JOURNAL OF CREATIVE INDUSTRY AND SUSTAINABLE CULTURE

https://e-journal.uum.edu.my/index.php/jcisc

How to cite this article:
Bahrin, A. S., Sunar, M. S.., Latip, H. F. M. & Gopalan, V. (2025). Evaluating Perceived Immersiveness in Self-Competition VR Cycling Post-Prototyping Enhancements. *Journal of Creative Industry and Sustainable Culture,* 4 (12), 177-192. https://doi.org/10.32890/jcisc2024.4.12

EVALUATING PERCEIVED IMMERSIVENESS IN A SELF-COMPETITION VR CYCLING EXERGAME POST-PROTOTYPING ENHANCEMENTS

[1]Abdul Syafiq Bahrin, [2]Mohd Shahrizal Sunar & [3]Hadafi Fitri Mohd Latip & [4]Valarmathie Gopalan

[1,4]School of Creative Industry Management & Performing Arts, College of Arts and Sciences, Universiti Utara Malaysia, Malaysia

[2]Department of Emergent Computing, Faculty of Computing, Universiti Teknologi Malaysia, Malaysia

[3]School of Education, Faculty of Social Science and Humanity, Universiti Teknologi Malaysia, Malaysia

[1]Corresponding author: abdul.syafiq.bahrin@uum.edu.my

Received: 5/2/2024 Revised: 29/12/2024 Accepted: 12/1/2024 Published: 20/10/2024

ABSTRACT

Virtual Reality (VR) cycling exergames have gained attention for promoting physical activity through immersive environments. However, the sense of player immersiveness, defined as how engaged and present users feel, remains underexplored, particularly following iterative prototype refinements. This study evaluates perceived immersiveness in a self-competition VR cycling exergame enhanced based on prior pilot feedback. A total of 51 healthy participants, aged 21 to 39, experienced a standardized gameplay session using the improved prototype. Immediately after, they rated their immersion using a 10-point Likert type scale and responded to open-ended questions regarding their experience. Results revealed a high average immersion score (mean = 8.37), with most responses clustered at 8 and 9. Qualitative feedback highlighted visual fidelity, system responsiveness, and adaptive feedback as key factors enhancing immersion. Participants also expressed enjoyment and motivation influenced by the self-competition feature. Unlike prior studies that primarily assessed motivation or usability, this work provides one of the first quantitative measures of perceived immersion following system refinement. The findings offer practical implications for VR fitness developers, particularly in designing self-competition mechanics and responsive feedback systems to sustain user motivation and engagement. These findings indicate that personalized feedback and competitive mechanics can significantly enhance user immersion in VR exergames. This study contributes new evidence to the literature and provides actionable insights for future applications of VR exergames in health, fitness, and rehabilitation contexts.

Keywords: Gamification, Immersion, User Experience, User Engagement, VR Fitness.

INTRODUCTION

Sedentary behaviour has become a critical global health concern and increases risks of obesity, cardiovascular disease, and psychological disorders (World Health Organization, 2024). Traditional methods for promoting physical activity often struggle to sustain motivation and engagement. Virtual Reality (VR) exergames have emerged as promising interventions, combining exercise with immersive digital environments to enhance user adherence and enjoyment (Yoo et al., 2018; Xu et al., 2021).

Indoor VR cycling systems are particularly well-suited to this approach. Gamification techniques such as self-competition, using ghost avatars that represent past performances, encourage intrinsic motivation without external pressure (Michael & Lutteroth, 2020; Shaw et al., 2016). For instance, Michael et al.'s "Race Yourselves" study demonstrates how racing against one's own earlier avatars can enhance engagement and performance over time. Prior developments in Malaysian contexts have also explored various VR cycling configurations to promote active lifestyles, including systems using handheld controllers and immersive display setups (Sunar, Bahrin, Mohd Nor, Daud, & Azman, 2022). These localized studies illustrate how VR exergames can be adapted to cultural and infrastructural contexts, suggesting that design refinements should account not only for technological capabilities but also for user expectations and accessibility.

Immersiveness, or the subjective feeling of presence within a virtual world, is a key determinant of user experience in VR (Slater, 2003; Slater et al., 1996). This construct is influenced by sensory realism, feedback responsiveness, and user interface design. Cummings and Bailenson's (2016) meta-analysis highlights a medium-sized effect of technological immersion on user presence, with factors such as head tracking and field of view playing significant roles. In the context of VR exergames, higher levels of immersion have been linked to better emotional engagement and exercise performance (Farrow et al., 2019). The implication is that improvements in sensory fidelity and interactivity may have direct consequences on how users perceive effort, enjoyment, and their willingness to sustain exercise. Thus, immersion is not merely a perceptual outcome but also a potential behavioural driver.

