributes to the perceptual-cognitive literature investigating the off-field decision-making performance of sporting individuals. Construct validity is an imperative measure of video-based tasks, as it differentiates between known skill levels.²³ When implementing a video-based test without this knowledge, it may be unclear whether differences are a result of the skill level differences, or the test design.⁹ Elite officials scored significantly higher than amateur umpires in each video mode, inferring strong

construct validity of both video modes. The results in the present study are analogous to previous video-based methods in Australian football umpires, where elite officials outperformed those from subsequent levels.⁶ Therefore, results suggest 360° VR is an appropriate tool to elicit skill-based decision-making differences.

VR is broadly defined as a video simulation of a real or imaginary environment.¹¹ Two key premises of using VR are to increase representativeness of an off-field environment and secondly to increase immersion in the task through visual changes that coincide with head movements.¹¹ The primary coaching method to improve decision-making skill within sports officials is to utilise video-based methods in an off-field environment. The findings of this study illustrate the application of 360° VR to immerse the umpire in the game environment from a first-person perspective with positive results. Participants rated 360° VR to be more like their match decision-making processes as assessed through the game-likeness ratings, indicating stronger ecological validity of the decision-making processes of the task. This suggests 360° VR could be a more ecologically valid method to present in-game vision for decision-making assessment purposes. Using HMDs allows the participant to select where they are looking, at critical points throughout the clip. In previous first-person investigations not using 360° VR,²⁸ the final footage is dependent upon the direction of the camera at the time of filming, therefore limiting the interactivity of the task. HMDs overcome this limitation and have been used to present VR footage in predicting deceptive movement of rugby players using virtual footage (i.e., not footage of a 360° real world scenario).¹⁵ Possibly due to the high interactivity of using a HMD, experts significantly outperformed novices in the task¹⁵ suggesting this to be a more representative presentation method, similar to 360° VR.¹⁶ Further, developing 360° VR scenarios compared to virtual computer environments is a more affordable process. When considering the accessibility and theoretical premises for using 360° VR along with the results of this study, it appears to be a suitable direction for sport-based decision-making research.

This study presents an opportunity for 360° VR to be examined further in the sporting literature. There is a significant research base utilising video-based methods to assess decision-making in sporting officials¹⁰ and players of different sports.^{8,29} Although there have been promising findings from these studies using broadcast footage, the current study demonstrates 360° VR is a reliable and valid method to assess perceptual-cognitive performance. Given the proposal of 360° VR as an appropriate decision-making assessment tool, future research should also consider 360° VR as a training tool to develop decision-making performance of officials, in addition to athletes.¹⁶ There is a range of empirical studies examining the effectiveness of video-based training for the development of decision-making skill,²⁷ found to be an effective means of hastening expertise of sporting individuals, especially during the off-season or when an athlete is injured.³⁰ As technologies such as 360° VR become more readily available, there is a need for researchers to further investigate how these methods may improve on-field performance. Future studies could utilise similar methods to this study to develop a selection of 360° VR clips for the purpose of assessing and training decision-making skill. Finally, the game-likeness rating used in this study only assessed the decision-making processes of the two technologies in relation to in-game decision-making performance. Future research should consider the impact of other factors such as the testing environment, response mode and decision-making scenarios (i.e., match footage vs. training situations) on the ecological validity of the task. This knowledge would provide researchers and practitioners with a greater understanding of how to create a stronger representation of in-game decision-making using these technologies.

In conclusion, this is the first study to examine the use of 360° VR as a reliable and valid decision-making assessment tool in sport.

The results highlight 360° VR is a reliable and valid assessment tool of decision-making in Australian football umpires, which is consistent with previously used video-based broadcast methods. The higher game-likeness ratings of 360° VR compared to match broadcast footage suggests 360° VR is a stronger representation of in-game decision-making processes. Future investigations should explore the use of this modality in other sports and contexts.

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