Journal of Coaching and Sports Science
Volume 4, Issue 2, 146-160.
e_ISSN: 2963-1483
https://www.journal.foundae.com/index.php/jcss/index
DOI: 10.58524/jcss.v4i2.912

Integration of Eye-Tracking Technology in Virtual Reality Applications for Basketball Training: A Mixed Methods Needs Assessment

Ahmad Rahmadani*
Universitas Islam Riau
Indonesia

Oki Candra
Universitas Islam Riau
Indonesia

Feby Elra Perdima
Universitas Dehasen Bengkulu
Indonesia

Syed Kamaruzaman Syed Ali
Universiti Malaya
Malaysia

Joseph Lobo
Bulacan State University
Philippines

Novri Gazali
Universitas Islam Riau
Indonesia

Article Info

Article history:
Received: September 2, 2025
Revised: October 15, 2025
Accepted: December 6, 2025

Keywords:
Virtual reality;
Eye-tracking;
Basketball;
User needs.

Abstract

Background: The integration of virtual reality (VR) and eye-tracking (ET) technologies has considerable potential for enhancing perceptual–cognitive skill development in basketball. However, existing research provides limited guidance on the technical and pedagogical requirements for designing VR–ET systems that are both instructionally meaningful and aligned with user needs.
Aims: This study aims to identify these key design requirements through a user-centred mixed-methods approach.
Methods: Semi-structured interviews and focus group discussions with coaches and lecturers were conducted to explore training challenges, expectations, and pedagogical considerations. Insights from the qualitative phase informed the development of a questionnaire administered to student-athletes (N = 120), allowing for the validation and prioritisation of system requirements. Qualitative data were analysed thematically, while quantitative data were examined using descriptive statistics.
Result: The integrated findings reveal six essential domains for effective VR–ET system design: immersive tactical–technical visualisation, interactive decision-making scenarios, gaze-based performance indicators, real-time visual feedback, learning support features, and implementation readiness. Users emphasised the value of VR–ET for enhancing tactical understanding, attentional control, and personalised training experiences.
Conclusion: This study contributes both theoretically and methodologically by addressing the lack of user-informed frameworks in VR–ET research and demonstrating the value of participatory mixed-methods approaches in sports technology development. The results provide a foundational design blueprint for future VR–ET prototypes and offer new insights into how immersive and gaze-based technologies can support athlete learning in team sports.

To cite this article: Rahmadani, A., Candra, O., Perdima, F. E., Ali, S. K. S., Lobo, J., & Gazali, N. (2025). integration of eye-tracking technology in virtual reality applications for basketball training: A mixed methods needs assessment. *Journal of Coaching and Sports Science, 4*(2), 146-160. https://doi.org/10.58524/jcss.v4i2.912

INTRODUCTION

Advances in virtual reality (VR) technology have reshaped modern sports training, particularly in disciplines such as basketball that demand rapid decision-making and precise visual–kinaesthetic coordination (Liu et al., 2023; Pagé et al., 2019; Rahmadani et al., 2025; Richard et al., 2022). Yet conventional training often cannot reproduce complex, high-pressure game situations needed to develop athletes' perceptual–cognitive skills systematically. Sport science literature emphasises that abilities such as anticipatory judgment, spatial attention, and situational awareness are fundamental to expert performance and require ecologically valid training environments (Roca et al., 2021). VR offers this advantage by enabling immersive, repeatable tactical simulations that are difficult to create on the court (Witte et al., 2025), while also enhancing athlete motivation and engagement (Mouatt et al., 2020). These factors highlight the urgent need to design VR-based

*** Corresponding author:**
Ahmad Rahmadani, Universitas Islam Riau, INDONESIA. ✉ahmadrahmadani@edu.uir.ac.id

systems that directly support the increasing cognitive demands of contemporary team sports.Visual attention plays a central role in basketball performance, influencing shooting accuracy, tactical awareness, and decision-making speed under pressure (Milley & Ouellette, 2021; Moeinirad et al., 2022; Zhao et al., 2023). Studies consistently show that expert athletes employ more efficient gaze behaviours, such as longer fixations on relevant cues and more rapid information sampling, which correlate with superior performance outcomes (Sirnik et al., 2022). Gaze-contingent and perception-based training has demonstrated potential for improving visual search strategies and cognitive efficiency in complex game situations (Limballe et al., 2022). These findings highlight the need for training systems capable of capturing and enhancing athletes' perceptual–cognitive processes in ecologically valid environments.

Integrating eye-tracking (ET) technology into VR offers a promising pathway to address these needs. ET enables the precise recording and analysis of gaze behaviour during immersive training, allowing researchers and coaches to examine attentional patterns, visual strategies, and decision-making processes in real time (Ji et al., 2019). Evidence suggests that ET-supported interventions can improve attentional control and provide actionable insights into perceptual–motor coordination in sports (Kredel et al., 2023; Liu et al., 2023). Early VR–ET integrations also demonstrate benefits such as enhanced scenario realism (Adhanom et al., 2023; Luidolt et al., 2020), improved biomechanical observation (Iskander et al., 2019), and better monitoring of psychological states including stress and cognitive load (Stoeve et al., 2022). These developments collectively indicate that VR–ET systems can provide a rich platform for adaptive, data-driven training.

Despite these advancements, research on VR and ET in sport remains fragmented, with most studies examining the two technologies separately (Heilmann & Witte, 2021; Pastel et al., 2023) and offering limited insight into how gaze behaviour interacts with decision-making in dynamic team environments. Existing VR work often focuses on performance testing rather than identifying the pedagogical or design requirements necessary for effective system development (Chandra et al., 2019; Richlan et al., 2023). Technical constraints, such as gaze-tracking accuracy, latency, and interface responsiveness, also restrict realistic integration in movement-rich settings (Aitcheson-Huehn & Kiefer, 2024). Importantly, recent reviews show that athletes and coaches are seldom included in technology design processes, leading to systems that do not align with real training needs (Gestri, 2024; King et al., 2025).

Responding to these limitations, this study aims to identify the technical and pedagogical requirements for developing a VR-based basketball training system integrated with ET technology, using a participatory mixed-methods approach involving coaches, lecturers, and athletes. By engaging end-users throughout the early stages of system conceptualisation, this study provides a structured, empirically grounded design blueprint that bridges the gap between VR–ET technological capabilities and real-world coaching and learning contexts. This work advances existing literature by moving beyond post-implementation evaluation and providing a user-informed, contextually relevant foundation for the development of immersive, gaze-based training systems in team sports.