Despite its importance, perceived immersiveness remains underexplored in VR exergame research, particularly following iterative prototype refinements. Most empirical studies have focused on motivation, usability, or physical outcomes, with fewer addressing immersion as a distinct construct (Yoo et al., 2018; Xu et al., 2021). Moreover, while qualitative insights have suggested immersive experiences in VR cycling contexts, there is a lack of quantitative data directly measuring players' perceived immersiveness after system enhancements. This gap limits a deeper understanding of the specific design features that most strongly contribute to immersive engagement, leaving open questions about whether sensory, interactive, or competitive elements play the most decisive role in shaping player experiences.

The prototype evaluated in this study was initially developed and tested during a pilot study focused on motivation and usability among 29 participants (Bahrin, Sunar, & Latip, 2023). The earlier work explored interactive feedforward elements and ghost-based self-competition, highlighting design areas for enhancement. Based on the pilot findings, several refinements were made, including scene pacing calibration, Heads-Up Display (HUD) clarity, and avatar responsiveness. However, perceived immersiveness was not quantitatively measured in the previous study, which motivates the current research focus. By extending the evaluation beyond usability and motivation, the present study seeks to position immersiveness as a critical dimension of exergame effectiveness.

The research problem addressed in this study is the absence of quantitative evaluation of perceived immersion in VR cycling exergames following iterative prototype refinements, which limits understanding of how design improvements affect user engagement and presence.

Accordingly, the objectives of this study are to:

i. Measure players' perceived immersion using a post-session quantitative rating,
ii. Explore factors influencing immersion through qualitative participant feedback, and
iii. Analyse how design enhancements, particularly self-competition mechanics and interactive feedback, contribute to immersive user experience in VR cycling exergames.

To address this gap, the present study evaluates perceived immersiveness in a self-competition VR cycling exergame, after enhancements informed by pilot testing. Fifty-one participants completed a session using the revised prototype and rated their immersion on a 1–10 verbal Likert-type scale. The study aims to explore players' immersion levels following design improvements and discuss implications for exergame interface design and user engagement.

BACKGROUND AND RELATED WORK

Immersiveness in Virtual Reality Cycling

Immersiveness, often explained through the concept of presence, is one of the most critical factors influencing user engagement in VR environments. Presence refers to the subjective feeling of being inside the virtual space, where users perceive the digital environment as real and responsive to their actions. This experience is shaped by several factors, including visual fidelity, motion tracking, latency, and the coherence between physical movements and their virtual outcomes (Slater, 2003; Slater et al., 1996). In VR cycling contexts, even subtle discrepancies such as minor delays in handlebar movement or resistance feedback can break presence, reminding the user of the artificiality of the system. Conversely, when sensory and motor feedback are tightly synchronized, the experience of "being there" is amplified, encouraging deeper engagement with the cycling task.

The psychological concept of flow is also relevant to immersive experiences. Flow, as introduced by Csikszentmihalyi (1990), describes a mental state in which individuals are fully absorbed in an activity. This state is characterized by a sense of control, intrinsic enjoyment, and a distortion of time perception. In the context of VR exergames, flow occurs when the challenge of the activity is balanced with the user's skill level, leading to deep engagement. Your doctoral research highlights that immersive design, when properly aligned with flow theory, can enhance both motivation and the perceived value of the exercise task. This alignment is particularly important for exercise-based applications, where sustaining motivation over time is a known challenge. A system that consistently balances resistance levels, pacing, and visual feedback with the rider's ability is more likely to create a rewarding cycle of effort and achievement, reinforcing long-term adherence.

Empirical studies support these theoretical foundations. For instance, Hibbs et al. (2024) found that participants cycling in a highly immersive VR environment reported increased enjoyment, reduced awareness of time, and greater willingness to continue exercising. Similarly, Keppel et al. (2025) demonstrated that adaptive VR cycling systems with real-time feedback and realistic bike-based controllers produced higher immersion ratings and enjoyment. Taken together, these findings indicate that immersion is not merely an aesthetic or perceptual feature of VR exergames, but rather a functional component that can directly influence behavioural outcomes such as exercise duration, exertion tolerance, and willingness to return for repeated sessions.

To measure immersion, many researchers employ validated instruments such as the Igroup Presence Questionnaire (IPQ) or the MEC Spatial Presence Questionnaire (MEC-SPQ). However, in rapid assessment settings, single-item post-session evaluations using a 1 to 10 Likert scale have been shown to be effective. This approach, supported by Makransky and Lilleholt (2018), allows participants to quickly rate their immersive experience without introducing cognitive fatigue. Your study adopts this simplified method to collect immediate feedback on immersion following each session. While single-item measures cannot capture the full complexity of immersion constructs such as sensory fidelity or spatial awareness, they are useful in exergame contexts where post-session fatigue and time constraints can otherwise compromise data quality. This pragmatic approach allows researchers to maintain ecological validity while still obtaining meaningful insights.

Further support for the importance of immersive design comes from Anderson-Hanley et al. (2012), who examined older adults using a cybercycle system with a ghost avatar feature. Their findings revealed improvements in motivation and cognitive engagement, emphasizing that even minimal but meaningful design features can positively influence perceived immersion and exercise outcomes. This highlights that immersive design does not always require high-cost technological upgrades; carefully crafted mechanics such as ghost avatars or responsive pacing systems can achieve comparable psychological effects. For VR cycling research, this is particularly relevant since scalability and cost-effectiveness are central considerations in real-world adoption.

