Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: www.tandfonline.com/journals/rjsp20

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To cite this article: Francesca Celestina Rosanna Gala , Silvia Francesca Maria Pizzoli , Emiliano Cè & Claudia Repetto (18 Aug 2026): Effects of immersive training on sports perceptual-cognitive skills: A systematic literature review, Journal of Sports Sciences, DOI: 10.1080/02640414.2026.2718641

To link to this article: https://doi.org/10.1080/02640414.2026.2718641

Published online: 18 Aug 2026.

JOURNAL OF SPORTS SCIENCES
https://doi.org/10.1080/02640414.2026.2718641

SPECIAL ISSUE PAPER

Effects of immersive training on sports perceptual-cognitive skills: A systematic literature review

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ABSTRACT

Immersive training using virtual reality (VR), 360° video, and CAVE environments shows potential for enhancing perceptual-cognitive skills in sports; however, evidence remains limited and methodologies heterogeneous. This systematic review synthesised quantitative controlled interventions examining immersive training in healthy participants, focusing on measurement tools and study quality. Fourteen studies met inclusion criteria. Methodological quality was evaluated using the Downs and Black checklist. Extracted data included participant demographics, sport discipline and expertise, immersive technology type, training characteristics, targeted cognitive domains, outcome measures, main findings, subjective evaluations, and transfer effects. The assessed cognitive domains included: higher-order processes (n = 9; decision-making, anticipation), attention (n = 3; gaze control, visual search), processing speed (n = 3), and executive function (n = 2; inhibitory control). Behavioural outcomes were commonly used, with three studies employing cognitive assessments (Stroop and Vienna tests). Moderate-to-large effect sizes suggest that immersive training may enhance decision-making and processing speed. However, heterogeneity in study design and limitations in reporting, validity, and statistical power highlight the need for rigorous RCTs with cognitive and transfer measures to clarify the effectiveness and underlying mechanisms of immersive perceptual-cognitive training in sport.

ARTICLE HISTORY
Received 8 September 2025
Accepted 22 July 2026

KEYWORDS
Virtual reality; immersive technology; cognitive functions; Perceptual functions; athletes; systematic review

Introduction

Over the past decade, rapid technological advances have prompted sports organisations worldwide to adopt extended reality (XR) for sports skills training. Considerable investment has been directed toward developing immersive tools aimed at enhancing sports performance. However, despite widespread enthusiasm and the theoretical potential of these technologies, there is currently no empirical evidence demonstrating actual improvements in on-field performance. XR is an umbrella term encompassing technologies that blend real and virtual environments to varying degrees of immersion and interactivity, including virtual reality (VR), 360° video, augmented reality (AR), and mixed reality (MR) (Kittel et al., 2024). Within this continuum, different XR systems have been employed in sports research, training, and assessment, depending on the desired level of ecological validity and user engagement. The present systematic review focuses specifically on animated VR and 360° video delivered via head-mounted displays (HMDs), as well as Cave Automatic Virtual Environment (CAVE) systems. VR refers to a computer-generated simulation of a three-dimensional environment viewed through HMD, with which users can interact, providing a fully immersive experience that responds to head and body movements (Craig, 2013). Conversely, 360° video, captured from the real world using omnidirectional cameras and viewed through HMD, offers high ecological fidelity, immersion, and affordability, but does not allow interactivity (Kittel et al., 2020). VR, featuring computer-generated 3D environments, typically requires higher costs and programming skills than 360° video, which is simpler to implement and offers greater real-world fidelity. Unlike 360° video, VR may engage distinct visual processing systems, with Runswick (2023) reporting that 360° video primarily activates the ventral stream, whereas VR engages both the ventral and dorsal streams due to its visual action control component. Finally, CAVE systems are room-sized, projection-based installations in which stereoscopic images are projected onto multiple walls (and often the floor) enabling full-body, natural movements. Users typically wear motion-capture systems that track markers placed on the body to update

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the visual scene in real time and allow interaction (Cruz-Neira et al., 1993).

Immersive technologies are creating new opportunities for sports training by enabling embodied simulations that engage perceptual, proprioceptive, and affective systems. Grounded in theories of embodied cognition, these simulations highlight the body's central role in learning (Barsalou, 2008; Wilson, 2002). *Embodiment* refers to the psychological experience of owning and controlling a virtual body perceived as an extension of the physical self (Casula et al., 2022). It comprises three components: ownership, the feeling that the virtual body belongs to the user (Kilteni et al., 2012); agency, the sense of controlling and initiating its movements (Piccione et al., 2019); and self-location, the experience of being situated within the virtual body and its environment (Bailenson et al., 2008). These elements enhance both *presence*, defined as the subjective sense of being in the virtual environment despite being physically located elsewhere (Witmer & Singer, 1998), and *immersion*, defined as the objective sensory fidelity of the system (Bowman & McMahan, 2007). VR, combining a first-person perspective with contingent feedback and active motor engagement, typically produces stronger embodiment than 360° video or CAVE setups. High sensory realism and effective multisensory integration (visual, auditory and haptic), together with feedback and naturalistic interaction, further enhance presence, making virtual experiences more compelling and conducive to learning (Bohil et al., 2011; Slater & Wilbur, 1997). Immersive simulations may also engage the mirror neuron system. Observing oneself performing an action from a first-person perspective appears to activate neural pathways that overlap with those involved in actual execution, potentially supporting action understanding, imitation, and motor learning (Ge et al., 2018; Rizzolatti & Craighero, 2004). This mechanism provides additional theoretical support for immersive sports training, reinforcing the principles of embodied cognition by linking perception and action at the neural level.

Sporting contexts are inherently dynamic, requiring athletes to perceive relevant information, process it cognitively, and make rapid decisions under pressure. Immersive technologies such as VR, 360° video, and CAVE systems can recreate sport-specific scenarios within safe and controlled environments (Gray, 2019), providing opportunities to train perceptual-cognitive skills in game-representative contexts rather than in isolation. Practising within such contexts enables athletes to account for external variables and the situational demands that characterise competitive scenarios (Kelly et al., 2022). Moreover, because this type of training does not require physical exertion, it may be particularly beneficial for athletes recovering from injury. Beyond physical rehabilitation, perceptual-cognitive training may further support the recovery process by restoring sport-specific reaction speed and anticipatory skills, capacities that are often inhibited during recovery. However, to date, no studies have directly investigated this topic.

Perceptual-cognitive skills refer to the ability to perceive sensory information from the environment and to process, interpret, and integrate this information through higher-order cognitive functions, ultimately enabling goal-directed action execution (Hodges et al., 2021). These skills encompass fundamental visual abilities, such as peripheral vision and visual search, as well as advanced cognitive functions including selective attention, pattern recognition, anticipation, working memory, and decision-making (Broadbent et al., 2015; Williams et al., 2011). Although some interventions may target either perceptual or cognitive components more specifically, research suggests that these domains are rarely independent of one another (Fransen, 2024). In sporting contexts, athletes use their perceptual-cognitive skills to classify environmental information, detect and discriminate between relevant and irrelevant stimuli (e.g., through efficient gaze fixations), and allocate their attention accordingly. These skills also involve identifying and recognising patterns or targets and integrating this information with prior knowledge and experience to guide action. Perceptual-cognitive skills are crucial for reading the game environment, anticipating opponents' behaviours, and making rapid and accurate decisions under pressure. Expert athletes typically demonstrate superior perceptual-cognitive skills compared with novices (Wu et al., 2025). Among these skills, decision-making has been the most extensively studied (Kittel et al., 2024) and is defined as the ability to rapidly evaluate available options and select the most effective course of action in a given situation (Bar-Eli et al., 2011).