METHOD

Research Design

This study uses an exploratory mixed-methods approach, combining qualitative and quantitative methods within the framework of user-centered participatory design (PD). PD allows coaches, lecturers, and athletes to participate as co-designers, not just objects of study, in line with participatory principles that emphasize user ownership from the early stages of design (Vaughn & Jacquez, 2020). In line with the exploratory sequential mixed-methods approach, the qualitative phase was conducted first to generate in-depth insights into user needs and preliminary system requirements, followed by a quantitative phase to validate and prioritise these findings among a larger participant group. This sequential structure ensured that the quantitative instrument was developed directly from qualitative results and that the final interpretation integrated both data strands.

Participants

This study was conducted in Riau Province, Indonesia, from April to June 2025. Three groups of participants were involved: basketball coaches, physical education lecturers, and university student athletes. These three groups represent technical, pedagogical, and practical perspectives in technology-based training. Participants were selected using purposive sampling for coaches and lecturers and stratified purposive sampling for student athletes to ensure diverse and relevant representation of the training context in Riau Province. Although the study did not receive formal approval from an institutional review board, all procedures were carried out in accordance with standard ethical research practices. Participants received clear explanations of the study's purpose, procedures, potential risks, and the study's voluntary nature before taking part. Written informed consent was obtained before participation, and confidentiality was ensured by anonymising personal data and securely storing all research materials. Details of participant characteristics are presented in Table 1.

Table 1. Characteristics of Research Participants

Participant Category	N	Male (%)	Female (%)	Age (Mean ± SD)	Age Range	Inclusion Criteria
Coach	15	11 (73%)	4 (27%)	34.1 ± 4.8	28–43	Active ≥ 2 years, certified, actively coaching a team
Lecturer	8	5 (62.5%)	3 (37.5%)	40.5 ± 5.2	33–49	Experience in VR-based sports or educational technology
Student-Athletes	120	78 (65%)	42 (35%)	20.3 ± 1.6	18–24	Active on a university basketball team ≥ 1 semester, experience with digital/field interaction

Data Collection

Data collection followed an exploratory, sequential, mixed-methods design comprising a qualitative phase (interviews and focus group discussions) and a subsequent quantitative phase (questionnaire survey). The qualitative phase was used to explore user needs and generate preliminary system requirements, while the quantitative phase validated and prioritised these findings. The procedures, purposes, and instruments used in each phase are described below, and a summary of the sequential process is presented in Table 2 to enhance methodological clarity.

Qualitative Phase

The qualitative phase comprised semi-structured interviews followed by focus group discussions (FGDs) with basketball coaches and physical education lecturers. The interviews aimed to explore participants' initial perceptions, training challenges, and expectations related to the integration of virtual reality and eye-tracking technologies. These sessions generated experiential and perceptual data concerning training limitations, desired feedback mechanisms, and preferred technological features. The subsequent FGDs were conducted separately with coaches and lecturers to validate and refine the interview findings. During the discussions, participants reviewed preliminary themes, prioritised essential system features, and clarified requirements related to visualisation, interaction, and gaze-based feedback. The refined qualitative themes served as the foundation for developing the quantitative questionnaire, ensuring strong alignment between the two phases. To ensure qualitative trustworthiness, member checking and researcher triangulation were implemented throughout the analysis process, enhancing the credibility and dependability of the findings.

Quantitative Phase

The quantitative phase consisted of a survey administered to 120 student-athletes to validate and prioritise the system requirements derived from the qualitative phase. The questionnaire included 28 items across six domains. It used a 5-point Likert scale to measure perceptions of the importance of key system features, including interactivity, eye-tracking integration, visual feedback, interface accessibility, and training module structure. The purpose of this phase was to provide numerical validation of the qualitative themes, identify priority features, and strengthen the overall findings with measurable trends. Instrument quality was evaluated through validity and reliability procedures. Content validity, assessed using the Content Validity Ratio (CVR), showed that all items exceeded the minimum threshold of 0.62. Reliability analysis demonstrated strong internal consistency for the total scale (α = 0.89), with sub-domain reliability coefficients ranging from 0.78 to 0.87.

Table 2. Summary of Mixed-Methods Data Collection and Integration Process

Phase / Stage	Method Used	Participants	Main Activities	Outputs / Contributions
Stage 1 (Qualitative)	Semi-Structured Interviews	Coaches & Lecturers	Identifying training problems, VR–ET expectations, design needs	Preliminary system requirements
Stage 2 (Qualitative)	Focus Group Discussions	Coaches & Lecturers	Validation & refinement of themes, prioritisation of features, design specification	Final qualitative themes; basis for questionnaire
Stage 3 (Quantitative)	Questionnaire Survey	Student-Athletes (N=120)	Rating importance of features; evaluating technical & pedagogical needs	Quantitative validation & prioritisation
Integration Phase	Triangulation & Cross-Analysis	Researchers	Merging QUAL + QUAN findings	Final VR–ET training requirements & prototype directions

Validity and Reliability of Instruments

Quantitative Instrument (Questionnaire)

The questionnaire's validity and reliability were evaluated through content validation and internal consistency testing. Content validity was assessed using the Content Validity Ratio (CVR) with five experts in sport pedagogy and sport technology. All items obtained CVR values ranging from 0.72 to 1.00, exceeding the minimum threshold of 0.62, indicating strong content relevance. Reliability was assessed using Cronbach's alpha, which indicated high internal consistency for the overall scale (α = 0.89). Domain-level coefficients ranged from 0.78 to 0.87, reflecting acceptable to excellent reliability across all constructs. Details of each domain, sample items, CVR values, and alpha coefficients are presented in Table 3.

