

Development of a virtual reality-based futsal training teaching model to improve cognitive skills

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Published online: April 30, 2026

Accepted for publication: April 15, 2026

DOI:10.7752/jpes.2026.04064

Abstract:

This study aims to evaluate the effectiveness of a Virtual Reality-based futsal tactical learning model, developed through a Research & Development approach using the ADDIE design, in improving the cognitive skills of junior high school players, operationalized as tactical awareness, perceptual skills, and decision-making, integrated into a composite cognitive skills score. The central hypothesis is that combining small-sided games-based field training with additional tactical Virtual Reality sessions will lead to greater improvement in cognitive skills than conventional training alone. The subjects consisted of two groups of 45 junior high school students each participating in futsal extracurricular activities. To evaluate effectiveness, the control group followed a standard game-based training program. In contrast, the experimental group followed the same program with additional Virtual Reality sessions using the “Virtual Reality Edukasi Player” application, which presents immersive futsal tactical scenarios from the player's perspective. Cognitive skills were measured with a multi-method instrument battery that assesses tactical awareness, perceptual skills and decision-making in the form of a TCTOF-BRA-style written test adapted to the futsal context containing multiple-choice statements regarding tactical solutions and video-based decision-making measured through a test modeled on the TacticUP Soccer Test, using video footage of futsal match scenarios and at key moments of players choosing the best action, then converted into a composite cognitive skills score. The analysis results showed that all variables in both groups showed a significant pre-posttest increase, as indicated by the Wilcoxon test, with z values ranging from -4.701 to -5.841 and $p < 0.001$. The rank-biserial coefficient ranged from -0.911 to -1.000, indicating a large effect size on tactical awareness, perceptual skills, decision-making, and the composite cognitive skills score in each group. However, the Mann–Whitney test on the post-test cognitive skills scores showed a highly significant difference between the experimental and control groups ($U = 211$; $p < 0.001$) with an effect size of 0.792 (equivalent to $d \approx 2.06$), indicating a very high probability that the experimental group students have higher cognitive skills scores than the control group which clearly confirms that the Virtual Reality-based futsal tactics learning model is effective in strengthening the cognitive skills of Junior High School students beyond conventional training and has the potential to be adopted as a strategic component in the youth futsal training curriculum.

Key Words: Virtual Reality Education Player, Tactical Futsal, Cognitive Skills, Junior High School Students

Introduction

Futsal, as a high intensity sport, requires players to simultaneously integrate technical, physical, and cognitive abilities within a limited space and time. In the context of youth development, particularly at the junior high school level, cognitive abilities such as tactical awareness (playing intelligence), perceptual skills, and rapid and accurate decision-making are key determinants of performance quality because they guide the processes of perception, interpretation, and action in rapidly changing game situations (Kalén et al., 2021; Scharfen & Memmert, 2021; Vestberg et al., 2020). Various studies have shown that these abilities are intertwined with executive function and domain-generic cognitive control and consistently correlate with on-field performance at different stages of athlete development (Barcellos et al., 2022; Kalén et al., 2021; Scharfen & Memmert, 2021; Vestberg et al., 2020). Thus, cognitive-tactical skill development can no longer be viewed merely as supplementary, but rather as a core component of youth futsal training design, so that it is not only focused on developing physical aspects (Sutirta & Akhmad, 2025).

The ecological-dynamic approach emphasizes the importance of designing constraint-based training tasks and reduced-game formats to mimic the pressure and complexity of real matches, thereby encouraging tactical adaptation and decision-making variability in young players (Errama et al., 2025; Pedreño, 2025; Pizarro et al., 2021). Small-Sided Games (SSGs) provide an information-rich environment; format manipulations such as 2v2 or 3v3 alter cognitive load and significantly impact the speed and accuracy of decisions in passing, dribbling, and shooting (Nunes et al., 2024; Petiot et al., 2021). Systematic reviews and

game performance assessment frameworks confirm that integrating cognitive-tactical challenges into SSG through the Teaching Games for Understanding (TGfU) approach and similar models can improve game understanding and tactical behaviors that can be transferred to matches (Clemente & Sarmiento, 2020; Ortiz et al., 2023; Pizarro et al., 2021). In the context of learning, the TGfU model is designed to address the weaknesses of conventional sports learning approaches, which tend to emphasize repetition of techniques without considering the game context (Apriani et al., 2025). In this context, the development of youth futsal training models should focus on enriching perceptual stimulation and cognitive demands, rather than simply repeating basic techniques that tend to be conventional.

While the contributions of SSG and game-based approaches to tactical development and decision-making have been recognized, youth futsal training models in many contexts are still dominated by an emphasis on physical conditioning and technical mastery, typically structured as SSG and conditioning drills to mimic the demands of a match and improve fundamental skills such as ball control, passing, and shooting (Asian-Clemente et al., 2021). Integration of cognitive and tactical aspects is emerging through game-based learning, TGfU, decision-training, and approaches emphasizing scanning activities, with reports of improved tactical awareness, perceptual skills, and decision-making in young athletes (Barba-Martí-n et al., 2020; Eldridge et al., 2022; Silva et al., 2020, 2021). However, the degree of emphasis on cognitive/tactical content still depends heavily on program design and coach philosophy, so many youth coaching curricula remain primarily focused on physical and technical objectives (Shen & Shao, 2022; Silva et al., 2020, 2021). Recent evidence suggests that a hybrid of structured and unstructured training can shift the focus toward improving cognitive outcomes and game decisions, provided it is systematically designed (Práxedes et al., 2021).

In the context of junior high school futsal in Indonesia, including public junior high schools in Makassar City, field observations and interviews with coaches reveal a similar pattern: training sessions are dominated by SG (Soccer Skills) and technical drills. In contrast, explicit training in cognitive-tactical skills and game intelligence remains limited. This is despite the characteristics of futsal, which is characterized by small pitches, a high tempo, and time-space pressures, requiring junior high school players to be able to read the game context, anticipate opponent movements, and choose the right action in a split-second (Barcellos et al., 2022; Pizarro et al., 2021). This condition emphasizes the need for training solutions that not only maintain the advantages of SSG and game-based approaches but also enrich the cognitive-tactical dimension through media that are more structured, measurable, and adaptive to the characteristics of adolescent development.

The development of Virtual Reality (VR) technology presents new opportunities in sports training, particularly for developing perceptual-cognitive skills, tactical understanding, and game intelligence through immersive, controllable game scenarios. In elite women's soccer, Richard et al. (2021) reported a case study in which VR-based perceptual-cognitive training was integrated into daily training alongside constraint-based tasks, enabling a systematic evaluation of players' perceptual-cognitive skills and the benefits of the training context. Furthermore, research on immersive training systems with a bird's-eye view demonstrated improved cognitive-spatial abilities, enabling athletes to interpret dynamic game play more comprehensively and make better tactical decisions (Sumi & Okuyama, 2024). These findings align with evidence that game intelligence, as measured by design fluency, correlates with on-field performance among elite soccer players, suggesting that VR interventions targeting this cognitive construct could improve decision-making (Finkenzeller et al., 2021; Vestberg et al., 2020).