Immersive technologies such as VR, 360° video, and CAVE systems may be useful for training perceptual-cognitive skills due to their ability to deliver sport specific context. However, further evaluation of the validity of these simulations is necessary to ensure their effectiveness for skill development. Construct validity refers to the extent to which a simulation accurately reflects performance differences (D. J. Harris et al., 2021), while face validity concerns how realistically the simulation represents the actual task (Bright et al., 2012). Wood et al. (2021) examined the construct validity of a soccer-specific VR simulator and found partial overlap between real and virtual performance, suggesting some capacity to distinguish experts from novices in soccer drills. Similarly, Feist et al. (2025) assessed both the construct and face validity of a 360° video simulation in women's soccer and found results supporting both types of validity. In different sport contexts, recent VR batting studies have provided positive but partial support for construct validity, suggesting that some performance outcomes may be more sensitive than others to simulation features and highlighting the need for a more fine-grained assessment of performance sub-components (Runswick, Philips, et al., 2026; Runswick, Phillips, et al., 2026). Overall, this is an emerging area of research, and further work is needed to determine whether immersive environments can provide valid and reliable assessments and training contexts that meaningfully translate to real-world performance.

Despite their theoretical promise and increasing use in sports training (Putranto et al., 2023), empirical evidence on the effects of immersive technologies in enhancing perceptual-cognitive skills remains limited. Most existing reviews have adopted primarily descriptive approaches, documenting VR applications in sport and discussing their potential to enhance performance, support perceptual-cognitive training, and foster sport-related psychological skills (Faure et al., 2020; Neumann et al., 2018; Richlan et al., 2023). However, these analyses provide little empirical evidence on the effectiveness of immersive training interventions. To date, only two reviews (Connolly et al., 2025; Jia et al., 2024) have conducted more rigorous evaluations of VR-based training effects on decision-making, reporting improvements in response speed in team sports but finding no evidence of transfer effects or long-term benefits. Consequently, further synthesis of intervention-based evidence is needed to better understand the effectiveness of immersive training for perceptual-cognitive skill development.

This systematic literature review differs from Jia et al. (2024) and Connolly et al. (2025) by addressing a broader range of perceptual-cognitive functions, rather than focusing solely on decision-making. Furthermore, unlike Kittel et al. (2024), who examined all perceptual-cognitive functions across diverse populations and technologies, the present review focuses exclusively on interventions conducted in VR, 360° video, and CAVE environments with healthy sport participants (from elite athletes to novices), while excluding studies employing AR, MR, or involving officials. This narrower scope allows for a more precise evaluation of intervention studies.

In particular, this systematic review investigates the effectiveness of immersive technology-based training (VR, 360° video, CAVE) for enhancing sports-related perceptual-cognitive skills. Specifically, it aims to: (1) determine whether existing intervention studies provide sufficient evidence to address this question; (2) identify the perceptual-cognitive skills targeted; (3) examine the most frequently investigated cognitive domains; and (4) analyse the assessment methods used for these skills. In addition, the review (5) critically evaluates the methods, intervention designs, control conditions, and overall quality of included studies. Finally, it (6) discusses limitations of the current evidence base and provides clearer guidance for future research.

Methods

Search procedure

The present systematic literature review was prospectively registered in the PROSPERO database (ID: CRD42025644564). It was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). Electronic databases (PsycINFO, PubMed, SCOPUS and Web of Science) were searched on 1 April 2025. Search terms were ('Virtual reality' OR 'Virtual environment' OR 'Virtual world' OR 'Virtual systems' OR 'Immersive environments' OR 'Immersive video' OR '360 video' OR 'Simul*') AND (Sport) AND ('Perceptual-cognitive' OR 'Perceptual-motor' OR 'Perceptual functions' OR 'Decision-making' OR 'Anticipation' OR 'Attention' OR 'Memory' OR 'Pattern recognition' OR 'Reaction time' OR 'Processing speed' OR 'Executive function' OR 'Skill' OR 'Cognit*'). Search terms were limited to the title, abstract, or index term fields. Rayyan software was used to remove duplicates and screen records. Two authors (FCRG and SFMP) conducted the screening process independently, first by title and abstract, and then by full text. The procedure required discussing any disagreements with a third author (CR).

Inclusion and exclusion of studies

In line with the PICO approach (Richardson et al., 1995) inclusion criteria were selected as follows:

(I) Participants: studies were eligible if they involved healthy participants engaging in sports, regardless of age, type of sport, or level of expertise.
(II) Intervention: studies were included if they implemented a training intervention designed to enhance perceptual-cognitive skills using immersive technologies. Animated Virtual Reality (VR) and real-world 360° video, delivered via Head-Mounted Display (HMD) or Cave Automatic Virtual Environment (CAVE), were eligible. In

addition, only quantitative intervention studies (i.e., training studies) were included.

(III) Comparison: studies were considered eligible if they included a control condition. This could be a nonexposed control group, an alternative intervention group, or a within-subjects design (i.e., pre-post comparison or crossover trials).

(IV) Outcome: studies that included outcome measures relating to perceptual-cognitive skills were included to evaluate the short- and long-term effectiveness of immersive training. Perceptual-cognitive skills were defined according to the framework proposed by Hodges et al. (2021), encompassing both perceptual abilities (e.g., visual search, peripheral vision) and higher-order cognitive processes such as attention, pattern recognition, anticipation, working memory, and decision-making.

Following the previous order, the exclusion criteria were established as follows: studies involving officials and eSports were excluded. Studies that used immersive technologies for applications other than training (e.g., rehabilitation) were also excluded. Studies involving Augmented Reality (AR), Mixed Reality (MR), or 3D Multiple Object Tracking (3DMOT) were not considered. In addition, quantitative assessment studies (i.e., validity/reliability studies using VR, 360° video, or CAVE as assessment tools) and qualitative studies (e.g., interview studies) were excluded. No language or time restrictions were applied to the identified articles.

Data extraction

Following the screening process, two authors (FCRG and SFMP) independently extracted the relevant data from the full texts included in the study. For each study, an overview was provided including the following information: authors and year of publication; technology used; participant demographics; sport and skill level; intervention details; perceptual-cognitive skills targeted; outcome measures; main findings; and overall study quality. Perceptual-cognitive skills were first identified and then categorised within cognitive domains. Data on users' subjective evaluations of immersive technologies, such as sense of presence, embodiment, enjoyment and usability, were also extracted. Where possible, transfer effects were reported to assess whether perceptual-cognitive training translate to real-world sports performance.

Quality assessment

Quality was assessed using the Downs and Black Checklist (Downs & Black, 1998) for reporting quality, internal validity (bias and confounding), external validity and statistical power. Out of 27 questions and a maximum possible score of 32, a higher score indicated a lower risk of bias, whereas a lower score indicated a higher risk of bias. This tool was chosen because it allows for the evaluation of randomised controlled trials, non-randomised intervention studies, and within-subjects designs, providing a comprehensive appraisal of study quality across different study designs.