Table 3. Questionnaire Domains, Number of Items, Sample Items, Content Validity Ratio (CVR), and Cronbach's Alpha (CA)

Domain	Number of Items	Sample Item	CVR	Cronbach's Alpha (α)
Tactical and Technical Visualisation	5	"I find it easier to understand player positions and rotations through 3D visualisations."	0.80	0.82
Interactivity of Exercises and Scenarios	5	"The app should provide exercise scenarios that allow me to make decisions."	0.88	0.85

Domain	Number of Items	Sample Item	CVR	Cronbach's Alpha (α)
Eye-Tracking Integration	6	"I want the application to track the direction of my gaze during training."	0.92	0.87
Interface and accessibility	4	"Navigation within the application should be simple and intuitive."	0.72	0.80
Visual Feedback and Evaluation	4	"I want to receive alerts when I lose focus from the training target."	0.76	0.83
Implementation Readiness and Learning Support	4	"I hope that lecturers or trainers will be actively involved in the implementation of this application."	0.74	0.78
Total	**28**		0.72–0.92	0.89

Qualitative Data Trustworthiness

The trustworthiness of the qualitative data was ensured through member checking and researcher triangulation. The six participants, two coaches, two lecturers, and two athletes, reviewed the preliminary themes to confirm interpretive accuracy. Additionally, three independent coders analysed the qualitative dataset, and discrepancies were resolved through iterative discussion to achieve consensus. These strategies enhanced the credibility, dependability, and confirmability of the qualitative findings.

Integration of Qualitative and Quantitative Phases

To ensure coherence across phases, the questionnaire development followed a direct theme-to-item mapping strategy. Each theme emerging from interviews and FGDs, such as needs related to tactical–technical visualisation, interactive decision-making scenarios, gaze-based feedback, interface usability, and implementation readiness, was translated into measurable questionnaire items. All six qualitative themes were incorporated into the quantitative instrument, although some were operationalised using fewer items when conceptual overlap existed (e.g., learning support and implementation readiness). No contradictions emerged between the qualitative and quantitative phases. Instead, the quantitative results reinforced the qualitative insights by confirming the exact priority domains and providing a clearer ranking of user needs across a larger sample. This integrated approach ensured that the mixed-methods findings provided a coherent, scientifically grounded basis for designing the VR–ET training prototype.

Data Analysis Techniques

Qualitative data were analysed using Braun and Clarke (2021) thematic analysis procedure. This involved familiarisation with the transcripts, systematic coding, categorisation of codes, and theme generation. Themes were refined through iterative review and validated through researcher triangulation and member checking, ensuring analytical credibility and consistency with participants' perspectives. Quantitative data were analysed using SPSS version 26. Descriptive statistics (means, standard deviations, and frequency distributions) were employed to summarise participants' perceptions across questionnaire domains and identify priority system features. Reliability analysis using Cronbach's alpha assessed the internal consistency of each domain, while content validity was examined using the Content Validity Ratio (CVR) to ensure item relevance. These statistical procedures provided empirical support for validating and prioritising the qualitative themes and informed the development of the VR–ET training prototype.

Research Ethics

This study received ethical approval from the Research Ethics Committee of the Universitas Islam Riau (reference number UIR.KEP.04.01.04/2025). All participants provided informed consent before participation, with clear explanations of the research purpose, study procedures, potential risks, and their right to withdraw at any time without consequences. Confidentiality was safeguarded by anonymizing participant identities and securely storing all data on an encrypted server. For interviews and FGDs, explicit written consent for audio recording was also obtained. The study adhered to established research ethics principles, including respect for participant rights, confidentiality, and transparency, in accordance with the Declaration of Helsinki and international research ethics standards.

RESULTS AND DISCUSSION

Results

Qualitative Data

Thematic analysis of semi-structured interviews and FGDs produced six main themes that formed the basis for the development of survey instruments:

Theme 1: Contextual Tactical and Technical Visualisation

Participants emphasised the importance of tactical and technical simulations in realistic 3D visualisation formats. They felt that strategic representations, such as defence zones, fast breaks, and player positions on the court, would be more effective if visualised dynamically.

> "*Seeing player positions and rotations in simulation form really helps players understand the flow of the game*." (Coach 04)

Theme 2: Interactive Training and Decision-Making

The need to create an interactive training experience emerged as a key theme. Participants sought training scenarios that required players to make decisions in real matches rather than passively following instructions.

> "*Training should encourage players to think as they do in a match, not just repeat movements*." (Instructor 02)

Theme 3: Integration of Eye-Tracking as a Cognitive Evaluation Tool

Coaches and lecturers believe that ET can provide valuable data on players' visual attention, including gaze focus and distribution of observation. This data is considered crucial for evaluating non-physical performance aspects such as concentration and decision-making.

> "*With eye-tracking, we know whether players are focusing on the ball, opponents, or open space*." (Coach 10)

Theme 4: Simple and Accessible Interface

Support for an intuitive user interface and a system compatible with various devices (VR headsets, computers, smartphones) is a concern. People perceive high technological complexity as a barrier to adoption.

> "*If it requires expensive and complicated equipment, players will be reluctant to use it. It must be simple and flexible*." (Lecturer 01)

Theme 5: Real-Time Visual Feedback and Evaluation

An ideal training system is deemed necessary to provide instant feedback and visual performance results, such as heatmaps or notifications when technical errors occur. This is considered to enhance athletes' reflection and self-learning.

"*Players can learn on their own if they know where they're looking and when they lose focus.*" (Coach 07)

Theme 6: Implementation Support by Coaches and Lecturers

The adoption of training applications cannot be separated from human resource support. Coaches and lecturers need to be involved in implementation to ensure the system is used optimally in the training and learning process.

"*Without coaches guiding its use, the application is just an additional tool.*" (Lecturer 06)

Quantitative Data
Demographic Characteristics

The demographic characteristics of the participants in this study included gender, age, level of basketball playing experience, playing position, weekly training frequency, and previous experience with VR technology or digital media. A total of 120 student-athletes from the Physical Education program, active members of the university basketball team, participated in the study. The majority of participants were male (n = 78, 65.0%), while 42 participants were female (35.0%). By age group, the majority were aged 18–20 years (58.3%), followed by the 21–22 age group (31.7%), and the remaining 23–24 age group (10.0%).

In terms of playing experience, participants were classified into three categories based on their involvement in training and matches: beginners (31.7%), intermediate (35.0%), and advanced (33.3%). Regarding playing positions, the distribution is guards (37.5%), forwards (40.0%), and centres or other positions (22.5%). Regarding weekly training frequency, most participants trained 3–5 times per week (50.8%), while 28.3% trained fewer than 3 times and 20.9% trained more than 5 times per week. Most participants (76.7%) had prior experience with VR or other interactive digital technologies, which is an essential factor in interpreting the study results. The complete distribution of demographic characteristics is shown in Table 4.