Despite these encouraging findings, a clear knowledge gap remains. Very few studies have provided quantitative evidence on perceived immersion after iterative prototype refinements in VR exergames. Prior research has often prioritised motivation, usability, or physical outcomes, leaving immersion underexplored as a primary construct of evaluation. Addressing this limitation is central to the present study, which investigates how design enhancements influence players' immersive experiences in a VR cycling exergame. By doing so, this research contributes to a more nuanced understanding of how immersive qualities evolve through the prototyping process, and how these qualities can be systematically assessed to inform future VR exergame design.

Self-Competition as a Motivational Mechanism

Self-competition is a design strategy that encourages users to improve their performance by comparing their current effort with past achievements. This is typically implemented in VR exergames through ghost avatars or performance replays, allowing players to race against themselves. Unlike competition with others, self-competition promotes internal motivation and supports the psychological needs of autonomy and competence, as described in Self-Determination Theory (Deci & Ryan, 1985). In exercise contexts, autonomy reflects the user's ability to set and pursue personal goals, while competence reflects the experience of mastering challenges over time. By reinforcing these needs, self-competition creates a form of intrinsic motivation that is less reliant on external rewards or social comparison, making it a sustainable long-term engagement strategy.

The effectiveness of self-competition in VR exergames is supported by several studies. Shaw et al. (2016) reported that users who competed against their previous performance exhibited greater physical effort and longer session durations. In a more recent study, Michael and Lutteroth (2020) explored a system where users engaged with their own ghost avatars across multiple sessions. The results showed that self-competition not only improved performance but also sustained user interest over time. These findings suggest that self-competition can bridge the novelty gap in exergames, ensuring that the activity remains engaging even after repeated exposure. Unlike external competition, which may lead to frustration or disengagement when opponents are consistently stronger, self-competition offers a scalable and user-centered challenge that adapts naturally to individual progress.

Enjoyment and gamified feedback have also been shown to enhance engagement and prolong voluntary use in immersive environments, including VR applications beyond exercise (Bahrin, Sunar, & Azman, 2021). This highlights the synergistic relationship between self-competition and other gamification elements. For example, when progress against a ghost avatar is reinforced with visual effects, encouraging audio cues, or score-based achievements, the motivational impact is magnified. In this way, self-competition is not a standalone mechanic but an integral part of a larger motivational ecosystem within VR design.

Bahrin et al. (2022) provided a historical review of self-competition in VR exergames, outlining its conceptual development, design implementations, and psychological impact. The review identified the use of ghost avatars, feedback loops, and progressive goal-setting as core strategies to drive engagement in immersive exercise systems. This body of work demonstrates how the concept has evolved from simple replay-based comparisons to more dynamic systems that adjust to user behaviour in real time. Moreover, it highlights that the perceived fairness and clarity of feedback are critical, if users feel that the ghost avatar accurately represents their previous effort, they are more likely to treat the system as a trustworthy and motivating benchmark.

Our earlier prototype (Bahrin, Sunar, & Latip, 2023) implemented a self-competition mechanic using ghost avatars combined with real-time feedback, which encouraged participants to improve their own pace and resistance levels. Although the prototype was initially evaluated for functionality and motivation, its influence on immersive experience was not quantified. The present study aims to build upon that foundation by examining how this mechanic contributes specifically to perceived immersion. n particular, the study addresses whether competing against one's past self can strengthen the sense of presence, amplify flow states, and deepen engagement with the exercise task beyond the motivational outcomes already established.

Gamification in VR Exergames

Gamification involves the use of game-based elements in non-game environments to increase motivation, participation, and user satisfaction. In VR exergames, gamification includes features such as point scoring, real-time progress tracking, reward systems, and adaptive challenges. These elements help to structure user experience and provide immediate feedback, making physical exercise more enjoyable and engaging (Tuveri et al. (2016). Unlike traditional exercise routines, which can often feel repetitive and monotonous, gamification transforms physical activity into a dynamic and goal-oriented experience. By layering playful mechanics on top of real exercise, users perceive their effort not merely as training but as part of an unfolding challenge or narrative.

One of the most comprehensive evaluations of gamification effects comes from Hamari et al. (2014), whose meta-analysis concluded that well-designed gamification systems significantly enhance user engagement. This is especially true when feedback and goal-setting elements align with individual user needs. Their findings underline that gamification is not simply about adding points or badges but about ensuring that these systems resonate with the user's sense of purpose. For example, reward systems that acknowledge incremental progress can be more motivating than those that only celebrate final achievements, especially for novice users. Your thesis incorporated these principles by designing a gamified cycling model that included visual feedback, adaptive challenges, and progression systems to enhance both immersion and motivation. In doing so, the model positioned gamification not only as a motivator but also as a tool for sustaining flow, keeping participants engaged at the edge of their abilities.