Broader studies have shown that VR/AR technology can serve as an immersive training tool and an effective means of real-time feedback to develop tactical understanding and decision-making skills in team sports (Cossich et al., 2023). VR allows coaches to engineer complex game situations without physical risk, with the repetition of critical scenarios that are difficult to achieve in traditional on-field training. Furthermore, VR-based metrics such as Rate Correct per Second (RCS) provide an objective measure of perceptual-decisional efficiency during VR tasks, making it easier to track improvements in players' response speed and accuracy (Wilkerson et al., 2025). Within the framework of youth player development, these characteristics of VR are particularly relevant for conditioning players to become accustomed to scanning, processing multiple pieces of information, and selecting optimal tactical solutions under pressure, as emphasized in the literature on game intelligence in invasion sports (Hintermann et al., 2021; Jordet et al., 2020; Zhang et al., 2025).

Based on this foundation, the development of VR-based futsal tactics learning media in this study is realized as VR Player Education media accessible via a web platform and integrated into junior high school futsal training programs. This model is designed to combine ecological-dynamic principles and SSG practices with exposure to virtual tactical scenarios rich in visual information and structured decision points. Thus, the model is expected to measurably improve tactical awareness, perceptual skills, and decision-making in junior high school players while remaining aligned with the demands of real-life games (Kalén et al., 2021; Ortiz et al., 2023; Scharfen & Memmert, 2021).

While initial evidence on the effectiveness of VR in improving perceptual-cognitive skills and decision-making in athletes is promising, several key gaps remain, particularly regarding its integration into youth futsal/soccer tactics training. First, the validity of transfer to on-field performance in adolescent populations is still limited; Most VR studies have focused on adult athletes or have not directly linked improvements in VR tasks to real-life match decisions (Ardha et al., 2023; Cossich et al., 2023; Krupitzer et

al., 2022; Richard et al., 2021; Wang, 2024). Second, VR task design and ecological validity require content tailored to specific developmental stages and sport contexts; many protocols still use generic scenarios that do not fully reflect the dynamics of junior high school futsal (Krupitzer et al., 2022; Wang, 2024; Wood et al., 2020). Third, there is no standardized VR curriculum for youth development, either in terms of the progression of materials, integration with SSG, or outcome assessment procedures. This includes the need for cost-effectiveness data and scalable implementation guidelines in clubs or schools (Ardha et al., 2023; Wang, 2024). Fourth, accessibility, safety, and usability issues, such as the risk of cybersickness and potential injury, require systematic evaluation in the context of VR for adolescents (Vora et al., 2025; Wilkerson et al., 2025). Fifth, age-specific outcome measures for perceptual-cognitive skills and game intelligence in VR environments are lacking; existing metrics were generally developed for adults and require validation for younger populations (Finkenzerler et al., 2021; Wilkerson et al., 2025).

In response to this gap, this study aims to develop and test a Virtual Reality-based futsal tactical learning model for junior high school players that explicitly targets improving tactical awareness, perceptual skills, and decision-making in futsal. Specifically, this study seeks to: (1) design and validate futsal VR media with high content and ecological validity through the involvement of subject matter experts and media experts; (2) implement the VR model in futsal training programs at several junior high schools in Makassar, integrated with field training; and (3) evaluate the model's effectiveness on players' cognitive skills through pre- and post-intervention measurements. The novelty of this study lies in the development of a VR curriculum specifically tailored to the characteristics of junior high school futsal, its integration with the principles of SSG and TGfU, and the use of cognitive-tactical indicators relevant to the game intelligence framework that has been linked to on-field performance (Pizarro et al., 2021; Scharfen & Memmert, 2021; Vestberg et al., 2020). The research scope covers the context of school futsal coaching in Makassar City, with a focus on cognitive-tactical aspects. In contrast, physical and technical elements are maintained as a supporting background, so that the research results are expected to provide practical and theoretical contributions to the development of technology-based youth futsal training models in Indonesia.

Material & methods

Materials

This study employed a Research and Development approach with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model, ensuring systematic material selection from the analysis stage to development. The subjects were male junior high school students (aged 14–15) participating in futsal extracurricular activities at three public junior high schools, with at least six months of training experience and a health condition that permitted them to participate in an intensive training program. The learning context was futsal training based on small-sided games (SSGs), as SSGs have been shown to create an information-rich environment that stimulates cognitive skills such as tactical awareness, perceptual skills, and decision-making in invasion games like futsal (Kalén et al., 2021; Pedreño, 2025; Scharfen & Memmert, 2021).

Physical materials include a standard futsal pitch, distinguishing vests, and supporting equipment to modify the game space and format (e.g., 2v2, 3v3, 4v4) according to the constraint-led approach principle, which impacts the speed and accuracy of technical decisions (passing, dribbling, shooting) (Vestberg et al., 2020). The primary digital material is the VR application “VR Edukasi Player,” which runs on a simple device and a head-mounted display to present tactical futsal scenarios immersively. This application presents a real-life futsal game scenario that displays tactical attack and defense situations, player perspectives, and several decision options that must be selected quickly, thereby stimulating tactical awareness, perceptual skills, and decision-making under time pressure (Pedreño, 2025; Vestberg et al., 2020). The game performance assessment rubric used was developed by referring to the Offensive Tactical Knowledge Test (TCTOF-BRA) (Rechenchosky et al., 2022) and the Tactic UP Soccer Test (Machado & Teoldo, 2020), whose use in the soccer context has shown evidence of construct validity for measuring game behavior, tactical understanding, and decision-making (Bonilla et al., 2024; Matos et al., 2023; Pambudi et al., 2024).

Sample Preparation

The Analysis and Design phase of ADDIE was used to prepare the sample and intervention context. The research subjects were junior high school students from SMPN 24 Makassar, SMPN 3 Makassar, and SMPN 1 Makassar. In the analysis phase, training observations and coach interviews were conducted to identify the need for strengthening cognitive skills in junior high school futsal training, in line with findings that cognitive skills guide how players read the game context and choose actions under pressure (Kalén et al., 2021; Scharfen & Memmert, 2021). Based on these results, inclusion criteria (age, training experience, training attendance) and exclusion criteria (injury, health problems) were established to ensure participants were ready to participate in the SSG and VR training program. This research protocol was approved by the Institute for Research and Community Service, Makassar State University with number 5487/UN36.11/TU/2025.

In the Design phase, the sample was divided into an experimental and a control group. Participants and their parents received a written explanation of the program's objectives, procedures, and potential risks and benefits, and were then asked to complete a consent form. Before the intervention, all participants underwent an introductory session on the measurement procedures and VR equipment to reduce anxiety and the risk of

cybersickness. The training included video case studies and a limited pilot testing of the knowledge instrument based on the TCTOF-BRA and Tactic UP Soccer Test to ensure item clarity for junior high school players. Perceptual-cognitive skills and video-based decision-making were delivered through VR goggles, using pre-designed futsal video footage, and a tactical board, where players were asked to pause the video at key moments and choose the best course of action.