Table 4. Demographic Characteristics of Basketball Student-Athletes

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	78	65.0
	Female	42	35.0
Age	18–20 years	70	58.3
	21–22 years	38	31.7
	23–24 years	12	10.0
Level of Playing Experience	Beginner	38	31.7
	Intermediate	42	35.0
	Advanced	40	33.3
Playing Position	Guard	45	37.5
	Forward	48	40.0
	Center/Other	27	22.5
Training Frequency	< 3 times/week	34	28.3
	3–5 times/week	61	50.8
	> 5 times/week	25	20.9
VR/Digital Experience	Yes	92	76.7
	No	28	23.3

Descriptive Statistics

A quantitative analysis was conducted to evaluate the perceptions of 120 student athletes regarding their technical and pedagogical needs. Respondents completed a 28-item questionnaire developed based on six main domains identified through qualitative exploration. The analysis results showed that, in general, participants had positive perceptions of the features proposed in the VR-ET-based training application. The domain with the highest average score was Tactical and Technical Visualisation (M = 4.28, SD = 0.56), indicating a high need for 3D visual representations and realistic game strategy simulations in learning. The domain with the lowest average score was Implementation Readiness and Learning Support (M = 3.89, SD = 0.62). This reflects concerns about infrastructure readiness and the role of coaches or lecturers in supporting the technology's use. Detailed information on the average scores and standard deviations for each domain is presented in Table 5.

Table 5. Mean and Standard Deviation per Questionnaire Domain

No	Domain	Number of Items	Mean (M)	Standard Deviation (SD)
1	Tactical and Technical Visualisation	5	4.28	0.56
2	Interactivity of Exercises and Scenarios	5	4.21	0.59
3	Eye-Tracking Integration	6	4.14	0.61
4	Interface and accessibility	4	4.08	0.58
5	Visual Feedback and Evaluation	4	4.03	0.60
6	Implementation Readiness and Learning Support	4	3.89	0.62
Overall Average Total		28	4.11	—

Factor Validity Analysis

An Exploratory Factor Analysis (EFA) was conducted to determine whether the 28 questionnaire items aligned with the six domains identified in the qualitative phase. Sampling adequacy was confirmed by a KMO value of 0.89 and a significant Bartlett's Test of Sphericity (χ^2 = 2134.52, $p < 0.001$), indicating that the data were suitable for factor extraction. The correlation structure among variables, summarized earlier in Table 8, also supports factorability. Using Principal Component Analysis with Varimax rotation, six factors with eigenvalues > 1 were extracted, explaining 69.8% of the total variance. Eigenvalues and cumulative variance are presented in Table 6.

Factor loadings ranged from 0.61 to 0.84, exceeding recommended thresholds and demonstrating strong item–factor relationships. No problematic cross-loadings were observed, and each factor corresponded clearly to its conceptual domain: Tactical–Technical Visualisation, Interactivity, Eye-Tracking Integration, Interface & Accessibility, Visual Feedback, and Implementation Readiness. As shown in Table 7, the factor-loading patterns strongly reflect the qualitative themes, confirming alignment between inductive (QUAL) and deductive (QUAN) evidence. Together, Table 6 (variance structure) and Table 7 (factor loadings) demonstrate robust construct validity for the six-domain framework.

Table 6. Eigenvalues and Variance Explained

Factor	Eigenvalue	% Variance Explained	Cumulative %
1	6.42	22.9%	22.9%
2	4.18	14.9%	37.8%
3	3.36	12.0%	49.8%
4	2.41	8.6%	58.4%
5	1.87	6.7%	65.1%
6	1.32	4.7%	69.8%

Table 7. Summary of Factor Loadings

Domain	Factor Loading Range
Tactical–Technical Visualisation	0.68 – 0.84
Interactivity of Exercises	0.65 – 0.82
Eye-Tracking Integration	0.61 – 0.80
Interface & Accessibility	0.63 – 0.78
Visual Feedback & Evaluation	0.66 – 0.83

Pearson Correlation Analysis

Pearson correlation analysis revealed several significant positive relationships among the questionnaire domains, indicating interconnected user perceptions of the VR–ET training system (Table 8). The strongest association was found between Interactivity of Exercises and Scenarios and Eye-Tracking Integration ($r = 0.61$, $p < 0.01$), suggesting that participants who valued interactive, decision-based training scenarios also placed high importance on gaze-based tracking features. Moderate correlations were also observed between Visual Feedback and both Interactivity ($r = 0.46$, $p < 0.01$) and Eye-Tracking Integration ($r = 0.52$, $p < 0.01$), indicating that users who prioritised real-time feedback also valued gaze monitoring as a core system function.

In addition, Interface and Accessibility demonstrated significant correlations across all domains ($r = 0.34–0.49$, $p < 0.01$), highlighting their foundational role in supporting the usability of the VR–ET application. Lower but still significant correlations were noted for Implementation Readiness and Learning Support ($r = 0.29–0.51$, $p < 0.05$), showing that perceptions of institutional or instructional support were related, though less strongly, to preferences for specific technological features. Overall, the correlation pattern suggests that participants tend to view the VR–ET system holistically: preferences for interactivity, gaze-based features, and real-time feedback reinforce one another, while interface quality underpins user acceptance across all domains. The complete correlation matrix and significance levels for all domains are presented in Table 8.

Table 8. Pearson Correlation between Questionnaire Domains

Domain	1	2	3	4	5	6
1. Tactical and Technical Visualisation	1.00					
2. Interactivity of Exercises and Scenarios	0.47**	1.00				
3. Eye-Tracking Integration	0.39**	0.61**	1.00			
4. Interface and Accessibility	0.34**	0.43**	0.40**	1.00		
5. Visual Feedback and Evaluation	0.36**	0.46**	0.52**	0.49**	1.00	
6. Implementation Readiness and Learning Support	0.29*	0.38**	0.44**	0.42**	0.51**	1.00

Notes: n = 120; **p < 0.05 / ** p < 0.01*

One-Way ANOVA

A one-way ANOVA was conducted to evaluate differences in participants' perceptions (Likert-scale ratings) of the importance of tactical and technical visualisation in VR applications based on basketball playing experience. Experience levels (beginner, intermediate, advanced) were classified based on self-reported playing experience and competitive involvement, following standard categorizations in sport science. The analysis revealed significant group differences, $F(2,117) = 5.46$, $p = 0.006$, with a medium effect size ($\eta^2 = 0.085$), indicating that playing experience significantly influenced perceived importance.