Results

Search results

Following the PRISMA statement, the study search and selection process are presented in Figure 1. A total of 5,976 records were identified across PsycINFO (n = 240), PubMed (n = 347), Scopus (n = 3,367), and Web of Science (n = 2,022). A total of 1,953 duplicate records were automatically removed by Rayyan software before screening. The screening was blinded and conducted independently by two authors (FCRG and SFMP). A total of 4,023 records were screened for title and abstract, of which 3,975 were excluded. A total of 48 reports were assessed for eligibility, with 34 excluded after full-text review. Reasons for exclusion were: (a) no control group; (b) no perceptual-cognitive outcome; (c) no quantitative intervention; (d) no virtual reality/360 video/CAVE; (e) not related. A total of 14 studies were included in the review.

Characteristics of included trials: Study quality, population, sport, and level

Table 1 shows the results of the quality assessment of the included studies, as evaluated using the Downs and Black checklist. The assessment indicated variation in study quality, with six studies (n = 6) rated as fair (quality score 66%-72%) and six rated as good (≥75%). Two studies scored below 50% in their quality evaluation. The main limitations identified were in the areas of reporting and internal validity bias.

The sample sizes in the identified studies ranged from 6 to 80 participants, with 57% of the studies including between 15 and 30 participants. Regarding sex, eight studies (n = 8) included mixed samples of males and females, four studies (n = 4) included only males, and two studies (n = 2) included only females. The mean age of participants ranged from 13 to 25 years, with the research primarily focusing on adolescents and young adults. One study (n = 1) did not report participants' age. Table 4 shows the participants'

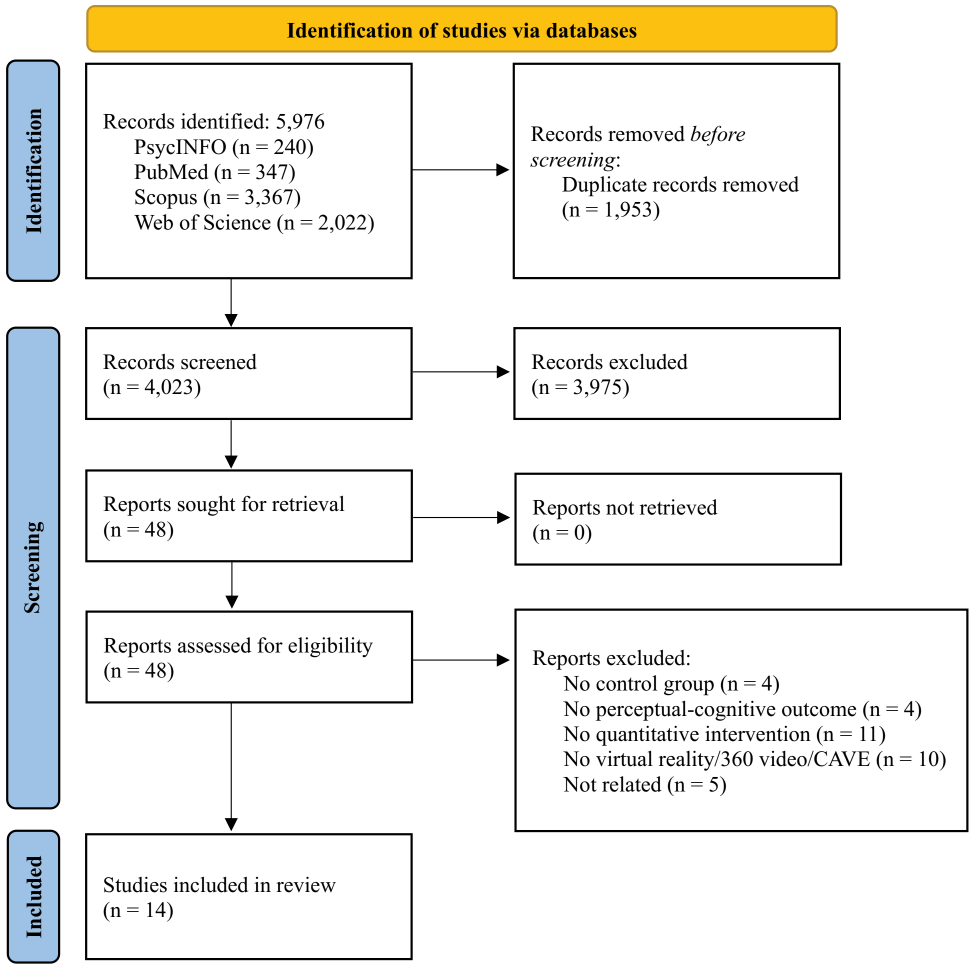

Figure 1. PRISMA flow diagram of systematic search and study selection.

Table 1. Quality assessment of the included studies using the Downs and black checklist.

Study	Reporting (/11)	External validity (/3)	Internal validity – bias (/7)	Internal validity – confounding (/6)	Power (/5)	Overall (/32)
Gray (2017)	8	1	5	5	5	24
Panchuk et al. (2018)	8	1	5	5	4	23
Pagé et al. (2019)	8	1	5	5	5	24
Petri et al. (2019)	9	1	5	4	4	23
D. J. Harris et al. (2020)	8	1	5	5	5	24
Kesilmis (2020)	7	1	4	4	5	21
Fortes et al. (2021)	8	1	5	6	5	25
Kincaid et al. (2021)	7	1	5	4	5	22
Tsai et al. (2021)	8	1	5	5	5	24
Romeas et al. (2022)	10	1	5	4	2	22
Fendrian et al. (2024)	4	1	2	3	5	15
D. Harris et al. (2024)	8	1	5	5	5	24
Nasu et al. (2024)	8	1	5	4	5	23
Kenjayeva et al. (2025)	1	1	0	3	5	10

Notes: Maximum possible scores are shown in the column headers. Higher scores indicate better methodological quality.

characteristics, including sample sizes, mean age, and standard deviation where reported.

The most frequently reported sport was basketball, addressed in four studies (Kenjayeva et al., 2025; Pagé et al., 2019; Panchuk et al., 2018; Tsai et al., 2021), followed by baseball (Gray, 2017; Kincaid et al., 2021), karate (Fendrian et al., 2024; Petri et al., 2019), and golf (D. Harris et al., 2024; D. J. Harris et al., 2020), each investigated in two studies. Handball (Kesilmis, 2020), football/soccer (Fortes et al., 2021), boxing (Romeas et al., 2022), and softball (Nasu et al., 2024) were each examined in one study. Eight studies described their samples as elite/expert athletes (Fortes et al., 2021; Gray, 2017; Kincaid et al., 2021; Nasu et al., 2024; Pagé et al., 2019; Panchuk et al., 2018; Petri et al., 2019; Romeas et al., 2022). According to Swann et al. (2015), they can be classified as either semi-elite or competitive elite athletes. The subcategories identified were as follows: studies including athletes competing at a national level (n = 2); studies including varsity athletes (n = 3); and studies including members of a national team or national top league (n = 3). One study focused on recreational players (Tsai et al., 2021), and three studies focused on novices (D. Harris et al., 2024; D. J. Harris et al., 2020; Kesilmis, 2020) to increase sensitivity and avoid ceiling effects. Two studies did not report the level of expertise (Fendrian et al., 2024; Kenjayeva et al., 2025). An overview of the sports and skill levels is provided in Table 2.