Experimental set-up

The Development and Implementation phase focused on setting up the training program and experimental procedures. The research design used a quasi-experimental pre- and post-test with a control group. Both groups (control and experimental) participated in a regular futsal training program based on SSG for eight weeks, three times per week, for approximately 90 minutes per session. During each session, the coach modified the game format (number of players, pitch size, touch rules, and time) to create varying cognitive loads and stimulate decision-making in match situations (Pedreño, 2025; Scharfen & Memmert, 2021; Vestberg et al., 2020).

The experimental group received two additional VR sessions per week (approximately 20 minutes per session) using VR Edukasi Player. The VR scenarios presented futsal attack, defense, and transition situations from the player's perspective, with several decision options to choose from within a limited time. After each scenario, the coach provided brief feedback to connect the decisions made in VR to the tactical principles discussed in SSG. Meanwhile, the control group underwent only field training without VR but with the same SSG and TGfU structure. Pre-test measurements were taken before the training cycle began, and post-tests were taken immediately after the eight-week cycle ended, consistent with the practice of sports VR interventions that assess pre-post changes (Reneker et al., 2020).

Table 1. Main Objective VR Training Session

Program Components	Group	Frequency Duration	&	Training Program Summary
Tactical VR Session (Player Education VR)	Experiment	2×/week, minutes/session, weeks	±20 8	A short warm-up, then 10–15 VR scenarios about futsal attack and defense from a player's perspective.
Post-session tactical reflection (field & VR)	Experiment	5–10 minutes at the end of the session	at the	A brief discussion of some key decisions in a VR scenario. Players explain their reasons for choosing an action and compare more effective alternatives.

Parameters

The Design and Development phase was used to formulate and operationalize the main parameters evaluated in the Evaluation phase. The primary parameters were cognitive skills, consisting of tactical awareness (TA), perceptual skills (PS), decision-making (DM), and a composite cognitive skills score (CS). TA is defined as a player's understanding of attack-defense principles, positioning, and tactical solutions aligned with the game phase. PS is the ability to scan, recognize space and free teammates, and predict the opponent's actions. DM is the speed and accuracy of action selection (passing, dribbling, shooting) in various situations of numerical advantage or inferiority.

Complementarily, specific tactical knowledge was assessed through a written test, in the style of the TCTOF-BRA, adapted to the futsal context, containing multiple-choice statements on tactical solutions (Rechenchosky et al., 2022). Perceptual-cognitive abilities and video-based decision-making were measured using a test modeled on the TacticUP Soccer Test, which uses video footage of futsal match scenarios and has players choose the best action at key moments (Machado & Teoldo, 2020). The composite CS score was calculated from combining the TA standard score with the results of the instrument validity test (content validity) using Aiken's V formula with a coefficient value of 0.906, PS with a coefficient value of 0.937, and DM with a coefficient value of 0.921, which means that all three indicators have high validity values.

Statistical Analysis

The evaluation phase in ADDIE is implemented through systematic statistical analysis to assess the effectiveness of the training model. The initial step involves compiling descriptive statistics (mean, standard deviation, minimum–maximum values) for all parameters in the pre- and post-test, followed by a normality test (e.g., Shapiro–Wilk) to verify that the data conform to the assumption of normality. This procedure aligns with reporting patterns for VR intervention and sports education research, which utilizes a combination of descriptive statistics, assumption tests, and pre- and post-test inferential tests (Asiabar et al., 2025; Reneker et al., 2020; Wibowo et al., 2023). To examine within-group changes, paired t-tests (or Wilcoxon signed-rank tests if normality was not met) were used on TA, PS, DM, and CS scores for each group. Between-group comparisons at post-test were performed using parametric tests (ANCOVA or independent t-test) when assumptions were met, or non-parametric tests (Mann–Whitney U) when data were non-normal, with pre-test scores controlled as covariates when necessary (Asiabar et al., 2025). In addition to p-values, effect sizes (e.g., Cohen's d or rank-biserial correlation) were reported to interpret the magnitude of the intervention effect and its

practical relevance. Data were analyzed using JASP. This approach aligns with reporting recommendations for VR sports studies that emphasize pre-post assessment, effect sizes, and the potential transfer of improvements in perceptual-cognitive and decision-making skills to real-world game contexts, particularly in young populations where research is still relatively scarce (Greenhough et al., 2021; Reneker et al., 2020; Wilkerson et al., 2024).

Results

Table 2. ADDIE Design Research

Development Procedure	Research Findings
Define Stage Identify needs	The Define phase in this study focuses on identifying the need for developing a tactical futsal training model based on Virtual Reality (VR) technology to support cognitive abilities and enhance players' decision-making skills. Observations, interviews with coaches, and literature reviews revealed that school-level and beginner club players still struggle with understanding game tactics, reading match situations, and making the best decisions within limited time and space. Conventional training has not fully provided dynamic, game-like simulations, emphasizing the need for a more interactive and contextual training medium. VR technology has the potential to offer safe, realistic, and measurable tactical training experiences without requiring a full futsal court or complete team, while also increasing players' motivation and engagement. However, challenges such as limited VR facilities, coaches readiness to integrate technology, and the need for appropriate difficulty adjustment must be addressed to ensure the effectiveness and applicability of the developed training model according to players cognitive development.
Design Stage Designing a Virtual Reality-Based Tactical Futsal Training Model and Cognitive Decision-Making Evaluation Tools	The design stage focuses on developing a Virtual Reality (VR)-based tactical futsal training model along with evaluation tools to measure players' cognitive abilities and decision-making performance. Tactical scenarios are designed to replicate real match conditions, including ball-receiving decisions, passing options, defensive positioning, space utilization, and responses under time pressure. The VR environment is developed to provide immersive first-person gameplay experiences that enhance players' tactical awareness and engagement. Additionally, measurable evaluation indicators are created to assess pattern recognition, reaction speed, decision accuracy, and understanding of team strategies. The training model and assessment instruments are designed to be adaptive to different player skill levels and practical for coaches to implement, ensuring alignment with the objective of enhancing cognitive skills and improving decision-making in futsal.
Developing Stage Expert Review of Material, Expert Review of Media, Small-Scale Trials, and Large-Scale Trials	In the developing stage, the Virtual Reality (VR)-based tactical futsal training model that has been designed is transformed into an initial prototype. A material expert review involving futsal specialists is conducted to evaluate the accuracy of tactical content, strategy suitability, and its relevance in improving players' cognitive abilities and decision-making skills. In addition, a media expert review involving professionals from Informatics Engineering and Educational Technology is carried out to assess the technical quality of the VR application, including interface design, interactivity, navigation clarity, and overall effectiveness as a training medium. After revisions based on expert feedback, the product undergoes a small-scale trial with a limited group of futsal players to observe initial usability, user comfort, and responses during tactical simulation activities. Based on improvements from this stage, a large-scale trial is then conducted with a greater number of players to examine the broader effectiveness of the model, particularly in enhancing cognitive performance and decision-making abilities during real game situations. The results from the entire development process serve as the foundation for final refinement of the product before advancing to a wider implementation stage.
Disseminate Stage Wide scale distribution	The following is a link to the Virtual Reality-based tactical futsal training model that has been uploaded and shared through the Google Drive platform https://drive.google.com/drive/folders/1DVR4m-cH3T20xIa9qfT_kfp4SaLkfpd https://vr-futsal-benny-badaru.netlify.app/