Post-hoc Tukey tests showed that advanced players reported significantly higher scores than beginners ($p = 0.004$). No significant differences were observed between beginners and intermediate players ($p = 0.186$) or between intermediate and advanced players ($p = 0.089$). These findings indicate that the observed differences were primarily driven by contrasts between beginners and advanced players, as presented in the ANOVA summary (Table 10) and post-hoc comparisons (Table 11). As shown in Table 9, the Mean and SD values represent participants' average Likert-scale scores and their variability, with advanced players reporting the highest perceptions ($M = 4.05$, $SD = 0.39$), followed by intermediate ($M = 3.81$, $SD = 0.48$) and beginner players ($M = 3.68$, $SD = 0.45$). Figure 1 visually demonstrates these group differences, showing that advanced players had significantly stronger perceptions than beginners ($p < 0.01$).

Table 9. Average Score and Standard Deviation Based on Experience Level

Experience Level	N	Mean	SD
Beginner	38	3.68	0.45
Intermediate	42	3.81	0.48
Advanced	40	4.05	0.39
Total	**120**	**3.85**	**0.46**

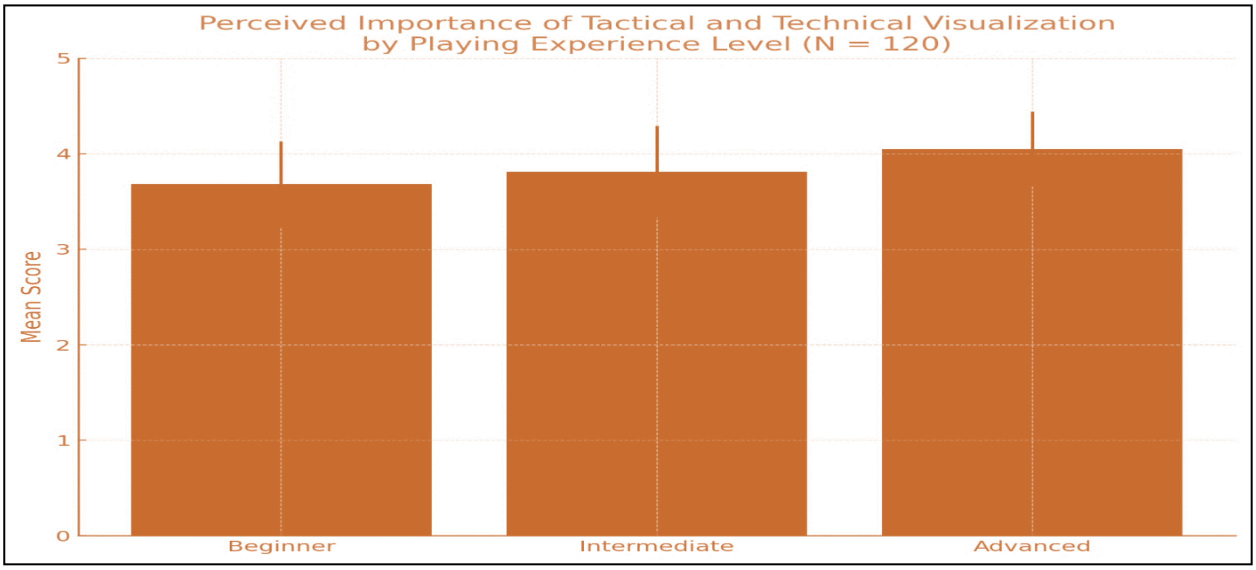

Figure 1. Differences in perceived importance of tactical and technical visualization by playing experience level

Table 10. One-Way ANOVA Results

Source of Variation	df	F	Sig. (p)
Between Groups	2	5.46	0.006 **
Within Groups	117		
Total	**119**		

Notes: *** p < 0.01 indicates a significant difference between groups.*

Table 11. Post-Hoc Tukey HSD Test Results

Group Comparison	Mean Difference	Sig. (p)
Beginner – Intermediate	-0.13	0.186
Beginner – Advanced	-0.37*	0.004
Intermediate – Advanced	-0.24	0.089

Notes: *Post-hoc Tukey HSD test, * p < 0.05, ** p < 0.01.*

Discussion

User Needs and Technology Acceptance in VR-ET Basketball Training

The findings of this study demonstrate that both athletes and coaches show a strong interest in VR training environments that incorporate eye-tracking technologies. Participants consistently emphasised that the most valuable component of such systems is the ability to visualise tactical and technical elements in an immersive format. This supports earlier claims that VR-based simulation enhances athletes' understanding of game structure, improves situational awareness, and provides a safe environment for practising complex tactical patterns (Panchuk et al., 2018; Yunchao et al., 2023). In particular, participants highlighted the relevance of VR for modelling dynamic elements of play, such as defensive rotations or transition scenarios, which are traditionally difficult to reproduce with real-time precision in conventional training sessions.

Interactive training scenarios also emerged as a central expectation among users. This aligns with research showing that VR environments that require athletes to make real-time decisions encourage deeper cognitive engagement and promote learning transfer to on-court performance (Jia et al., 2024). Recent studies similarly emphasize that interactive and decision-rich simulations strengthen perceptual–cognitive processing, particularly when athletes are required to respond to dynamic cues under time pressure (Jia et al., 2024; Kokubu et al., 2025). The desire for interactive modules suggests that athletes value technology not merely as a visual tool but as a platform for active problem-solving that mirrors the demands of competitive decision-making. Such findings support the view that immersion combined with interactivity can enhance perceptual–cognitive skill development in team sports, a claim reinforced by evidence showing that VR-based decision training improves anticipation, gaze behavior, and tactical awareness more effectively than passive video-based approaches (Zhao et al., 2022).