Interventions and controls

Table 2 shows the technologies used for immersive training. Of the included studies, seven used a Head-Mounted Display (HMD) with animated Virtual Reality (VR) (n = 7), six used 360° real-world VR (n = 6) and one used an animated Cave Automatic Virtual Environment (CAVE) (n = 1).

Table 4 shows the study designs and intervention details of the included studies. Five studies (n = 5) employed a control group (no intervention) for comparison. In the studies by Panchuk et al. (2018); Kincaid et al. (2021), and Nasu et al. (2024), participants were recruited from the same team and allocated to either an intervention or a control group. The intervention group completed immersive training in addition to their regular practice, whereas the control group continued with conventional training alone. In contrast, in Fendrian et al. (2024) and Kenjayeva et al. (2025), it is unclear whether participants were recruited from the same team and shared the same conventional training. Although the intervention group performed immersive training alongside their usual sports activities and the control group continued their usual activities, it remains unclear whether these 'usual activities' were fully comparable. To continue, seven studies (n = 7) used alternative intervention groups (e.g., 2D videos, game footage, VR game simulation or magnetic board) as comparators. One study (n = 1) included both a control group and intervention groups, while another study (n = 1) employed a crossover design.

The duration of the intervention ranged from single sessions to 8 weeks. In six studies (n = 6) the intervention lasted 4–6 weeks, with 2 to 3 sessions per week. One study (n = 1) involved an 8-week intervention conducted 3 times per week, while another study (n = 1) implemented a 3-week intervention conducted 4 times per week. A total of two studies (n = 2) involved a 1-week intervention with 3 to 4 sessions, and three studies (n = 3) involved a single training session. One study (n = 1) did not report any intervention details.

Perceptual-cognitive skills and their assessment

Among the studies included in this review, the most frequently analysed perceptual-cognitive skill was decision-making (n = 8), followed by processing speed (n = 3), gaze control (n = 2), and inhibitory control (n = 2). Other skills analysed included visual search or selective attention (n = 1) and anticipation (n = 1). For each study, perceptual-cognitive skills were categorised into cognitive domains (see Table 3), following established cognitive psychology frameworks and the work of Hodges et al. (2021). Inhibitory control was classified in the executive function domain, while anticipation and decision-making were categorised as higher-order cognitive processes. Visual search or selective attention, and gaze control were classified within the attention domain as they involve the ability to allocate cognitive resources to relevant stimuli. Processing speed was considered a distinct domain to emphasise cognitive processing through response time measures. The analysis revealed that the primary focus was on higher-order cognitive processes (n = 9), followed by processing speed (n = 3), attention (n = 3) and executive function (n = 2).

Perceptual-cognitive skills were primarily assessed using behavioural measures before and after the intervention. Behavioural measures typically involve task-based tests and performance outcomes, such as gaze behaviour or decision-making in sport-specific situations. Three studies (n = 3) employed standardised cognitive tests (Stroop test, Vienna Test System) to evaluate underlying cognitive components such as inhibitory control, and processing speed, independent of sport-specific execution.

In five studies (D. J. Harris et al., 2020; Nasu et al., 2024; Panchuk et al., 2018; Petri et al., 2019; Romeas et al., 2022), the immersive task was administered three times: to assess participants' baseline performance, as the training intervention itself, and to reassess performance post-training. To prevent learning effects, different stimuli were used during the assessment sessions compared to the training phase. A familiarisation period was also included to ensure valid performance comparisons with controls and minimise potential bias.

The decision-making and anticipation processes were commonly evaluated using video-based tests, in which videos were paused at key decision points and participants were required to respond. Both accuracy and response time were analysed. Four studies (n = 4) used

Table 2. Description of technology type, sport, and skill level of the included studies.

Study	Technology type	Sport	Skill level
Gray (2017)	CAVE (Animated) Single 6.9′ (2.11 m) (h) × 4.8′ (1.47 m) (v) screen using a Proxima 6850 + LCD projector updated at a rate of 60 Hz.	Baseball	Junior, Varsity / Competitive
Panchuk et al. (2018)	360°VR (Real world) Videos recorded in the real world and viewed via an HMD (Oculus Rift SDK) or on a mobile phone.	Basketball	Junior / Elite / National U19
Pagé et al. (2019)	360°VR (Real world) Videos recorded in the real world and viewed using a Utopia 360 HMD equipped with a smartphone.	Basketball	Junior/Senior, Varsity/Competitive (highest level at the academic institution)
Petri et al. (2019)	HMD (Animated) Custom-made and viewed using an HMD (Oculus Rift DK2).	Karate	Junior / National competition (blue and brown belt, 1st–4th Kyu)
D. J. Harris et al. (2020)	HMD (Animated) Developed using the game engine Unity 2018.2.10f1 and the Unity Experiment Framework and presented via an HTC Vive HMD.	Golf	Novice (Adult) Undergraduate students with no prior formal golf putting experience, selected to increase sensitivity to the intervention and avoid ceiling effects.
Kesilmis (2020)	HMD (Animated) No further details.	Handball	Novice (Junior) The Handball-VR and Handball groups had no prior handball experience. Both groups completed basic handball training 1.5 h × 3 days/week × 8 weeks (100% attendance).
Fortes et al. (2021)	360°VR (Real world) Videos recorded in the real world and viewed using a Utopia 360 HMD equipped with a smartphone.	Football (soccer)	Junior / National level
Kincaid et al. (2021)	HMD (Animated) Developed using Unity 3D Game Engine and presented with an Oculus Quest headset.	Baseball	Junior/Senior, Varsity / Competitive
Tsai et al. (2021)	HMD (Animated) 360°VR (Real world) Developed using Unity 2017.4.9 game engine and presented via HTC Vive Pro HMD.	Basketball	Recreational (Adult) Graduate/undergraduate students competing as amateur basketball players for their department team.
Romeas et al. (2022)	360°VR (Real world) Developed using Unity and presented via HTC Vive Pro HMD.	Boxing	Senior / Elite / National Team
Fendrian et al. (2024)	No details were reported regarding the technology referred to as ‘virtual reality’.	Karate	Junior school-based karate athletes (competitive level not reported)
D. Harris et al. (2024)	HMD (Animated) Developed using Unity 2019.2.12 game engine and presented via HTC Vive Pro HMD.	Golf	Novice (Adult) Novice golfers with no prior formal putting experience, selected to increase sensitivity to the intervention and avoid ceiling effects.
Nasu et al. (2024)	360°VR (Real world) Videos recorded in the real world and viewed using a Meta Quest 2 HMD.	Softball	Senior / Elite / National Top League
Kenjayeva et al. (2025)	HMD (Animated) No further details.	Basketball	Sports students / basketball players (competitive level not reported)

Notes: CAVE, Cave Automatic Virtual Environment. VR, Virtual Reality. HMD, Head-Mounted Display.

immersive video tests (Nasu et al., 2024; Panchuk et al., 2018; Petri et al., 2019; Romeas et al., 2022). One study (n = 1) used 2D video tests (Tsai et al., 2021). To prevent overlap with the training material, unique videos were used during testing. Participants were given the opportunity to familiarise themselves with the videos beforehand, and no feedback was provided following their responses.

Decision-making was also assessed through on-field performance (Gray, 2017), small-sided games (Fortes et al., 2021; Panchuk et al., 2018) and on-court tests (Pagé et al., 2019), with accuracy being the primary outcome measure.