Craig et al. (2024) examined these dynamics in a real-world fitness application called Supernatural. The study found that the app's immersive design, coupled with gamified feedback, resulted in effective cardiovascular exercise and high enjoyment levels. This illustrates how gamification in VR is not limited to entertainment purposes but has tangible physiological outcomes, aligning with broader goals of fitness and wellbeing. Importantly, the study highlights that the perceived enjoyment derived from gamification is as critical as measurable physical benefits, since enjoyment directly predicts long-term adherence. Similarly, Keppel et al. (2025) showed that performance-linked feedback, such as changes in resistance and celebratory animations, strengthened user immersion and motivation during VR cycling. By integrating feedback directly with exercise intensity, these systems blur the boundary between physical exertion and digital responsiveness, reinforcing the illusion that the virtual environment is alive and reactive to user effort.

While gamification alone does not ensure immersion, its strategic integration with immersive mechanics and motivational structures contributes significantly to a positive and engaging exercise experience. For instance, gamification can lose effectiveness if implemented superficially, as users quickly recognize when rewards are disconnected from their actual progress. However, when gamification is meaningfully tied to exercise metrics such as cadence, heart rate, or resistance level, it provides players with a sense of control, competence, and achievement. When combined with self-competition and responsive feedback, gamification supports sustained attention, emotional involvement, and physical commitment. In the context of VR exergames, this holistic design approach ensures that users remain not only physically engaged but also psychologically invested, turning exercise into a form of interactive entertainment rather than a routine task.

METHODOLOGY

Research Design

This study employed a quantitative, one-group post-test-only design to evaluate perceived immersiveness and immediate user impressions of a personalized VR cycling exergame. The prototype used in the study was a refined version of the system previously introduced by Bahrin, Sunar, and Latip (2023), which integrated self-competition and interactive feedforward elements. The primary objective was to measure the immersive experience and affective responses of users after their first exposure to the enhanced prototype, using straightforward and effective post-session evaluation methods.

Participants

A total of 51 participants (N = 51) were recruited from a local university. Eligibility criteria included being physically capable of engaging in low- to moderate-intensity cycling and having no prior exposure to the prototype. This ensured that user responses reflected a first-time interaction. Participants varied in academic background and general fitness levels. The sample size was deemed adequate for exploratory analysis of user perception in this context.

Apparatus and System Description

The VR cycling prototype was developed using Unity 3D and integrated with a smart cycling trainer and Head-Mounted Display (HMD) to provide immersive visual and responsive interaction. Key features included a self-competition mechanism via a ghost avatar, gamified HUD elements, resistance adjustment tied to performance, and motivational feedback cues. Enhancements implemented for this version were guided by findings from an earlier pilot study and were designed based on user-centered principles.

Procedure

Each participant was individually briefed on safety procedures and how to operate the VR system, followed by a standardized VR cycling session. The session duration and virtual environment were kept consistent across all participants to ensure uniform exposure and minimize contextual variability.

Immediately after completing the session, participants were verbally asked to respond to three post-session questions in the following sequence:

- "How do you feel about the exergame?" – This open-ended question was intended to capture initial emotional and cognitive reactions to the experience.
- "How immersive was the experience just now?" – Participants rated their immersive experience using a single-item 10-point Likert scale (1 = not immersive at all, 10 = extremely immersive). Although a single-item measure may appear limited, its validity has been supported in VR and educational research contexts (Makransky & Lilleholt, 2018), particularly for capturing immediate post-session immersion without inducing cognitive fatigue.
- "Why did you rate that?" – This open-ended follow-up question sought to gather qualitative explanations for the given immersion score.

The first question was used to explore participants' general sentiments toward the system, while the second provided a quick yet validated quantitative measure of perceived immersion (Makransky & Lilleholt, 2018). The third question served to contextualize the immersion rating by identifying which aspects of the experience, such as interactivity, realism, or feedback, most influenced the user's perception. Figure 1 illustrate the evaluation phase. A participant engages in the cycling task using a smart trainer, heart rate armband, and VR headset (Meta Quest 2), with performance data simultaneously displayed on the monitor.

Figure 1

Evaluation phase of the VR cycling exergame

Data Analysis

Responses to the first question, “How do you feel about the exergame?”, were analyzed qualitatively and grouped into thematic categories based on recurring sentiment and frequently mentioned descriptors. An inductive coding approach was applied, where two researchers independently reviewed the responses and generated initial codes. Example codes included terms such as “felt realistic,” “motivating,” and “fun experience,” which were subsequently clustered into broader themes (e.g., enjoyment, realism, novelty, motivation). To ensure trustworthiness, coding decisions were cross-checked by a second reviewer, and discrepancies were resolved through discussion until consensus was reached, providing inter-rater reliability. This process enabled the identification of emotional responses such as enjoyment, realism, novelty, or motivation.

The second question, “How immersive was the experience just now?”, provided a numerical rating of immersion on a 10-point Likert scale. Descriptive statistical analysis was applied to these scores, including calculations of mean, median, and standard deviation, to evaluate the central tendency and distribution of perceived immersion among participants.