Eye-tracking integration was likewise perceived as an essential component of the proposed VR system. This aligns with earlier work indicating that gaze behaviour reflects key indicators of expertise, attentional control, and decision efficiency in high-speed sport environments (Kredel et al., 2023). ET provides insights into how athletes allocate visual attention during tactical scenarios, making it a powerful complement to immersive VR training. However, ET has known limitations: it captures foveal gaze direction but does not fully represent peripheral perception or covert attentional shifts (Pastel et al., 2023; Vater et al., 2020). These findings reinforce the need for multi-method approaches, combining ET with performance measures, occlusion paradigms, or physiological indicators, to more comprehensively assess perceptual–cognitive processes during training.

Overall, the results indicate that users value VR–ET systems not only for enhancing technical skills but also for supporting cognitive and tactical development. These insights emphasise the importance of designing user-centred training tools that integrate visualisation, interactivity, and gaze-based assessment to meet the multifaceted demands of modern basketball performance.

Interface Challenges and Implementation Issues

Although perceptions of this technology are generally positive, the domain with the lowest score is Implementation Readiness and Learning Support (M = 3.89, SD = 0.62), suggesting concerns about infrastructure support and human resources for in-use. These results align with the Technology Acceptance Model (TAM) (Wang et al., 2024), which states that perceptions of ease of use, facilitating conditions, and external assistance play major roles in influencing user adoption. Recent VR adoption studies similarly report that system usability, technical support, and device compatibility are recurring barriers in educational and training contexts (Makransky & Mayer, 2022; Radianti et al., 2020). In line with this, participants in the present study highlighted the importance of a user-friendly interface and compatibility with existing devices, which is also supported by findings in VR-based sports education showing that ease of use strongly influences continued engagement (Chen & Li, 2024; Michalski et al., 2019). Correlation analysis also revealed a significant relationship between interactivity and ET integration ($r = 0.61$, $p < 0.01$), indicating that users who value realistic decision-making scenarios also tend to value the diagnostic capabilities of ET technology. This correlation confirms the potential of multimodal systems that integrate motor, visual, and cognitive training, an approach supported by recent work demonstrating the benefits of combining VR, gaze analytics, and perceptual–cognitive tasks (Kokubu et al., 2025; Kredel et al., 2023).

Influence of Playing Experience on Technology Perception

The ANOVA results confirmed significant differences in perception based on playing experience, $F(2, 117) = 5.46$, $p = 0.006$. Post-hoc analysis revealed that the differences were mainly between beginners and advanced players. Advanced players showed significantly higher ratings for visualisation features ($p = 0.004$), while no significant differences were observed between beginners and intermediates or between intermediates and advanced players. This finding is consistent with the expertise reversal effect (Schrader & Kalyuga, 2023), which argues that learners with greater expertise are better able to benefit from complex visualisations because they possess more mature cognitive schemas. Recent VR and perceptual–cognitive research also shows that expert athletes are more capable of extracting meaningful tactical cues and interpreting advanced visual information in immersive simulations (Kokubu et al., 2025; Kredel et al., 2023). These studies highlight that skilled performers rely on refined gaze strategies and enriched domain knowledge, enabling them to process complex displays more efficiently than novices. Advanced players, therefore, were better able to interpret and apply tactical visualisation, making the VR-ET system particularly valuable to them. In contrast, beginners may require additional scaffolding or instructional support to maximize the benefits of such features, aligning with broader findings that novices often struggle to integrate rich visual information without structured guidance (Lappi & Veas, 2025).

Implications

The study's findings suggest several important implications for the development of VR–ET training technologies in basketball. First, the strong emphasis on immersive tactical–technical visualisation indicates that future VR systems should prioritise scenario realism and dynamic modelling of game situations. Second, the high perceived value of interactive decision-making modules highlights the need for training applications that promote cognitive engagement rather than passive observation. Third, integrating ET as a diagnostic tool offers opportunities for more personalised, data-driven feedback, which may improve both training efficiency and athlete learning outcomes. Finally, differences based on experience level suggest that VR–ET systems should incorporate adaptive features to support both novice and advanced athletes.

Research Contributions

This study contributes to the limited body of research on VR–ET integration in team sport training by identifying user-driven technical and pedagogical requirements. By involving coaches, lecturers, and athletes in a participatory, mixed-methods design, the study provides an empirically grounded blueprint to guide the development of future VR–ET prototypes. It also expands theoretical understanding of how perceptual–cognitive tools such as ET can be meaningfully embedded within VR training ecosystems.

Limitations

Although this study provides important insights into user needs and perceptions, several limitations should be acknowledged. First, the research was conducted exclusively in Riau Province, Indonesia, limiting generalisability to other settings or competitive levels. Second, both qualitative and quantitative components relied on self-reported data, which may be affected by recall bias or limited familiarity with VR–ET technologies. Third, the study did not measure behavioural or performance outcomes, preventing causal inference regarding the effectiveness of VR–ET systems. Fourth, no prototype testing was conducted, restricting understanding of system usability under realistic decision-making conditions.

Suggestions

Future research should employ longitudinal or experimental designs to examine the long-term effects of VR–ET training on perceptual–cognitive and performance outcomes. Trials conducted in authentic training or competitive simulations would enhance ecological validity. Expanding participant demographics to include youth athletes, elite players, and multiple regions would improve external validity. Incorporating additional technologies, such as biofeedback sensors, motion tracking, or AI-driven analytics, may enhance the precision and personalisation of feedback. Finally, developing practical dashboards for coaches and athletes will be essential for real-world implementation, ensuring that VR–ET systems align with pedagogical and coaching objectives.

CONCLUSION

This study provides an integrated understanding of user needs for developing a VR-based basketball training system equipped with eye-tracking technology. By combining qualitative insights from coaches and lecturers with quantitative perceptions of student-athletes, the findings highlight a consistent emphasis on immersive tactical–technical visualisation, interactive decision-making scenarios, and gaze-based feedback as essential components of effective VR–ET training. Users perceive VR not merely as a technological enhancement but as a tool for supporting perceptual–cognitive development, tactical understanding, and personalised learning pathways. The study advances theoretical perspectives on technology-supported sports training by demonstrating how VR and ET can be jointly leveraged to meet both technical and pedagogical requirements in team sport contexts. Practically, the results offer concrete design guidelines for future VR–ET systems, including the need for realistic 3D simulations, intuitive interfaces, and features that enable coaches to monitor visual attention and provide evidence-based feedback. The findings also emphasise that successful implementation requires institutional readiness and coach involvement, not solely technological innovation. Overall, this research establishes an empirical foundation for the development of adaptive, data-driven VR–ET training systems aligned with modern basketball demands, while opening pathways for future work such as prototype development, experimental evaluation, and longitudinal studies examining training transfer to on-court performance.