Further behavioural outcomes included gaze control (D. J. Harris et al., 2024, 2020), measured in milliseconds as quiet eye duration (i.e., fixation stability and accuracy on target objects), and visual search behaviour (Fortes et al., 2021), evaluated by the number and duration of fixations on relevant locations.

Among the studies that employed standardised cognitive tests, Fortes et al. (2021) were the first to use the Stroop test to assess inhibitory control, a method later adopted by Fendrian et al. (2024). In this test, participants completed the mismatch condition, in which they were required to name the colour of the word rather than read the word itself. Accuracy and response time were recorded as outcome measures. Furthermore, Petri et al. (2019) used the Reaction Test (RT) from the Vienna Test System (Schuhfried, Vienna, Austria) to evaluate response speed. This approach differs from the methods employed by Kesilmis (2020) and Kenjayeva et al. (2025), who assessed response speed within game scenarios by

Table 3. Cognitive domains associated with perceptual-cognitive skills targeted in the included studies.

Study	Perceptual-cognitive skills	Cognitive domain
Gray (2017)	Decision-making	Higher-order cognitive processes
Panchuk et al. (2018)	Decision-making	Higher-order cognitive processes
Pagé et al. (2019)	Decision-making	Higher-order cognitive processes
Petri et al. (2019)	Decision-making, Response speed	Higher-order cognitive processes, Processing speed
Kincaid et al. (2021)	Decision-making	Higher-order cognitive processes
Tsai et al. (2021)	Decision-making	Higher-order cognitive processes
Romeas et al. (2022)	Decision-making	Higher-order cognitive processes
Fendrian et al. (2024)	Inhibitory control	Executive function
Nasu et al. (2024)	Anticipation	Higher-order cognitive processes
Fortes et al. (2021)	Decision-making, Inhibitory control, Visual search or Selective attention	Higher-order cognitive processes, Executive function, Attention
D. J. Harris et al. (2020)	Gaze control	Attention
D. Harris et al. (2024)	Gaze control	Attention
Kesilmis (2020)	Response speed	Processing speed
Kenjayeva et al. (2025)	Response speed	Processing speed

focusing on motor responses rather than isolated cognitive processing.

All detailed information regarding assessment procedures and outcome measures is reported in Table 4.

The effect of training with immersive technologies on perceptual-cognitive functions

Table 4 shows the results of the studies evaluating the effects of immersive training on perceptual-cognitive functions.

Concerning decision-making, only one study, Kincaid et al. (2021), reported no significant results. In contrast, Panchuk et al. (2018) reported mixed findings: significant improvements were observed in both the experimental group (elite female basketball players trained with 360° VR) and the control group, with large effect sizes. Other studies have reported significant improvements in both intervention and control groups, with the intervention groups demonstrating greater gains. For example, Gray (2017) reported significant improvements from pre- to post-intervention following adaptive training in a virtual environment. These gains were maintained after one month and were associated with large effect sizes. Although the control groups also improved, the group that received adaptive training showed greater gains. Similarly, Pagé et al. (2019) reported that both the 360° VR and 2D groups improved in trained plays; however, the 360°VR group significantly outperformed the 2D and game footage groups in response accuracy for untrained plays, with a large effect size. Fortes et al. (2021) also found significant improvements in both 360°VR and 2D groups, with the 360°VR group demonstrating greater gains. Petri et al. (2019), using a crossover design, reported that both intervention conditions led to significant improvements in response time and accuracy from pre- to post-test, with large effect sizes. In Phase 1, the control group also improved in response time, though with moderate effect sizes. To conclude, Tsai et al. (2021) found no difference between 360°VR and animated VR training, with both groups outperforming the magnetic board group in response time at post-test.

Regarding inhibitory control, mixed results emerged. Fortes et al. (2021) reported that both the 360°VR group and the 2D control group showed significant improvements, with no differences between them. In contrast, Fendrian et al. (2024) found a significant between-group difference at post-test, with a large effect size, suggesting that VR training may have a significant effect compared to conventional training. However, the internal validity score for this study was not reported to be high.

Concerning gaze control, D. J. Harris et al. (2020) found no significant improvements in golfers who were trained in VR compared to traditional training. However, in a subsequent study by the same authors (D. Harris et al., 2024), gaze-adaptive VR training during golf putting led to significant improvements in gaze control from pre- to post-intervention, whereas the control group showed no significant changes.

In terms of processing speed, Kesilmis (2020) reported that the VR group significantly improved in average reaction time and movement time compared to the control group. This finding is consistent with the results of Kenjayeva et al. (2025), who found a significant between-group difference at post-test, suggesting that immersive training may have a positive effect on processing speed. However, the internal validity score for this study was not reported to be high. In contrast, Petri et al. (2019) did not report significant differences, which could be related to the use of reaction time-based cognitive measures with the Vienna Test System.

Five studies examined how these effects transfer to on-field performance. Gray (2017) investigated whether perceptual-cognitive skills trained in an adaptive baseball batting virtual environment transfer to real baseball performance and found promising results. Specifically, Gray reported significant improvements from pre- to post-intervention following adaptive training in the virtual environment. Moreover, these findings were

Table 4. Characteristics of included studies.