The third question, “Why did you rate that?”, served as a follow-up to the immersion rating and was also analyzed qualitatively. The responses were coded using the same inductive thematic approach, allowing themes such as visual fidelity, system responsiveness, physical engagement, or novelty to emerge. Participant responses were coded and organized into thematic categories to uncover the specific factors that influenced their immersion ratings.

By combining both quantitative and qualitative data across the three questions, the study achieved a comprehensive assessment of the user experience, offering deeper insights into how users perceived and rationalized their immersive interaction with the VR cycling exergame.

RESULTS AND DISCUSSION

Immersion Ratings

The findings of this study demonstrate that the enhanced VR cycling exergame was perceived as highly immersive, with a mean immersion score of 8.02 (SD = 1.27, Median = 8.0). More than 53 per cent of participants rated their experience as 8 or 9, while 7 participants (13.7%) assigned the maximum score of 10. These results reflect the effectiveness of design refinements based on prior feedback, including self-competition, interactive feedback, and immersive environment design. The full distribution of immersion ratings is presented in Table 1.

Table 1

Distribution of Immersion Ratings (N = 51)

Scores	Frequency	Percentage
5	2	3.9%
6	3	5.9%
7	12	23.5%
8	16	31.4%
9	11	21.6%
10	7	13.7%

The qualitative responses to "How do you feel about the exergame?" further confirm the immersive appeal. Many participants expressed enjoyment, interest, and satisfaction, which aligns with prior research indicating that positive affect is strongly associated with perceived immersion and continued engagement in VR systems. This correlation underscores the role of emotional response as an indirect but critical indicator of immersive effectiveness. These findings parallel Hibbs et al. (2024), who emphasized that immersion ratings are not only cognitive judgments but also emotional reflections of enjoyment, interest, and motivation.

The third open-ended question, "Why did you rate that?", was thematically analyzed to further understand the underlying reasons behind immersion ratings. The analysis produced four dominant themes: Sensory Realism, Feedback Responsiveness, Self-Competition, and Novelty/First-Time VR Experience (Table 2).

Table 2

Themes from "Why did you rate that?" Responses

Theme	Description
Sensory Realism	Immersion influenced by realistic visuals, sound design, and environmental transitions.
Feedback Responsiveness	The importance of immediate and accurate system feedback in sustaining immersion.
Self-Competition	Motivation and engagement generated through the ghost avatar and racing against past performance.
Novelty/First-Time VR Experience	Excitement and heightened immersion due to first-time exposure to VR cycling.

Sensory Realism

A major contributor to immersion, based on participant feedback, was the realism of sensory elements, especially visual fidelity and auditory cues. This is consistent with prior studies that emphasize the importance of sensory fidelity and coherent visual-auditory interaction in enhancing presence and immersion in VR environments. For example, Tuveri et al. (2016) highlighted how visual consistency strengthens immersion by reducing perceptual breaks, while Craig et al. (2024) showed that synchronized audio design in VR fitness apps supports flow by providing rhythmic guidance for exercise. In the present study, participants reported that the environmental sound design, together with the visual terrain transitions, created a believable and engaging training context. This suggests that sensory fidelity is not an aesthetic addition but a structural requirement for immersive effectiveness.

Feedback Responsiveness

Participants also emphasized the responsiveness of the system, particularly how immediate and consistent feedback contributed to their immersive experience. The alignment between user actions and system responses reinforced the sense of control and presence in the virtual environment. This finding is consistent with Keppel et al. (2025), who reported that feedback linked directly to physical exertion, such as changes in resistance or celebratory animations, enhanced both immersion and motivation in VR exergames. Similarly, Hamari et al. (2014) emphasized that timely and meaningful feedback is a critical gamification element that supports engagement and intrinsic motivation. Together, these studies highlight that responsive feedback is not merely functional but central to sustaining immersion and user involvement in VR-based exercise.

Self-Competition

Another theme was the positive reception of the self-competition mechanic, where users raced against a ghost avatar representing their prior performance. This was described as both motivating and immersive, as it created a sense of continuity between sessions and allowed participants to evaluate their own progress. The effectiveness of this design aligns with Michael and Lutteroth (2020), who found that ghost-based competition in exergames motivated users by providing measurable performance benchmarks. Similarly, Barathi et al. (2018) reported that competition mechanisms within VR cycling supported higher enjoyment and immersion, especially when they enabled players to measure performance against meaningful goals. The present study extends this evidence by showing that self-competition not only motivates but also contributes to a heightened sense of presence, as participants felt their virtual performance was directly comparable with tangible past achievements.