In the Analysis and Design phase, observations, coach interviews, and a literature review confirmed the need for a futsal tactical training model that explicitly targets the cognitive skills of junior high school players, given that previous tactical VR studies have been dominated by adult samples and rarely compared VR with conventional training in adolescents (Greenhough et al., 2021; Reneker et al., 2020). This was then translated into the design of futsal VR scenarios (attack, defense, and transition) from the player's perspective, which required scanning and action selection and aligned with a design fluency-based game intelligence measurement framework (Finkenzeller et al., 2021; Vestberg et al., 2020). In the Development phase, the "Player Education VR" prototype and assessment tools were validated by content and media experts; feedback on tactical relevance, visual clarity, system stability, and feedback patterns were integrated into product revisions until they were suitable for field testing. The Implementation phase then applies this model in a junior high school futsal training program and measures its impact on tactical awareness, perceptual skills, and decision-making. At the same time, the Evaluation phase assesses the effectiveness of the model through pre-post and inter-group

analyses, in line with current reporting practices for sports VR trials (Asiabar et al., 2025; Cossich et al., 2023; Reneker et al., 2020).

Table 3. Test of Normality Data Result

Measurement	Students	Valid	Missing	Std. Deviation	Shapiro-Wilk	P-value of Shapiro-Wilk	Range	Min	Max
Pre-Test TA	Control	45	0	1.624	0.822	< .001	4	13	17
Pre-Test TA	Experiment	45	0	1.502	0.746	< .001	4	12	16
Post-Test TA	Control	45	0	1.595	0.909	0.002	5	14	19
Post-Test TA	Experiment	45	0	1.29	0.738	< .001	3	17	20
Pre-Test PS	Control	45	0	1.643	0.813	< .001	4	13	17
Pre-Test PS	Experiment	45	0	1.468	0.802	< .001	4	12	16
Post-Test PS	Control	45	0	1.546	0.852	< .001	4	14	18
Post-Test PS	Experiment	45	0	1.29	0.738	< .001	3	17	20
Pre-Test DM	Control	45	0	1.7	0.788	< .001	4	13	17
Pre-Test DM	Experiment	45	0	1.44	0.696	< .001	3	13	16
Post-Test DM	Control	45	0	1.667	0.883	< .001	6	13	19
Post-Test DM	Experiment	45	0	1.25	0.78	< .001	3	17	20
Pre-Test CS	Control	45	0	4.793	0.77	< .001	12	39	51
Pre-Test CS	Experiment	45	0	4.271	0.73	< .001	10	38	48
Post-Test CS	Control	45	0	4.317	0.817	< .001	12	42	54
Post-Test CS	Experiment	45	0	3.814	0.758	< .001	9	51	60

Tactical Awareness (TA), Perception Skills (PS), Decision Making (DM), Cognitive Skills (CS)

In the Analysis and Design phase, observations, coach interviews, and a literature review confirmed the need for a futsal tactical training model that explicitly targets the cognitive skills of junior high school players, given that previous tactical VR studies have been dominated by adult samples and rarely compared VR with conventional training in adolescents (Greenhough et al., 2021; Reneker et al., 2020). This was then translated into the design of futsal VR scenarios (attack, defense, and transition) from the player's perspective, which required scanning and action selection and aligned with a design fluency-based game intelligence measurement framework (Finkenzeller et al., 2021; Vestberg et al., 2020). In the Development phase, the "Player Education VR" prototype and assessment tools were validated by content and media experts; feedback on tactical relevance, visual clarity, system stability, and feedback patterns were integrated into product revisions until they were suitable for field testing. The Implementation phase then applies this model in a junior high school futsal training program and measures its impact on tactical awareness, perceptual skills, and decision-making. At the same time, the Evaluation phase assesses the effectiveness of the model through pre-post and inter-group analyses, in line with current reporting practices for sports VR trials (Asiabar et al., 2025; Cossich et al., 2023; Reneker et al., 2020).

Table 4. Wilcoxon signed-rank Test Result

Pre Test	Post Test	W	z	df	p	Rank-Biserial Correlation	SE Biserial Correlation	Rank-Lower	Rank-Upper
Tactical Awareness (Ctl)	Tactical Awareness (Ctl)	0	-5.511		< .001	-1.000	0.179	-1.000	-1.000
Tactical Awareness (Exp)	Tactical Awareness (Exp)	0	-5.841		< .001	-1.000	0.170	-1.000	-1.000
Perception Skills (Ctl)	Perception Skills (Ctl)	0	-5.012		< .001	-1.000	0.197	-1.000	-1.000
Perception Skills (Exp)	Perception Skills (Exp)	0	-5.841		< .001	-1.000	0.170	-1.000	-1.000
Decision Making (Ctl)	Decision Making (Ctl)	28	-4.701		< .001	-0.911	0.191	-0.957	-0.819
Decision Making (Exp)	Decision Making (Exp)	0	-5.841		< .001	-1.000	0.170	-1.000	-1.000
Cognitive Skills (Ctl)	Cognitive Skills (Ctl)	0	-5.841		< .001	-1.000	0.170	-1.000	-1.000
Cognitive Skills (Exp)	Cognitive Skills (Exp)	0	-5.841		< .001	-1.000	0.170	-1.000	-1.000

The Wilcoxon signed-rank test results showed a statistically significant difference between pre-test and post-test scores for all cognitive variables in both the control and experimental groups. All parameters, namely Tactical Awareness (TA), Perception Skills (PS), Decision Making (DM), and Cognitive Skills (CS), showed a significance value of $p < .001$, indicating a consistent increase in scores after the intervention in each group. The negative z-statistic values in all tests indicate a systematic change from pre-test to post-test (an increase in scores at the final measurement). Furthermore, the effect size based on the rank-biserial correlation was firm to near-perfect for almost all variables in both the control and experimental groups, with confidence intervals that remained in the large effect category. Even for the decision-making variable in the control group, which showed a slightly lower effect value than the other variables, the strength of the influence remained in the vast category. Methodologically, these findings confirm that the training program delivered during the intervention period, whether based on SSG alone or in combination with VR, significantly improved students' tactical cognitive skills, with substantial magnitudes of change across all measured constructs. This pattern aligns with findings that VR training in adult soccer improves performance on perceptual-cognitive and decision-making tasks, and that improvements in higher-order cognitive measures (e.g., design fluency) are related to on-field performance (Finkenzeller et al., 2021; Vestberg et al., 2020).