Study	Participants	Design	Interventions	Perceptual-cognitive skills	Outcome measures	Results	Transfer evaluations	Subjective evaluations
Gray (2017)	N = 80 M 17/18 yrs	Assessment: pre, post, 1-month retention.	Groups: adaptive training in a batting VE; batting in a VE; real batting; control. Training: 2×/week, 6 weeks, 30 pitches/session, 45 min.	Decision-making	Batting test in VE and on-field (total hits, % of swings inside/outside the strike zone). Pitch recognition test in VE (pitch types and balls/strikes correctly identified). Total of 20 pitches/test.	Interaction effects for all variables, except for total number of balls/strikes identified (ES large). Adaptive VE showed significant improvements from pre to post, maintained after 1 month, and greater than those in the other groups (ES large).	Yes	No
Panchuk et al. (2018)	N = 18 IG: 5 M/6F CG: 4 M/3F 17.0 ± 0.6	Assessment: pre, post.	Groups: 360°VR; control. Training: 3–4×/week, 3 weeks, 15 clips/session, 5-min pre-training. 41 videos total.	Decision-making	Immersive video test (accuracy): 5 familiarisation clips, 15 unique clips, 15 min.	No interaction effect for accuracy ($p = 0.275$). Time effect for IG (F): $p = 0.004$; CG (F): $p = 0.007$. ES large.	Yes	Yes
Pagé et al. (2019)	N = 27 21 M/6F 19.4 ± 3.7	Assessment: pre, post.	Groups: 360°VR; 2D; game footage. Training: 1×/day, 4 days, 50 clips/session. 120 videos total (80 × 2, 40 × 1). Video duration: 14.7 ± 0.2 sec.	Decision-making	On-court test (accuracy): 12 trained plays and 6 untrained plays (accuracy). 4 answer options: 1 best option (2 points), 2 acceptable options (1 point), and 1 worst option (0 points).	Interaction effect ($p < 0.001$, ES large). The VR and 2D groups significantly outperformed the game footage group ($p \le 0.001$, ES large) in trained plays. The VR group outperformed both the 2D and game footage groups ($p \le 0.002$, ES large) in untrained plays.	Yes	No
Petri et al. (2019)	N = 15 A: 5 M/3F 15.0 ± 1.7 B: 5 M/2F 15.1 ± 1.2	Cross-over design (wash-out: 4 months). Assessment: pre1, post1, pre2, post2.	Training: reaction training in VR, 10 sessions over 6 weeks, 10–15 min/session.	Decision-making, response speed	12 VR attacks: response time, response accuracy, and type of response. Vienna test system: reaction time and motor response time.	Both intervention groups significantly improved from pre to post in response time (A $p = 0.000$; B $p = 0.000$) and response accuracy (A $p = 0.000$; B $p = 0.000$), ES large. Phase 1, CG also improved in response time ($p = 0.000$, ES moderate).	No	No
D. J. Harris et al. (2020)	N = 40 21F 21.6 ± 1.5	Assessment: pre, post.	Groups: golf putting in VR or in real-world. Training: 1 session, 40 putts.	Gaze control	10 putts in VR (quiet eye duration in milliseconds).	No interaction effect for quiet eye durations ($p = 0.75$, ES small).	Yes	No
Kesilmis (2020)	N = 70F 11–14 yrs	Assessment: pre, post.	Groups: handball VR group; handball group. Training: 8 weeks. VR and handball groups practiced 3×/wk, 1.5 h/session. VR group also trained in VR 3×/wk, 30 min.	Response speed	Reaction time at Fitlight Trainer System: 13 LED lights (total movement time in seconds, average light extinguishing time, and missed lights).	After the intervention, the VR group significantly differed from the handball group in average reaction time and movement time ($p = 0.001$; $p = 0.043$).	No	No
Fortes et al. (2021)	N = 26 M 15.4 ± 0.3	Assessment: pre, post.	Groups: 360°VR; 2D. Training: 3×/week, 6 weeks, 20 clips/session. 160 videos total (100 × 3, 60 × 1). Video duration: 10.2 ± 0.4 sec.	Decision-making, visual search or selective attention, inhibition	SSGs (5v5; 3v3) to assess decision-making (passing) and visual search (fixations and fixation duration). Stroop to assess inhibition (accuracy and response time).	Interaction effects for decision-making ($p < 0.01$) and visual search ($p < 0.01$), ES moderate. Both groups improved, greater improvements in 360°VR ($p < 0.01$). No interaction effect for inhibition, ES moderate. Both groups improved ($p < 0.01$), no differences between them.	No	No
Kincaid et al. (2021)	N = 24 M 18–22 yrs	Assessment: pre, post.	Groups: VR training (ball colours, trajectory types, strike vs. ball); control. Training: 2–3×/week, 3–4 weeks, 12 sessions total.	Decision-making	2-task test: identification of pitch and ball/strike type using GameSense software (tablet-based); ball colour call-out using a pitching machine.	No interaction effects for GameSense ($p = 0.866$) and ball-colour recognition performance ($p = 0.330$).	No	Yes
Tsai et al. (2021)	N = 45 36 M/9F 21.12 ± 1.89	Assessment: pre, post.	Groups: magnetic board; 360° VR; animated VR. Training: 1 session, 19 clips, 40 min.	Decision-making	2D video test (accuracy and decision time): 10 clips total.	No interaction effects. Time effect for decision time, $p < 0.001$. At post-test, both 360° ($p < 0.001$) and animated VR ($p < 0.01$) outperformed the magnetic board group.	No	Yes

(*Continued*)

Table 4. (Continued).

Study	Participants	Design	Interventions	Perceptual-cognitive skills	Outcome measures	Results	Transfer evaluations	Subjective evaluations
Romeas et al. (2022)	N = 6 IG: 2 M/1F CG: 1 M/2F 25.1 ± 1.8	Assessment: pre, post.	Groups: 360° temporal video-occlusion; VR game simulation. Training: 2–3×/week, 5 weeks, 10 min/session, 11 sessions total. 333 videos total, 24–36 clips/session. Video duration: 5–15 sec.	Decision-making	Accuracy (%) and response speed (s) on 360°VR video-occlusion test. 37 videos total.	The 360°VR group improved accuracy compared to control. No p-values or effect sizes reported.	No	Yes
Fendrian et al. (2024)	N = 30 M IG, 14.13 ± 0.6 CG, 13.80 ± 0.8	Assessment: pre, post.	Groups: VR; control. Training: physical activity in VR or no VR (control), 3 days over one week.	Inhibition	Stroop: naming the colour of 20 words, ignoring the written text (time).	Significant post-test difference between groups ($p = 0.000$, ES large).	No	Yes
D. Harris et al. (2024)	N = 24 13 M/11F 21.0 ± 1.2	Assessment: pre, post.	Groups: VR gaze adaptive training during golf putting; real-world golf putting. Training: 1 session, 30 putts, 30 min.	Gaze control	Quiet eye duration during putting task.	Interaction effect ($p < 0.001$, ES large). Significant improvement from pre to post in the gaze adaptive group for quiet eye duration ($p = 0.001$). No differences from pre to post in the control group.	Yes	No
Nasu et al. (2024)	N = 17F VR, 24.9 ± 2.9 2D, 23.5 ± 4.0	Assessment: pre, post.	Groups: pitch speed anticipation training in VR; control. Training: 8 sessions over 4 weeks, 15-min post-training, 40 pitches/session.	Anticipation	VR tests: 20 pitches, percentage of correct responses to pitch type (accuracy). 20 swings to balls with unknown pitch type (response speed).	Six members of the training group showed improvement in response accuracy (ES large); seven members showed improvements in response speed (ES large). The control group showed no consistent change.	No	No
Kenjayeva et al. (2025)	N = 60 40 M/20F	Assessment: pre, post.	Groups: shooting training in VR; control. Training: no mention of frequency or duration.	Response speed	Speed of response to game scenarios (outcome measure not reported).	Significant between-group variance ($p = 0.000$); no effect sizes or additional analyses reported.	No	No

Notes: IG, Intervention Group. CG, Control Group. ES, Effect Size. VR, Virtual Reality. VE, Virtual Environment. SSGs, Small-Sided Games.

maintained after one month and were associated with large effect sizes. Although the control groups also improved, the group that received adaptive training in the virtual environment showed greater gains. Similarly, Pagé et al. (2019) assessed decision-making with on-court tests in trained and untrained plays. The 360°VR group significantly improved in trained plays and outperformed both the 2D and game footage groups in untrained plays, with large effect sizes, suggesting that using 360°VR results in transferable and generalised gains. In contrast, Panchuk et al. (2018) used small-sided games to evaluate decision-making and found a significant interaction effect ($p = 0.032$), which may suggest a positive transfer effect of 360°VR compared to the control group; however, no significant differences were observed at follow-up. To continue, D. J. Harris et al. (2020, 2024) assessed golf putting performance by measuring the radial error of the ball from the hole (in centimetres) but did not find any statistically significant improvements, suggesting that gaze-adaptive training did not enhance real-world putting performance.