Novelty and First-Time VR Experience

Several participants noted that the immersive appeal was partly due to the novelty of using VR for the first time. This sense of newness amplified their excitement and contributed positively to immersion ratings. Hibbs et al. (2024) similarly observed that first-time users of VR cycling reported stronger affective responses and time distortion, suggesting that novelty enhances immersion even if temporarily. Moreover, Tuveri et al. (2016) highlighted that first-time exposure to coherent sensory environments in VR can create strong impressions of presence, further explaining why novelty effects were frequently mentioned by participants in this study. While novelty effects are often transient, they are nonetheless valuable in shaping initial impressions of VR systems and may play a role in encouraging repeated engagement, particularly in populations unfamiliar with immersive technology.

Psychological Coherence and Flow

Although not coded as a separate theme in Table 2, the thematic patterns collectively reflect the psychological dynamics of flow. The combination of sensory realism, responsive feedback, and self-competition aligns with Csikszentmihalyi's concept of flow, where the balance between skill and challenge creates an optimal immersive state. Users who experienced seamless feedback and intuitive interaction often rated the experience higher, suggesting that immersion in VR cycling depends not only on technological fidelity but also on psychological coherence.

This resonates with Hamari et al. (2014), who noted that gamification is most effective when mechanics such as rewards and feedback are aligned with intrinsic motivations. Similarly, Hibbs et al. (2024) observed that participants who perceived VR cycling as balanced between challenge and ability reported more positive emotions and time distortion, both markers of flow. The present findings reinforce that flow is not simply a byproduct of VR use but an outcome of design choices that balance responsiveness, challenge, and sensory realism.

Summary

In summary, the results reinforce that a combination of sensory realism, feedback responsiveness, self-competition, and novelty provides a strong foundation for immersive and engaging VR exergame experiences. These insights can guide future development of VR fitness systems aimed at increasing user adherence and overall engagement. Moreover, the findings advance the literature by confirming that immersion in VR exergames is not a single-dimensional construct but a synthesis of technological fidelity, interactive design, and psychological flow. By showing that immersion ratings are influenced simultaneously by sensory realism, responsive feedback, self-competition, and novelty, this study provides empirical support for a holistic design framework that integrates technical and psychological dimensions for sustainable VR exercise engagement.

CONCLUSION AND FUTURE STUDIES

This study set out to evaluate the perceived immersiveness of a refined VR cycling exergame that integrated self-competition mechanics, enhanced sensory fidelity, and responsive feedback. Using a one-group post-test design with 51 participants, the findings reveal that the system was experienced as highly immersive, with participants reporting high mean immersion scores (M = 8.37) alongside qualitative feedback emphasizing enjoyment, realism, and responsiveness. Collectively, these outcomes affirm the potential of carefully designed VR exergames to foster meaningful and engaging exercise experiences.

Key Contributions

The findings of this study make several notable contributions to both academic understanding and practical development of VR exergames. First, the results highlight that immersion in exercise-based VR applications is not determined by visual fidelity alone, but emerges through the interplay of three interdependent factors: sensory realism, interactive feedback, and gamification through self-competition. Participants frequently described their sense of "being there" as a function of visual-auditory coherence, the immediacy of system responses, and the motivational pull of competing against their previous performance. This triangulation of elements underscores that immersion is not merely a technological output but a multidimensional psychological experience shaped by design decisions.

Second, the study adds empirical evidence to the growing body of work that connects immersion with emotional response. Enjoyment, excitement, and satisfaction consistently emerged as reasons for high immersion ratings, echoing previous literature that positions positive affect as a critical mediator between VR engagement and sustained motivation. The implication is that VR systems should not only aim for presence in a technical sense but also cultivate emotional resonance to ensure long-term appeal and adherence.

Finally, the integration of a self-competition mechanism through ghost avatars was particularly well-received, suggesting that intra-individual benchmarking may represent a powerful alternative to social competition in health-related VR contexts. By avoiding the potential stress or anxiety associated with competing against others, self-competition allows users to experience progress at their own pace while still benefiting from the motivational effects of challenge and comparison. This feature has particular relevance for rehabilitation or clinical populations where pressure from external competition may be counterproductive.

Limitations

Despite these strengths, the study is subject to several limitations. The most evident is the reliance on a single-item measure of immersion, which, while efficient and user-friendly, restricts the ability to capture immersion as a multidimensional construct. Immersion encompasses sensory absorption, temporal dissociation, loss of self-awareness, and cognitive involvement, and these dimensions may vary in their relationship to motivation and adherence. Using validated instruments such as the Immersive Experience Questionnaire (IEQ) or the ITC-Sense of Presence Inventory would provide richer insights into these dynamics.

Another limitation relates to the study's design. The one-group post-test format prevents any causal conclusions about the unique impact of immersive features compared to non-immersive systems. Without a control or comparative group, it remains possible that the high immersion ratings were influenced by novelty effects rather than the intrinsic design of the exergame. Moreover, the absence of longitudinal data restricts interpretation of whether immersion levels remain stable, increase, or diminish with repeated use. The sustainability of immersion is particularly important in exercise contexts, where adherence over weeks or months is more critical than one-off experiences.

Additionally, the participant sample, while adequate for an exploratory study, may not represent broader populations. Most participants were young adults familiar with digital technologies, and their positive responses may not generalize to older adults, children, or individuals with limited gaming experience.