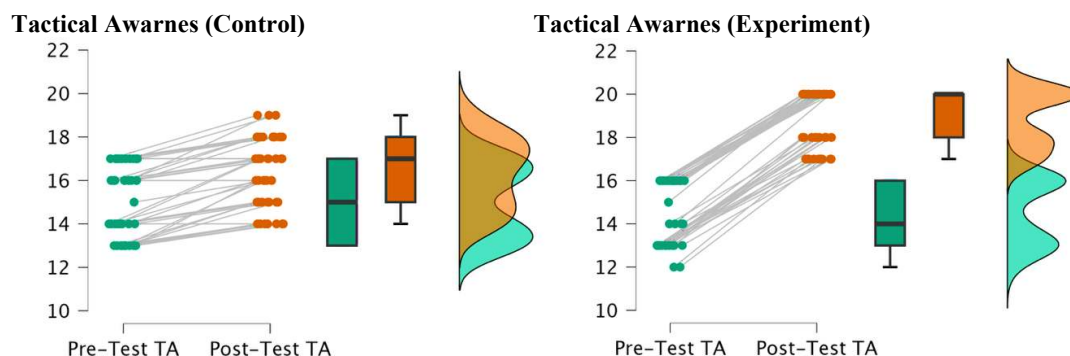


Figure 1. *Tactical Awareness Test Result Comparison*

In the control group, TA scores increased from pre-test to post-test for most participants, as indicated by the upward trend in the individual correlation lines. The boxplot shows a median shift toward higher scores at post-test, with a relatively wider distribution compared to pre-test. However, there is still considerable inter-individual variation, so the increase is moderate and not entirely homogeneous across participants. Meanwhile, in the experimental group, the increase in TA scores appears more consistent and more focused on higher scores. Nearly all individual lines show a clear upward trend from pre-test to post-test. The boxplot shows a larger median shift than in the control group, with the post-test distribution showing a more pronounced upper tail. The density plot also indicates that the post-test distribution in the experimental group shifted substantially toward higher, more homogeneous scores. This visual interpretation suggests that while both groups experienced increases in Tactical Awareness after the training period, the experimental group receiving the Virtual Reality-based intervention demonstrated stronger, more consistent improvements, and with a distribution of performance more restricted to the high-score category than the control group. This strengthens the inferential finding that integrating VR into futsal training positively contributes to students' tactical awareness development.

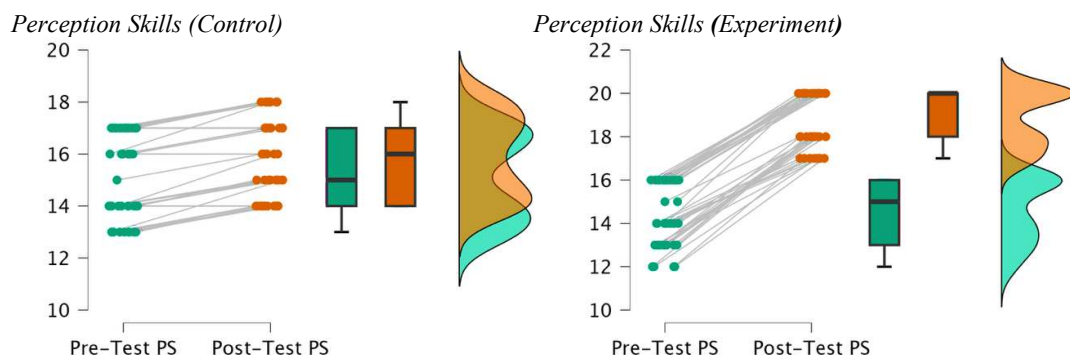


Figure 2. *Perception Skills Test Result Comparison*

In the control group, most participants showed an increase in scores from pre-test to post-test, as evidenced by the upward trend in the individual lines. The boxplot shows a shift in the median toward higher scores after the intervention, although the distribution's range still shows relatively similar inter-individual variation compared to baseline. The density curve also indicates a shift in the distribution toward higher scores, but the increase appears moderate and is not yet fully concentrated in the upper range. In contrast, in the experimental group, the increase in PS scores appears more consistent and substantial. Nearly all individual lines show a clear upward trend, with a larger median shift compared to the control group. The post-test distribution appears more concentrated in higher scores, as indicated by the upward shift in the boxplot and the density curve concentrated in the upper range. Furthermore, the variation in post-test scores appears more homogeneous, suggesting that perceptual improvement occurred more evenly among participants. This visual interpretation shows that although conventional game-based training has a positive impact on improving Perception Skills, the integration of Virtual Reality-based interventions in the experimental group resulted in stronger, more consistent, and more concentrated improvements in the high-performance category, thus strengthening the indication of the effectiveness of VR-based learning models in developing students' perceptual skills.

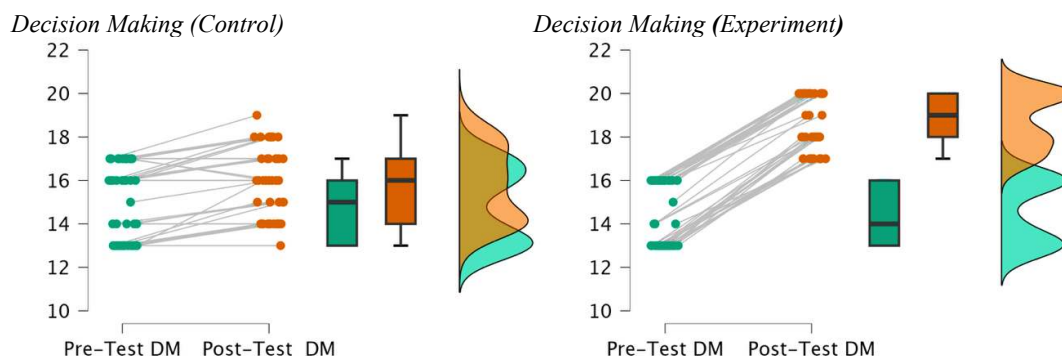


Figure 3. **Decision Making Test Result Comparison**

In the control group, most participants showed an increase in scores from pre-test to post-test, indicated by the upward trend in the connecting lines for individual scores. The boxplot shows a shift in the median toward higher scores after the training period, although relatively widespread variations in scores remain. The post-test density distribution also shifted to the right compared to the pre-test, indicating an increase in decision-making ability. However, this increase appeared gradual and was not entirely concentrated in the highest score range. In contrast, in the experimental group, the rise in decision-making scores appeared more pronounced and consistent. Nearly all participants showed a visually significant increase in scores, with individual lines moving sharply toward higher values. The post-test boxplot shows a larger median shift than in the control group, as well as a distribution more concentrated in the high-score category. The density curve also shows a dominant concentration of scores in the upper range, indicating that the improvement in decision-making ability occurred more evenly and intensively in the group receiving the Virtual Reality-based intervention. This visualization shows that although conventional game-based training can improve students' decision-making abilities, the integration of VR-based tactical learning models produces more substantial improvements, is more consistent between individuals, and is more concentrated on high performance, thus strengthening the indication of the effectiveness of VR interventions in developing decision-making abilities in the context of futsal.