Subjective evaluation of immersive training and technology used

Five of the included studies implemented subjective evaluations and found that immersive training was perceived as enjoyable and effective, with the technology itself reported as easy to use. In addition, positive findings were reported regarding the sense of presence within the virtual environment and its realism. In particular, the survey results reported by Panchuk et al. (2018) showed that athletes found the training beneficial for improving their on-court performance and enjoyed the realism of the scenarios. Similarly, Kincaid et al. (2021) reported positive feedback regarding the realism, effectiveness, and enjoyment of VR training. The study by Romeas et al. (2022) assessed enjoyment (mean ± SEM: 7.67 ± 0.56) and relevance (7.00 ± 0.26) of the training using a scale from 1 to 10, and sense of presence (9.17 ± 2.24) using a scale from 1 to 20. On the Simulator Sickness Questionnaire, participants reported mild disorientation and oculomotor discomfort; however, these symptoms did not result in a significant motion sickness effect. Through interviews, Fendrian et al. (2024) identified potential impacts on eye health resulting from prolonged VR use, as well as the need for a safe and spacious environment in which to conduct the training. Overall, participants reported that the training was enjoyable, easy to implement, and that the exercises could be carried out without supervision. To conclude, Tsai et al. (2021) reported positive results on the Slater-Usoh-Steed (SUS) and Technology Acceptance Model (TAM) questionnaires. They found no difference in sense of presence between 360° (SUS Count: M = 3.33, SD = 2.18; SUS Mean: M = 5.59, SD = 1.00) and animated VR (SUS Count: M = 3.06, SD = 1.94; SUS Mean: 5.36, SD = 1.00), both being acceptable in terms of usability (perceived usefulness: M = 4.59, SD = 1.01; perceived ease of use: M = 5.13, SD = 1.01; behavioural intentions: M = 5.92, SD = 0.89).

Discussion

This systematic literature review critically evaluated intervention studies involving immersive training aimed at enhancing perceptual-cognitive skills in sports tasks. Fourteen intervention studies that delivered immersive training via VR, 360° video or CAVE technology and compared it to different control conditions, met the inclusion criteria. These studies involved healthy sport participants and primarily focused on adolescents and young adults with an average age reported to be between 13 and 25 years old. A variety of sports have been examined, with basketball being the most frequently studied. The samples included male and female participants of different skill levels, including experts, amateurs and novices. While this diversity may enhance the generalisability of the findings, it also introduces variability, making it difficult to draw specific conclusions. Regarding the dose-response relationship, the most common timeframe identified has been four to six weeks, with two to three sessions per week. This period appears to be both feasible and potentially effective for perceptual-cognitive training through immersive technologies. Decision-making has been the most frequently analysed perceptual-cognitive skill, followed by processing speed, inhibitory control, gaze control, visual search or selective attention, and anticipation. These findings highlight the key role of executive functions in sport, as athletes must quickly process information and make accurate decisions in dynamic, high-pressure situations. Perceptual-cognitive skills were primarily assessed using behavioural measures before and after the intervention. Three studies specifically administered standardised cognitive assessments, such as the Stroop test and the Vienna Test System battery, to evaluate these skills, while five studies analysed on-field performance. A consistent methodological feature across studies was the use of the same immersive task for both training and assessment. When training and assessment occur within the same immersive environment, additional methodological considerations arise. Specifically, it is important to familiarise the control group with the immersive environment, while ensuring that the assessment stimuli for the intervention group differ from those used in training, as the intervention group is already familiar with them.

Studies have generally reported positive effects of immersive training on decision-making skills, though exceptions exist. Kincaid et al. (2021) found no significant results, and Panchuk et al. (2018) reported mixed findings, with significant improvements observed in both experimental and control groups. Improvements in the control groups may be attributed to alternative training methods, such as 2D videos, game footage, or magnetic boards, as well as learning effects and other non-specific factors. Overall, the studies included in this review suggest that both the experimental groups (trained with immersive technology) and the control groups (receiving no intervention or alternative non-immersive training) showed improvements, but the experimental groups consistently demonstrated greater gains. This conclusion is supported by Gray (2017); Pagé et al. (2019); Fortes et al. (2021); Petri et al. (2019), and Tsai et al. (2021). Significant improvements have been reported among athletes trained using immersive technologies, such as VR/360° video and CAVE, from pre- to post-intervention, with these athletes outperforming those who received traditional or control training methods. These findings align with the scoping review by Jia et al. (2024), who concluded that animated VR and 360° video have strong potential to enhance decision-making speed in team sports. Moreover, their results suggest that these technologies constitute valuable tools for evaluating decision-making, supporting their use as assessment methods in many studies included in the present review. Similarly, Kittel et al. (2024) reported that 60% of the studies they examined focused primarily on decision-making. They included quantitative, qualitative, and mixed-methods research and involved XR technologies, confirming that decision-making is the most extensively investigated perceptual-cognitive skill in sports contexts. With respect to processing speed, the findings reported by Kesilmis (2020) and Kenjayeva et al. (2025) were also positive. However, the low internal validity of the latter study suggests caution in interpreting its results. In contrast, Petri et al. (2019), who employed the Vienna Test System to assess processing speed, did not observe significant effects. The reported improvements in decision-making and processing speed may be attributed to the ecological validity and perceived realism provided by immersive training solutions (VR, 360° video, and CAVE). This interpretation is consistent with situated cognition theories, which emphasise that skill acquisition is grounded in sensorimotor interaction with the environment (Shapiro & Spaulding, 2019), rather than in decontextualised information processing as typically found in 2D tablet-based tasks or magnetic-board interventions. Moreover, Tsai et al. (2021) reported no significant differences in training effects between 360° video and animated VR, suggesting that the overall quality and fidelity of the immersive experience may be more important than the specific technology employed. Beyond decision-making and processing speed, findings for other perceptual-cognitive skills are more mixed. Results on inhibitory control from Fortes et al. (2021) and Fendrian et al. (2024) were inconsistent, possibly due to differences in the design of control groups (active vs. inactive). Findings on gaze control were also mixed, as reported by D. Harris et al. (2020, 2024), suggesting that the effectiveness of immersive training may depend more on the design of the intervention than on the specific technology employed. In line with this, Kittel et al. (2024) also reviewed studies on perceptual-cognitive skills beyond decision-making and identified only limited evidence for abilities such as gaze control, anticipation, and memory. Despite the inconclusive results, the authors emphasised the importance of training these skills and the need for further research in this area. Moreover, Kittel et al. (2024) scoping review of XR technologies for perceptual-cognitive skills identified 16 intervention studies. Not all of these included control groups, and the methods employed were highly heterogeneous. These are limitations that we also report, which prevented us from conducting a meta-analysis and overall stating its effectiveness so far.

Only five intervention studies have investigated whether training perceptual-cognitive skills with immersive technologies transfers to on-field performance. Results are generally described as promising by Gray (2017) and Pagé et al. (2019), although control groups also showed improvements. In contrast, no transfer effects were reported by Panchuk et al. (2018) and D. J. Harris et al. (2020, 2024), further highlighting the need for additional research to establish the external validity of these training programmes. This cautious view aligns with Fransen's position paper (Fransen, 2024), which concludes that there is currently no consistent evidence of far transfer from perceptual-cognitive training tools to sports performance, and that existing claims often exceed the available data.

An additional consideration concerns the use of standardised cognitive tests as outcome measures to evaluate the effectiveness of immersive perceptual-cognitive training. Three studies employed assessments, such as the Stroop test and the Vienna Test System, to measure inhibitory control and response speed. This highlights an ongoing and recent debate within the field, which focuses on two main issues: (1) the limited implementation of cognitive testing within sports contexts, and (2) the question of whether such measures are sufficiently sensitive to detect performance changes, or whether they should be replaced by more sport-specific tasks that assess the same constructs with higher ecological validity.