ACKNOWLEDGMENT

We would like to thank the Directorate of Research, Technology, and Community Service (DRTPM) for providing funding support for this research.

AUTHOR CONTRIBUTION STATEMENT

AR, OC, and FEP designed the study and developed the research instruments. AR and OC conducted the interviews and focus group discussions, while FEP coordinated data collection from student-athletes. SAK and JL contributed to methodological refinement and assisted with data interpretation. NG supported quantitative analysis and statistical validation. All authors contributed to drafting, reviewing, and approving the final manuscript.

AI DISCLOSURE STATEMENT

The authors used AI-based language-editing and reference-search assistance tools (such as QuillBot and AI-powered scholarly search platforms) to support grammar refinement, clarity improvement, and reference identification during manuscript preparation. After using these tools, the authors thoroughly reviewed, edited, and validated all content to ensure accuracy and integrity. The authors take full responsibility for the final version of this publication.

CONFLICTS OF INTERES

The authors confirm the absence of any financial, institutional, or personal conflicts of interest that could have influenced the conduct of this study, the analysis of the data, the preparation of the manuscript, or its publication.

REFERENCES

Adhanom, I. B., MacNeilage, P., & Folmer, E. (2023). Eye tracking in virtual reality: A broad review of applications and challenges. *Virtual Reality*, *27*(2), 1481–1505. https://doi.org/10.1007/s10055-022-00738-z

Aitcheson-Huehn, N., & Kiefer, A. W. (2024). The utility of head-mounted eye gaze tracking for vision-in-action assessments to enhance skill acquisition and sport performance: A strengths, weaknesses, opportunities, and threats analysis. *Journal of Motor Learning and Development*, *13*(1), 246–256. https://doi.org/10.1123/jmld.2023-0050

Braun, V., & Clarke, V. (2021). *Thematic Analysis: A Practical Guide*. SAGE Publications.

Chandra, A. N. R., Jamiy, F. El, & Reza, H. (2019). A review on usability and performance evaluation in virtual reality systems. *International Conference on Computational Science and Computational Intelligence (CSCI)*, 1107–1114. https://doi.org/10.1109/CSCI49370.2019.00210

Chen, H., & Li, H. (2024). User Experience of virtual reality-based digital sports: A topic modeling approach. In B. T.X. (Ed.), *Proceedings of the Annual Hawaii International Conference on System Sciences* (pp. 4473–4482). IEEE Computer Society. https://doi.org/10.24251/HICSS.2024.538

Gestri, L. G. (2024). Assessment of design values in designing product standards: A design study on a sport PPE. *International Journal of Sports Science and Physical Education*, *9*(1), 15–25. https://doi.org/10.11648/j.ijsspe.20240901.13

Heilmann, F., & Witte, K. (2021). Perception and action under different stimulus presentations: A review of eye-tracking studies with an extended view on possibilities of virtual reality. *Applied Scie*, *11*, 1–12. https://doi.org/10.3390/app11125546

Iskander, J., Hossny, M., & Nahavandi, S. (2019). Using biomechanics to investigate the effect of VR on eye vergence system. *Applied Ergonomics*, *81*(August 2018), 102883.

https://doi.org/10.1016/j.apergo.2019.102883
Ji, B., Wang, Z., Xu, K., & Liu, H. (2019). The feasibility of a virtual reality system for attention analysis. *Proceedings - 2nd China Symposium on Cognitive Computing and Hybrid Intelligence, CCHI 2019*, 207–211. https://doi.org/10.1109/CCHI.2019.8901928
Jia, T., Sitthiworachart, J., & Morris, J. (2024). Application of simulation technology in football training: A systematic review of empirical studies. *The Open Sports Sciences Journal*, *17*, 1–13. https://doi.org/10.2174/011875399X277947231228071109
Jia, Y., Zhou, X., Yang, J., & Fu, Q. (2024). Animated VR and 360-degree VR to assess and train team sports decision-making: a scoping review. *Frontiers in Psychology*, *15*, 1–15. https://doi.org/10.3389/fpsyg.2024.1410132
King, M. H., Knox, B., Martin, T., Vicenzino, B., & Costa, N. (2025). Can athletes design their own technology solutions? Athlete voice driving co-design in sports technology development and implementation. *Dtsch Z Sportmed*, *76*, 178–181. https://doi.org/10.5960/dzsm.2025.636
Kokubu, M., Shojima, K., Kikumasa, S., Oki, Y., & Mieda, T. (2025). Gaze behavior and decision-making in simulated defensive situations for baseball fielders using a head-mounted display. *Asian Journal of Sport and Exercise Psychology*, *56*, 1–10. https://doi.org/10.1016/j.ajsep.2025.10.002
Kredel, R., Hernandez, J., Hossner, E., & Zahno, S. (2023). Eye-tracking technology and the dynamics of natural gaze behavior in sports: an update 2016 – 2022. *Frontiers in Psychology*, *14*, 1–7. https://doi.org/10.3389/fpsyg.2023.1130051
Lappi, O., & Veas, E. (2025). The racer's gaze: Visual strategy in high-speed sports expertise. *Journal of Vision*, *25*, 1–21. https://doi.org/10.1167/jov.25.8.16
Limballe, A., Kulpa, R., Vu, A., Mavromatis, M., & Bennett, S. J. (2022). Virtual reality boxing: Gaze-contingent manipulation of stimulus properties using blur. *Frontiers in Psychology*, *13*, 1–13. https://doi.org/10.3389/fpsyg.2022.902043
Liu, P. X., Pan, T. Y., Lin, H. S., Chu, H. K., & Hu, M. C. (2023). Vision coach: Design and effectiveness study on VR vision training for basketball passing. *IEEE Transactions on Visualization and Computer Graphics*, *30*(10), 6665–6677. https://doi.org/10.1109/TVCG.2023.3335312
Luidolt, L. R., Wimmer, M., & Krosl, K. (2020). Gaze-dependent simulation of light perception in virtual reality. *IEEE Transactions on Visualization and Computer Graphics*, *26*(12), 3557–3567. https://doi.org/10.1109/TVCG.2020.3023604
Makransky, G., & Mayer, R. E. (2022). Benefits of taking a virtual field trip in immersive virtual reality: Evidence for the immersion principle in multimedia learning. *Educational Psychology Review*, *34*, 1771–1798. https://doi.org/10.1007/s10648-022-09675-4
Michalski, S. C., Szpak, A., & Loetscher, T. (2019). Using virtual environments to improve real-world motor skills in sports: A systematic review. *Frontiers in Psychology*, *10*(SEP), 1–9. https://doi.org/10.3389/fpsyg.2019.02159
Milley, K. R., & Ouellette, G. P. (2021). Putting attention on the spot in coaching: Shifting to an external focus of attention with imagery techniques to improve basketball free-throw shooting performance. *Frontiers in Psychology*, *12*(April), 1–9. https://doi.org/10.3389/fpsyg.2021.645676
Moeinirad, S., Abdoli, B., Farsi, A., & Ahmadi, N. (2022). Training visual attention improves basketball three-point shot performance under pressure. *Sport Sciences for Health*, *18*(3), 853–861. https://doi.org/10.1007/s11332-021-00866-0
Mouatt, B., Smith, A. E., Mellow, M. L., Parfitt, G., Smith, R. T., & Stanton, T. R. (2020). The use of virtual reality to influence motivation, affect, enjoyment, and engagement during exercise: A scoping review. *Frontiers in Virtual Reality*, *1*, 1–23. https://doi.org/10.3389/frvir.2020.564664
Pagé, C., Bernier, P.-M., & Trempe, M. (2019). Using video simulations and virtual reality to improve decision-making skills in basketball. *Journal of Sports Sciences*, *37*(21), 2403–2410. https://doi.org/10.1080/02640414.2019.1638193
Panchuk, D., Klusemann, M. J., & Hadlow, S. M. (2018). Exploring the effectiveness of immersive video for training decision-making capability in elite, youth basketball players. *Frontiers in Psychology*, *9*, 1–9. https://doi.org/10.3389/fpsyg.2018.02315
Pastel, S., Marlok, J., Bandow, N., & Witte, K. (2023). Application of eye-tracking systems integrated into immersive virtual reality and possible transfer to the sports sector - A systematic review. *Multimedia Tools and Applications*, *82*(3), 4181–4208. https://doi.org/10.1007/s11042-022-