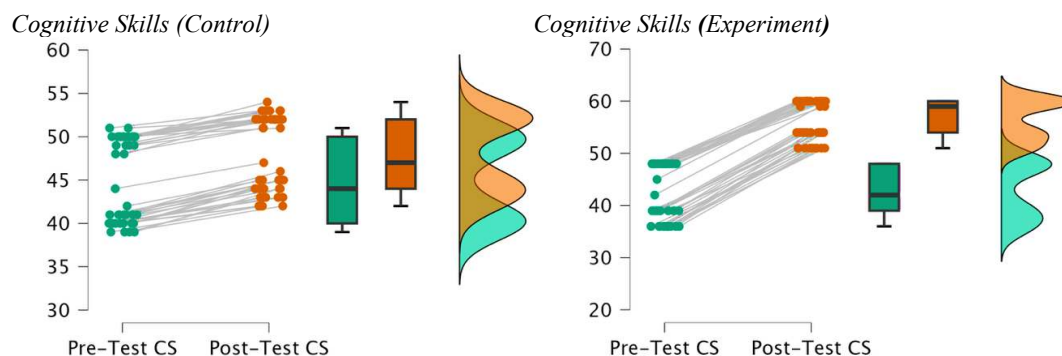


Figure 4. **Cognitive Skills Test Result Comparison**

In the control group, CS scores increased after the training period, as indicated by most individual lines moving towards higher post-test scores. The boxplot shows an upward shift in the median, suggesting a general improvement in cognitive abilities. However, the distribution of scores still shows considerable variation. The density curve also indicates a shift in the distribution towards higher scores, although the distribution was not entirely in the highest performance range. In contrast, in the experimental group, the increase in Cognitive Skills scores appeared more pronounced and systematic. Nearly all participants showed a consistent rise in scores from pre-test to post-test. The boxplot shows a larger median shift than in the control group, accompanied by a post-test distribution that is more concentrated in the high-score range.

The density visualization shows a sharper change in the distribution to the right, with a more homogeneous concentration of scores in the upper performance category. This visual interpretation suggests that while conventional game-based training has a positive impact on cognitive abilities, integrating a Virtual Reality-based tactical learning model produces more substantial improvements, is more consistent across individuals, and is more concentrated at the high-performance level. These findings strengthen the indication that VR interventions make a significant contribution to the development of comprehensive cognitive-tactical skills in the context of junior high school futsal learning.

Table 5. **Mann-Whitney Test Result**

		95% CI for Effect Size						
Test	Statistic	df	p	Effect Size	SE Effect Size	Lower	Upper	
Post-Test CS	Student	-9.757	88	< .001	-2.057	0.302	-2.566	-1.54
	Mann-Whitney	211	< .001	0.792	0.122	0.684	0.866	

The analysis results showed a statistically significant difference between the two groups ($p < .001$), indicating a difference in score distribution after the intervention. The test statistic confirmed that the experimental group's post-test scores were consistently higher than those of the control group. Furthermore, the effect size was large to huge, as indicated by a Mann-Whitney effect size of 0.792 with a 95% confidence interval that did not cross zero. This suggests that the difference is not only statistically significant but also has strong practical significance. Thus, these findings provide solid empirical evidence that integrating a Virtual Reality-based tactical learning model yields significantly greater cognitive improvement than conventional game-based training alone. These findings are consistent with the standard reporting pattern of VR intervention studies: combining descriptive statistics, pre-posttests, intergroup comparisons, and reporting effect sizes to interpret the practical significance of the training (Asiabar et al., 2025; Wibowo et al., 2023).

Cognitive Skills Post-Test Result Comparison

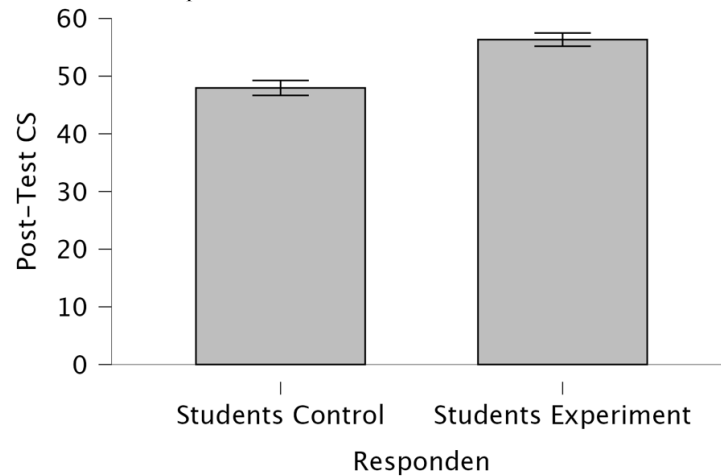


Figure 5. **Cognitive Skills Post Test Result Comparison**

Visually, the average score of the experimental group is higher than that of the control group. The difference in bar height indicates a clear difference in cognitive abilities after the intervention period. The error bars for both groups appear relatively small and do not overlap significantly, indicating that the variation within each group is well controlled and that the mean differences between groups are consistent. Substantively, this visualization reinforces the results of the previous inferential analysis, which showed that Virtual Reality-based interventions have a greater impact on improving cognitive skills than conventional training. Thus, this figure provides strong visual support for the claim that integrating a VR-based tactical learning model significantly enhances students' Cognitive Skills in the final stage of the intervention. This series of results provides

evidence that the VR-based futsal tactical learning model developed through the ADDIE approach is efficacious in improving junior high school students' cognitive skills, as evidenced by the composite CS score, which integrates TA, PS, and DM. Given the limited youth-specific evidence in the team sport VR literature (Greenhough et al., 2021; Wilkerson et al., 2025), these findings provide a significant empirical contribution and emphasize the need for more focused reporting of VR outcomes in youth populations.

Dicussion

Empirically, the main findings of this study demonstrate that the VR-based futsal tactical learning model developed through the R&D–ADDIE approach can improve junior high school players' cognitive skills, namely tactical awareness (TA), perceptual skills (PS), and decision-making (DM), which are then integrated into a composite cognitive skills (CS) score. Significant improvements occurred in both the control and experimental groups. Still, the experimental group receiving a combination of SSG–TGfU-based field training and VR sessions demonstrated a higher and more homogeneous post-training CS profile. This indicates that VR does not replace, but rather enhances, the effects of conventional game training by consolidating TA, PS, and DM components into a more stable game intelligence pattern across most players. The rationale for these findings can be understood from the intervention design: SSG provides an information-rich gaming experience and spatial-temporal pressure, while VR adds structured exposure to critical scenarios without physical risk, resulting in a significant increase in cognitive repetition within the same training time.

The improvements in both groups indicate that the program's foundation, SSG, is appropriate for the junior high school futsal context. Modified SSG environments, such as those involving player numbers, spatial dimensions, and game rules, have been shown to stimulate perceptual-cognitive development and decision-making quality in invasion sports (Kalén et al., 2021; Pedreño, 2025; Scharfen & Memmert, 2021). However, an additional advantage in the experimental group suggests that VR provides greater value in integrating the three components of cognitive skills. Since CS scores are calculated by combining standard scores for TA, PS, and DM, the significantly greater and more uniform CS improvement in the experimental group indicates that VR helps players “integrate” tactical understanding, perceptual processing, and decision-making into a coherent cognitive scheme when facing game situations. In coaching practice, this means players not only understand the principles of the game separately but also apply them quickly and consistently under pressure.