Concerning the first point, standardised cognitive tests offer an accurate and objective evaluation of cognitive function, which is particularly valuable following a concussion or other injuries, as they can support more informed and individualised return-to-play decisions. In addition, coaches can use cognitive tests to monitor both the cognitive effects of training and athletes' overall cognitive development over time. Moreover, Memmert et al. (Furley & Memmert, 2011; Scharfen & Memmert, 2019) support the broad transfer hypothesis, suggesting that superior cognitive functions, such as working memory capacity, inhibition, and attention, measured by standardised cognitive tests, correlate significantly with sport performance in elite youth soccer players. Accordingly, standardised cognitive tests may be valuable for talent identification, as they can reveal cognitive strengths that could predict future athletic success even before physical and technical skills are fully developed (Vestberg et al., 2012).

One of the studies included in this review (Romeas et al., 2022) administered cognitive tests from the Vienna Test System for monitoring purposes, comparing athletes' cognitive performance with normative data. Their results showed that elite boxers outperformed the normative group in reaction time, reaction speed under stress, decision-making speed, and sustained attention. These findings suggest that engagement in sport may be associated with enhanced cognitive functioning in specific domains. Furthermore, this aligns with the Cognitive-Skills Approach (Montuori et al., 2019), which suggests sport-specific cognitive abilities may rely on underlying perceptual-cognitive functions. This implies a potentially bidirectional relationship: sport engagement could enhance general perceptual-cognitive functions, while targeted training might reciprocally improve sporting performance.

In contrast, Fransen (2024) argues that there is no consistent evidence that superior performance on generic executive-function tests translates into football/soccer expertise. High scores in tasks such as the Stroop or N-back do not necessarily indicate proficiency in football/soccer or other sports, as improvements tend to remain confined to similar laboratory tasks rather than game situations. This perspective supports a distinction between general executive functions, typically assessed through standardised cognitive tests, and sport-specific executive functions that are embedded in domain-relevant actions such as anticipation and multitasking under fatigue and pressure, where processing is integrated and situated rather than modular.

Regarding the second point of discussion, Fortes et al. (2021) and Petri et al. (2019) reported no significant improvements in post-intervention standardised cognitive tests of inhibitory control and response speed following perceptual-cognitive training. These null findings may reflect either the fact that these abilities were not directly targeted by the training or the insufficient test sensitivity to detect subtle changes. Building on this, recent research has explored VR environments that provide ecological validity for assessing cognitive skills within sport-specific contexts, rather than relying solely on decontextualised cognitive tests. For example, Heilmann et al. (2021) developed SoccerBot360, a system designed to analyse cognitive abilities in a laboratory-controlled 360° soccer simulation. They assessed choice reaction, working memory, inhibition, and anticipation using modified cognitive tests adapted for the SoccerBot360, based on the Stroop, Corsi Block, anticipation, and choice reaction tests.

Given this debate, the inclusion of cognitive tests alongside sport-specific measures is recommended to advance understanding in this area and to explore the potential role of cognitive functioning as a mediator of the efficacy of immersive perceptual-cognitive training. Within this context, a recent insight is the use of immersive technologies to manipulate the situational demands of real-world competition and to recreate cognitive load, simulate anxiety, and induce pressure (Shields et al., 2026). Future research should also address this increasingly interesting topic of pressure-inducing scenarios, examining not only cognitive load but also physiological and psychological responses, as well as how regulating, or not regulating, these responses affects performance outcomes.

Study limitations and future directions

Some limitations should be considered when discussing the results. Although all studies adopted a pre-post design with at least two groups, not all employed comprehensive repeated measures analyses, such as ANOVA, to evaluate within-subject, between-group, and interaction effects. Moreover, statistical reporting was often incomplete or inconsistent in the presentation of p-values, effect sizes, and confidence intervals, thereby limiting the possibility of conducting a meta-analysis. Furthermore, the studies included in this review exhibited considerable heterogeneity in terms of populations, interventions, comparators, outcome measures, and intervention duration and frequency, thus rendering a formal meta-analysis or subgroup analyses not feasible. Therefore, the main limitations of this review relate to variability across studies and inconsistencies in statistical reporting, for which a narrative synthesis was considered more appropriate.

In order to facilitate future quantitative syntheses and strengthen the internal validity, researchers are encouraged to adopt more standardised reporting and to design rigorous randomised controlled trials that build on prior methodological recommendations in this area. In particular, conducting a priori power analyses and recruiting samples of adequate size according to the calculated statistical power are recommended to enhance the robustness and generalisability of findings. Small samples were a common methodological limitation across the reviewed studies. However, recruiting larger cohorts remains challenging in applied sports settings due to logistical constraints. One possible solution is to develop close collaborations between research centres and sports teams, which may allow interventions to be delivered to entire squads or divisions. To continue, the use of inactive control groups, such as no training or passive controls, is discouraged, as this limits the ability to isolate the specific effects of immersive perceptual-cognitive training interventions compared with active alternatives.

Beyond the consideration of internal validity, external validity was also a concern. Only five studies have examined how the effects of training in VR, 360° video, or CAVE systems transfer to on-field performance. Findings were mixed: two studies reported promising transfer effects to real-world performance, while three reported no improvement. This highlights a significant gap in the literature. Therefore, to comprehensively assess the effectiveness of immersive training, future research should routinely include sport-specific on-field performance measures rather than relying solely on virtual or laboratory outcomes. Moreover, future studies should consider not only transfer effect assessments but also retention tests to evaluate the long-term effectiveness of immersive training. These observations are consistent with those of Connolly et al. (2025), who also emphasised the challenge of drawing robust conclusions in this field. They identified the absence of a coherent research programme and the lack of standardised methods and analyses as key contributing factors. Moreover, the authors emphasised the importance of investigating learning transfer as it represents the ultimate goal of any training programme designed to enhance performance.

Conclusion

Immersive technologies, including animated VR, real-world 360° video, and CAVE systems, represent promising tools for off-field training, enabling targeted interventions to enhance sport-specific perceptual-cognitive skills. However, this systematic review does not seek to emphasise their promise; rather, it critically evaluates their effectiveness in improving these skills. Focusing solely on controlled intervention studies, we conclude that immersive training demonstrates positive effects on decision-making and promising effects on processing speed. Compared to decontextualised tasks, it may enhance learning through its high ecological fidelity and engagement of sensorimotor processes. Further research is needed to determine whether immersive training benefits other sport-specific perceptual-cognitive skills. This review describes the methodologies and outcome measures employed across studies, highlights their key limitations, and calls for more rigorous, methodologically consistent randomised controlled trials. Importantly, there is currently no evidence of transfer to actual on-field performance. Therefore, future research should incorporate real-world performance measures. Furthermore, modern sports science research would benefit from incorporating cognitive tests alongside sport-specific measures to explore immersive training's cognitive effects, their role as efficacy mediators, and mechanisms of transfer.

Author contributions

CRediT: **Francesca Celestina Rosanna Gala:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing; **Silvia Francesca Maria Pizzoli:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing; **Emiliano Cè:** Supervision, Writing – original draft, Writing – review & editing; **Claudia Repetto:** Conceptualization, Data curation, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

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