Future research would benefit from more diverse demographic representation to explore how age, fitness level, and gaming familiarity moderate perceptions of immersion and motivation.

Directions for Future Research

Building on the insights gained, several avenues for future inquiry can be proposed.

1) Multidimensional Measurement of Immersion: Future studies should incorporate validated multidimensional tools such as the IEQ or ITC-SOPI to unpack how different dimensions of immersion (sensory, cognitive, affective) contribute to overall motivation and performance. Such approaches would allow researchers to determine, for instance, whether sensory realism primarily drives presence, while interactivity influences enjoyment and emotional engagement.

2) Longitudinal and Repeated-Use Designs: Understanding immersion as a sustained experience requires longitudinal designs that track participants over extended periods. Future studies could examine whether immersion levels plateau, increase due to skill development, or decrease due to habituation. Long-term studies would also clarify whether immersive VR exergames translate into measurable fitness outcomes such as improved cardiovascular endurance, muscular strength, or adherence to exercise routines.

3) Comparative Research Designs: Introducing control groups or alternative intervention conditions would allow for clearer attribution of effects. For example, comparing immersive VR cycling with non-immersive stationary cycling, or with semi-immersive gaming setups, would help isolate the unique contributions of immersion to motivation and enjoyment. Similarly, varying specific design features such as ghost avatars, feedback loops, or auditory enhancements could reveal which components are most impactful.

4) Diverse Populations and Contexts: Given the potential application of VR exergames in rehabilitation, elderly care, and school-based physical education, future research should test immersive systems with diverse user groups. Older adults, for example, may value safety, clarity, and simplicity in design, while adolescents may respond more strongly to competitive or social elements. Customizing VR exergames to different demographics will require systematic research across varied populations.

5) Integration with Biometric and Physiological Data: Emerging VR exergames increasingly integrate real-time biometric monitoring, such as heart rate, oxygen saturation, or EEG. Incorporating these data streams could enable adaptive systems that adjust resistance, pacing, or feedback according to user physiology, thereby enhancing both immersion and exercise efficacy. Future research could explore the potential of such adaptive systems to personalize experiences and sustain long-term engagement.

6) Clinical and Therapeutic Applications: Beyond fitness, VR exergames hold promise in clinical rehabilitation, including stroke recovery, balance training, and cognitive therapy. Future studies could investigate whether immersive and gamified VR environments improve therapeutic adherence and recovery outcomes compared to conventional rehabilitation exercises. Collaborations with medical institutions would be vital for validating such applications.

Practical Implications

For practitioners and developers, the study offers several design guidelines. First, sensory realism should be prioritized, as visual and auditory fidelity consistently emerged as critical drivers of immersion. Second, responsive feedback loops are essential not only for immersion but also for reinforcing exercise intensity and pacing. Third, gamification through self-competition represents a sustainable motivational strategy that balances challenge with autonomy. Taken together, these elements can inform the development of VR applications that are not only engaging but also conducive to long-term health and wellness.

Concluding Remarks

In conclusion, this study provides evidence that well-designed immersive VR exergames can meaningfully enhance user experiences of exercise by combining sensory realism, interactive feedback, and self-competition. While limitations in measurement and design warrant caution, the promising results indicate that immersive VR can serve as a powerful tool for motivating physical activity, supporting rehabilitation, and promoting digital health more broadly. Future research should build on these foundations by employing multidimensional assessments, longitudinal designs, and diverse populations to further refine both theory and practice. Ultimately, the study affirms that immersion is not simply a technological achievement but a holistic outcome of design, psychology, and user engagement, one that holds substantial promise for shaping the future of exercise and health promotion in virtual environments.

ACKNOWLEDGMENT

We would like to thank the Ministry of Higher Education (MoHE) and Universiti Utara Malaysia (UUM), under the 2020 Academic Training Scheme for Bumiputera (SLAB), for the financial support provided throughout the research study. Additionally, special thanks are extended to the XRlab team at the Media and Game Innovation Centre of Excellence, Institute of Human Centered Engineering, Universiti Teknologi Malaysia (UTM), for their support. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by all authors.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Informed consent was obtained from all individual participants included in the study.

REFERENCES

Anderson-Hanley, C., Snyder, A. L., Nimon, J. P., & Arciero, P. J. (2011). Social facilitation in virtual reality-enhanced exercise: Competitiveness moderates exercise effort of older adults. Clinical Interventions in Aging, 6, 275–280. https://doi.org/10.2147/CIA.S25337

Bahrin, A. S., Sunar, M. S., & Azman, A. (2021, December). Enjoyment as gamified experience for informal learning in virtual reality. In International Conference on Intelligent Technologies for Interactive Entertainment (pp. 383–399). Springer International Publishing. https://doi.org/10.1007/978-3-030-92182-6_25

Bahrin, A. S., Sunar, M. S., Latip, H. F. M., & Zamri, M. N. (2022). Chronology of self-competition in virtual reality exergames: A historical review. Entertainment Computing, 43, 100513. https://doi.org/10.1016/j.entcom.2022.100513