When compared with previous research findings, this pattern of results is consistent with evidence that tactical VR training in soccer and other team sports can improve performance on perceptual-cognitive tasks and decision-making. Case studies of elite players have shown that when VR-based perceptual-cognitive training is integrated into daily training, cognitive performance on tasks relevant to the game context, such as visual encoding and positional decisions, is improved (Richard et al., 2021). Similar findings by Badaru et al., (2026) that Virtual Reality-based tactical futsal training is more effective than conventional training methods in improving athletes' tactical cognition and decision-making skills. A bird's-eye-view approach in VR has also been reported to improve spatial interpretation and tactical decision-making, thereby enhancing players' understanding of team-play structures (Sumi & Okuyama, 2024). The results of this study extend this evidence to the context of junior high school players, using a pre-post-test and control-group design, thereby bridging the gap that most previous research has focused on adult athletes.

The finding that CS improvements were relatively significant and evenly distributed across the experimental group is also consistent with the literature on the relationship between game intelligence and on-field performance. Higher-order cognitive measures, such as design fluency, have been linked to match performance and proposed as a proxy for game intelligence sensitive to post-intervention changes (Finkenzeller et al., 2021; Vestberg et al., 2020). Although this study did not directly use a design fluency test, the structure of CS as a TA–PS–DM composite is contextually proximal to that construct. Thus, improvements in CS may indicate an increased capacity of players to generate varied and adaptive tactical solutions in game situations, a key characteristic of game intelligence relevant to transfer to on-field performance.

Methodologically, the pattern of pre-post-test improvement and significant inter-group differences is also consistent with trends in VR intervention studies in sport. Normality tests, descriptive statistics, and pre-posttests (both parametric and nonparametric), along with reporting effect sizes, are standard approaches for describing training effectiveness (Asiabar et al., 2025; Wibowo et al., 2023). Quasi-experimental studies in adult soccer have shown that VR training based on decision-making tasks improves performance on VR tests and related cognitive measures. However, this effect is not always accompanied by detailed field data (Reneker et al., 2020). This study follows a similar pattern but places it in an adolescent context with a specific focus on futsal cognitive skills, adding contextual diversity to the literature, which has been dominated by college or non-athlete samples. Compared to non-immersive approaches, this study's findings align with evidence that video-based training can improve anticipation and decision-making skills in sports teams. Both animated and 360-degree VR have been reported to be effective for assessing and training decision-making, and observations have broadly suggested potential transferability of skills from immersive environments to real-world game situations (Jia, 2024). Conversely, systematically structured 2D video-based training has also been shown to improve cue-reading and decision-making abilities, suggesting that cognitive mechanisms between immersive and non-immersive media may overlap (Machado & Teoldo, 2020; Zhao et al., 2022). Thus, the superiority of

the futsal VR model in this study does not emerge in a vacuum but builds on a foundation of evidence that repeated exposure to visually cue-rich tactical scenarios whether in video or VR can strengthen players' cognitive schemas.

However, several limitations and potential contradictions need to be considered. First, much of the VR literature highlights that evidence of skill transfer from VR to youth match performance is still limited and requires more targeted trials (Finkenzeller et al., 2021; Jia, 2024; Sumi & Okuyama, 2024). This study aligns with these limitations because the primary outcomes measured were still cognitive and game performance in a training environment, rather than official match statistics or long-term performance indicators. Second, although the experimental group demonstrated significant CS improvements, the quasi-experimental design without individual randomization still leaves open the possibility that school- or coach-level contextual factors influenced the outcome. Third, this study has not used objective VR metrics, such as Rate Correct per Second, which has been proposed as a measure of decision-making speed and accuracy in VR tasks and has the potential to serve as an essential indicator for monitoring training responses in adolescents (Wilkerson et al., 2025).

From a theoretical perspective, the results of this study can be explained through several complementary frameworks. First, the ecological-dynamic and constraint-led learning frameworks emphasize the importance of designing training exercises that reflect the demands of the game, while allowing manipulation of task constraints to encourage exploration of tactical solutions (Pedreño, 2025). On-field simulations provide an information-rich game context, while VR expands the representative training space by projecting similar match scenarios, but with tight control over variables such as perspective, tempo, and complexity. This combination is consistent with the principles of TGfU and representation-based learning, which position players as problem solvers in modified game contexts, allowing tactical understanding and decision-making to develop through experience and reflection (Pedreño, 2025).

From a perceptual-cognitive training perspective, VR provides a cue-rich, time-pressured environment that targets information processing and decision-making skills in near-match conditions. Recent evidence suggests that VR training can improve tactical decision-making and pressure adaptation in high-performance sport contexts, particularly when scenarios are designed with relevant cues and clear feedback (Noury et al., 2023). In this study, the VR futsal scenario required players to scan, recognize attack or defense options, and select actions within a short timeframe; this aligns with the idea that training under time pressure strengthens information selection skills and decision speed, which are expected to carry over to match situations.

The concept of naturalistic decision-making emphasizes that decision quality is strongly influenced by context and prior experience. VR enables coaches to construct context-rich scenarios that reflect specific attack or defense patterns, helping players develop contextual priors that will allow faster, more accurate decisions on the pitch (Ashford et al., 2021). In other words, VR functions as an accelerated “experience bank,” allowing players to experience dozens of critical situations in a single session without physical risk and without having to wait for similar situations to arise in a real match.

From a neurocognitive perspective, various VR applications in sports have demonstrated improvements in the visuomotor mechanisms underlying anticipatory decisions, such as motor processing and hand-eye coordination. This supports the idea that carefully designed VR tasks can strengthen the visuomotor processes essential for anticipatory decisions in team sports (Saijo et al., 2025). In this study, the need to rapidly click or select tactical options in VR has the potential to train these visuomotor pathways, thereby supporting improvements in PS and DM, as reflected in CS scores. Furthermore, the VR platform provides opportunities for objective tracking of perceptual-cognitive performance and for targeted feedback, a feature increasingly highlighted as a key advantage of VR over other training media ((Noury et al., 2023; Saijo et al., 2025).

In terms of practical implementation, the study's positive results need to be weighed against the challenges of implementing VR in school settings. VR/XR adoption is heavily influenced by device costs, maintenance requirements, and adequate IT infrastructure support, although technology prices are trending downward (Moreno et al., 2020; Shankar, 2023). This study used a smartphone-based device and a simple head-mounted display, making it relatively realistic for a school context; however, scalability to many schools remains dependent on the ability to procure and maintain the devices. Furthermore, integrating VR into class schedules and extracurricular activities requires equitable access planning and scheduling to ensure equal opportunities for all students. In contrast, remote or flipped models require equitable connectivity and devices (Hubail et al., 2022).

Another challenge relates to content development and teacher/coach readiness. High-quality, age-appropriate VR content aligned with physical education goals requires time and resources to develop or curate (Moreno et al., 2020; Shankar, 2023). This research demonstrates that collaboration among futsal experts, media experts, and researchers can produce relevant, effectively used content; however, for widespread adoption, adequate teacher/coach training models and support systems are needed. Safety and usability aspects, such as the potential for cybersickness and safe device use by students, must also be addressed with clear guidelines and adequate supervision (Shankar, 2023). Recent reviews confirm that VR evidence in schools remains predominantly from non-sport contexts, and the transfer to on-field performance in adolescents remains an area that requires further exploration (Lu, 2024).