13474-y
Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 1–29. https://doi.org/10.1016/j.compedu.2019.103778
Rahmadani, A., Candra, O., Perdima, F. E., Gazali, N., & Omar-Fauzee, M. S. (2025). Cutting-edge tech for basketball: Virtual reality and machine learning in executive function and decision-making training. *Health, Sport, Rehabilitation*, *12*(2), 1–13. https://doi.org/10.58962/HSR.2026.12.2
Richard, G., Carriere, J. S. A., & Trempe, M. (2022). Basketball videos presented on a computer screen appear slower than in virtual reality. *Cognitive Processing*, *23*(4), 583–591. https://doi.org/10.1007/s10339-022-01100-6
Richlan, F., Weiß, M., Kastner, P., & Braid, J. (2023). Virtual training, real effects: a narrative review on sports performance enhancement through interventions in virtual reality. *Frontiers in Psychology*, *14*(October), 1-2. https://doi.org/10.3389/fpsyg.2023.1240790
Roca, A., Ford, P. R., & Memmert, D. (2021). Perceptual - cognitive processes underlying creative expert performance in soccer. *Psychological Research*, *85*(3), 1146–1155. https://doi.org/10.1007/s00426-020-01320-5
Schrader, C., & Kalyuga, S. (2023). Expertise reversal effect in a pen-tablet-based learning environment: The role of learningcentered emotions in the interplay between learner expertise and task complexity. *British Journal of Educational Psychology*, *93*(S2), 270–286. https://doi.org/10.1111/bjep.12547
Sirnik, M., Erčulj, F., & Rošker, J. (2022). Research of visual attention in basketball shooting: A systematic review with meta-analysis. *International Journal of Sports Science and Coaching*, *17*(5), 1195–1210. https://doi.org/10.1177/17479541221075740
Stoeve, M., Wirth, M., Farlock, R., Antunovic, A., Müller, V., & Eskofier, B. M. (2022). Eye Tracking-Based Stress Classification of Athletes in Virtual Reality. *Proceedings of the ACM on Computer Graphics and Interactive Techniques*, *5*(2). https://doi.org/10.1145/3530796
Vater, C., Williams, A. M., & Hossner, E. J. (2020). What do we see out of the corner of our eye? The role of visual pivots and gaze anchors in sport. *International Review of Sport and Exercise Psychology*, *13*(1), 81–103. https://doi.org/10.1080/1750984X.2019.1582082
Vaughn, L. M., & Jacquez, F. (2020). Participatory Research methods – choice points in the research process. *Journal of Participatory Research Methods*, *1*(1), 1–14. https://doi.org/10.35844/001c.13244
Wang, E. Y., Qian, D., Zhang, L., Li, B. S.-K., Ko, B., Khoury, M., Renavikar, M., Ganesan, A., & Caruso, T. J. (2024). Acceptance of virtual reality in trainees using a technology acceptance model: Survey study. *JMIR Medical Education*, *10*, 1–29. https://doi.org/10.2196/60767
Witte, K., Bürger, D., & Pastel, S. (2025). Sports training in virtual reality with a focus on visual perception: A systematic review. *Frontiers in Sports and Active Living*, *7*(March), 1–22. https://doi.org/10.3389/fspor.2025.1530948
Yunchao, M., Mengyao, R., & Xingman, L. (2023). Application of virtual simulation technology in sports decision training: A systematic review. *Frontiers in Psychology*, *14*, 1–9. https://doi.org/10.3389/fpsyg.2023.1164117
Zhao, C., Li, S., & Zhao, X. (2023). Empirical study on visual attention characteristics of basketball players of different levels during free-throw shooting. *PeerJ*, *11*, 1–18. https://doi.org/10.7717/peerj.16607
Zhao, J., Gu, Q., Zhao, S., & Mao, J. (2022). Effects of video-based training on anticipation and decision-making in football players: A systematic review. *Frontiers in Human Neuroscience*, *November*, 1–14. https://doi.org/10.3389/fnhum.2022.945067