Bahrin, A. S., Sunar, M. S., & Latip, H. F. M. (2023, November). Self-competition virtual reality cycling for enhanced motivation: Interactive feedforward adjustments. In International Conference on Innovation and Technology in Sports (pp. 99–105). Springer Nature Singapore. https://doi.org/10.1007/978-981-99-6769-4_12

Barathi, S. C., Finnegan, D. J., Farrow, M., Whaley, A., Heath, P., Buckley, J., & Lutteroth, C. (2018, April). Interactive feedforward for improving performance and maintaining intrinsic motivation in VR exergaming. https://doi.org/10.1145/3173574.3173786

In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (pp. 1–14). ACM. https://doi.org/10.1145/3173574.3173786

Craig, T. V., Rhodes, R. E., & Sui, W. (2024). Examining and comparing the energy expenditure of two modes of a virtual reality fitness game (Supernatural): Indirect calorimetry study. JMIR Serious Games, 12(1), e53999. https://doi.org/10.2196/53999

Csikszentmihalyi, M. (1990). Flow: The psychology of optimal experience. Harper & Row.

Cummings, J. J., & Bailenson, J. N. (2016). How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. Media Psychology, 19(2), 272–309. https://doi.org/10.1080/15213269.2015.1015740

Deci, E. L., & Ryan, R. M. (2013). Intrinsic motivation and self-determination in human behavior. Springer Science & Business Media. https://doi.org/10.1007/978-1-4899-2271-7

Farrow, M., Lutteroth, C., Rouse, P. C., & Bilzon, J. L. (2019). Virtual-reality exergaming improves performance during high-intensity interval training. European Journal of Sport Science, 19(6), 719–727. https://doi.org/10.1080/17461391.2018.1542459

Hamari, J., Koivisto, J., & Sarsa, H. (2014, January). Does gamification work? A literature review of empirical studies on gamification. In 2014 47th Hawaii International Conference on System Sciences (pp. 3025–3034). IEEE. https://doi.org/10.1109/HICSS.2014.377

Hibbs, A., Tempest, G., Hettinga, F., & Barry, G. (2024). Impact of virtual reality immersion on exercise performance and perceptions in young, middle-aged and older adults. PLOS ONE, 19(10), e0307683. https://doi.org/10.1371/journal.pone.0307683

Keppel, J., Strauss, M., Zhang, S., Stroehnisch, M., Lewin, S., Gruenefeld, U.,& Schneegass, S. (2025, April). The impact of bike-based controllers and adaptive feedback on immersion and enjoyment in a virtual reality cycling exergame. In Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (pp. 1–8). ACM. https://doi.org/10.1145/3706599.3720096

Makransky, G., & Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. Educational Technology Research and Development, 66(5), 1141–1164. https://doi.org/10.1007/s11423-018-9581-2

Michael, A., & Lutteroth, C. (2020, April). Race yourselves: A longitudinal exploration of self-competition between past, present, and future performances in a VR exergame. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (pp. 1–17). ACM. https://doi.org/10.1145/3313831.3376256

Shaw, L. A., Buckley, J., Corballis, P. M., Lutteroth, C., & Wünsche, B. C. (2016). Competition and cooperation with virtual players in an exergame. PeerJ Computer Science, 2, e92. https://doi.org/10.7717/peerj-cs.92

Slater, M. (2003). A note on presence terminology. Presence Connect, 3(3), 1–5.

Slater, M., Linakis, V., Usoh, M., & Kooper, R. (1996, July). Immersion, presence and performance in virtual environments: An experiment with tri-dimensional chess. In Proceedings of the ACM Symposium on Virtual Reality Software and Technology (pp. 163–172). ACM. https://doi.org/10.1145/3304181.3304205

Sunar, M. S., Bahrin, A. S., Mohd Nor, N. N., Daud, H. A., & Azman, A. (2022). Design and testing of virtual reality cycling exergame using handheld controller. Journal of Creative Industry & Sustainable Culture, 1(1), 123–152. https://doi.org/10.58459/jcisc.v1i1.15

Tuveri, E., Macis, L., Sorrentino, F., Spano, L. D., & Scateni, R. (2016, June). Fitmersive games: Fitness gamification through immersive VR. In Proceedings of the International Working Conference on Advanced Visual Interfaces (pp. 212–215). ACM. https://doi.org/10.1145/2909132.2909272

World Health Organization. (2024, June 26). Physical activity. https://www.who.int/news-room/fact-sheets/detail/physical-activity

Xu, W., Liang, H. N., Yu, K., & Baghaei, N. (2021, May). Effect of gameplay uncertainty, display type, and age on virtual reality exergames. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (pp. 1–14). ACM. https://doi.org/10.1145/3411764.3445801

Yoo, S., Carter, M., & Kay, J. (2018, October). VRmove: Design framework for balancing enjoyment, movement and exertion in VR games. In Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts (pp. 295–307). ACM. https://doi.org/10.1145/3270316.3272054