Based on the findings and theoretical framework above, several further research directions and agendas can be proposed. First, additional studies should integrate match performance indicators (e.g., practical pass statistics, chances created, or decision indices in official matches) to measure the extent to which CS improvements in VR and SSG training transfer to real-life games. Second, the use of VR objective metrics, such as Rate Correct per Second, could provide a more precise picture of changes in decision-making speed and accuracy during training programs and could serve as an essential indicator in the adolescent context (Wilkerson et al., 2025). Third, combining general cognitive measures, such as design fluency, with field indicators would enrich our understanding of the relationship between executive abilities and game intelligence among junior high school players (Finkenzeller et al., 2021; Vestberg et al., 2020).

Overall, this study demonstrates that a VR-based futsal tactical learning model developed using the ADDIE approach is a rational and effective intervention for improving junior high school players' cognitive skills. The results are consistent with recent evidence on the benefits of VR and immersive training on mental processing, speed, and accuracy of decision-making in the soccer context, while highlighting the need for further study on transfer to match performance and broad-scale implementation of strategies in school settings (Jia, 2024; Sumi & Okuyama, 2024; Zhao et al., 2022). Thus, this study provides a strong empirical and theoretical basis for integrating VR technology into youth futsal training curricula, both as a complement to conventional training and as a cognitive laboratory to hone the game intelligence of the next generation of players.

Conclusions

This study concludes that a virtual reality-based futsal tactical learning model developed through an R&D approach using the ADDIE design effectively improves junior high school players' cognitive skills. The integration of small-sided games-based field training and Teaching Games for Understanding sessions with VR has been shown to strengthen tactical awareness, perceptual skills, and cognitive decision-making, which are integrated into a composite skill score. The improvements were not only statistically significant but also demonstrated consistency and homogeneity of the cognitive-tactical profiles in the experimental group, making this model worthy of recommendation as a complement to conventional futsal training in school settings. However, this study has limitations, including its quasi-experimental design without individual randomization, the lack of official match performance indicators, and the lack of use of VR objective metrics to measure decision-making speed and accuracy. Therefore, generalizing the findings requires caution and is supported by further studies across more diverse contexts and samples. Based on these results, it is recommended that school futsal coaches begin integrating simple educational VR into their training programs, while maintaining the SSG portion and game-based approach as the primary foundation. Schools and education policymakers are expected to support the provision of minimal infrastructure and teacher/coach training to operate and integrate VR safely and pedagogically. Future researchers are recommended to test the transfer of skills to performance, use more objective VR metrics, and develop a standardized and replicable VR curriculum across youth futsal training contexts.

Based on the research findings, it is recommended that junior high school futsal coaches begin integrating VR-based training sessions into their regular training programs, with planned portions that do not replace field training. VR should be used as a "cognitive laboratory" to expose players to a variety of tactical scenarios in a structured manner. At the same time, small-sided games and game-based approaches remain the foundation for the development of technical and physical skills. Schools and education administrators are advised to provide basic infrastructure support, such as mobile devices, simple head-mounted displays, and adequate internet access to ensure consistent implementation of educational VR applications. Training and mentoring programs for physical education teachers and futsal coaches should be developed to equip them with the pedagogical and technical competencies to design, implement, and broadcast VR-based training sessions safely and effectively. For content developers and stakeholders, cross-disciplinary collaboration between sports experts, educational technologists, and software developers is needed to produce VR content that is contextual, age-appropriate, and aligned with the physical education curriculum. Developing practical guidelines or manuals for implementing VR in schools, covering safety, exposure duration, and classroom management, would greatly facilitate implementation in the field. For future researchers, it is recommended to examine the transfer of cognitive skills drilled through VR to actual match performance, using more comprehensive performance indicators. The use of more objective VR metrics and research designs that sample across regions or competition levels would strengthen the scientific basis for using VR in youth futsal training.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to enhance the clarity of the writing. After using the ChatGPT, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

Conflicts of interest The author declared no conflicts of interest.

Acknowledgments The author expresses their acknowledgments to Kemdiktisaintek for the support in completion this study through the 2025 Fundamental Research Scheme. (083/CT/DT.05.00/PL/2025)

Funding source This research was funded by Kemdiktisaintek trough Degree Number: 083/CT/DT.05.00/PL/2025

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Appendix

Table 1. Suggestions and Improvements to the Validator's Conceptual Model

Expertise/Agency of Origin	Suggestion
Informatics Engineering / Faculty of Engineering State University of Gorontalo	Media Display It is recommended to improve color consistency across scenes to create a more harmonious and visually appealing display. Text and instructional elements should be enhanced in terms of size and contrast to ensure better readability for all users. Technical Quality Application performance should be further optimized to prevent lag during fast-motion simulations. Wider device compatibility testing is recommended to ensure smooth use across commonly available VR equipment in schools/clubs. Interactivity & Functionality Additional gameplay scenarios are needed to provide more comprehensive tactical training situations. Include a real-time feedback feature (e.g., tactical decision scoring) so users can understand their mistakes and how to correct them. Benefits & Feasibility To maximize instructional benefits, it is recommended to provide a usage guide for coaches or teachers. Include an evaluation or performance tracking feature to monitor player progress after training sessions.
Educational Technology / Faculty of Sports Science and Health State University of Makassar	Media Display Consider adding more familiar icons or visual cues to support easier navigation within the VR media. Player character designs can be refined to better resemble real futsal players, increasing user engagement and relevance. Technical Quality Audio elements can be improved for more realistic feedback, such as ball sound effects and player communication. Navigation buttons and control responses should be made more responsive to support smooth transitions between menus and scenes. Interactivity & Functionality Controls and interaction mechanisms should be improved to feel more natural and closely mimic real on-field movements. A selectable difficulty level could be added to accommodate the varying skill levels of students/players. Benefits & Feasibility Training and familiarization activities should be provided for coaches and players to ensure optimal implementation.
Sports Science / Faculty of Sports Science State University of Semarang	Material Relevance It is recommended to expand the variety of tactics and formations included in the material so players can explore more game situations. Content Quality The structure is good but could be improved by clearly mapping the learning progression from basic to advanced levels. Feasibility of VR Integration Simulations can be enriched by adding various match conditions such as counter attacks, pressing, and defensive transitions. General Aspects & Benefits Including reflective components to help players review their progress after training will boost learning effectiveness.
Sports Coaching Education / Faculty of Sports Science and Health State University of Makassar	Material Relevance The connection between training content and the actual characteristics of futsal can be strengthened through real on-court scenario examples. Content Quality More detailed emphasis on movement patterns and player positioning should be added visually for easier understanding. Feasibility of VR Integration Learning experiences would be more optimal with performance indicators embedded during VR training sessions. General Aspects & Benefits The material could become a stronger innovation in sports learning if accompanied by guidance for coaches/teachers.