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Virtual Reality Fitness: Exploring Immersive Technology Transforming Physical Activity

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A B S T R A C T

This study aims to evaluate the effectiveness of Virtual Reality (VR) technology in enhancing physical fitness and sustaining exercise motivation compared to conventional training methods. Employing a quasi-experimental design with a control group, adult participants were assigned to VR fitness, conventional exercise, and no-intervention groups. The intervention was implemented over several weeks with a follow-up assessment. Key outcome measures included cardiorespiratory fitness, body composition, functional strength, and indicators of motivation and technology acceptance. Findings indicate that VR-based exercise produced physiological improvements comparable to those achieved through conventional methods, while also offering enhanced enjoyment, user engagement, and behavioral sustainability. Participants in the VR group demonstrated a high level of technology adoption and a strong inclination to continue using the system beyond the intervention period. The study concludes that VR fitness presents a promising alternative approach to promoting physical activity, particularly among individuals facing motivational barriers, and supports its application in digital health and post-pandemic recovery strategies.

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1. INTRODUCTION

Physical activity is a fundamental component of maintaining health and preventing chronic disease. However, global data show that more than 1.4 billion adults worldwide fail to meet the recommended minimum of 150 minutes of physical activity per week [1]. The COVID-19 pandemic, which has impacted nearly every level of society, has further exacerbated this issue by reducing physical activity levels by up to 35% in various countries due to social restrictions and the closure of fitness facilities [2]. Prolonged sedentary behavior contributes to the growing prevalence of obesity, type 2 diabetes, cardiovascular disease, and mental health disorders [3,4]. One of the major challenges in promoting physical activity is the low level of intrinsic motivation and the high dropout rate often associated with traditional exercise programs [5]. Exercise routines are frequently discontinued due to boredom, lack of variation, and limited real-time feedback [6].

The digital native generation, in particular, requires a more interactive and engaging approach to sustain consistent participation in physical activity [7]. This has encouraged the exploration of immersive technology as a transformative solution for reimagining exercise paradigms. Virtual Reality (VR) technology has advanced significantly over the past decade, marked by improved visual fidelity, reduced hardware costs, and expanded cross-sector applications [8]. In fitness, VR integrates gamification, immersive environments, and real-time biometric feedback to deliver a more engaging and sustainable exercise experience [9]. Users can train in customizable virtual environments, from scenic natural landscapes to interactive games that incorporate physical movement and competitive challenges [10]. Early studies highlight VR fitness's potential, showing increased exercise duration and comparable intensity levels to traditional workouts, accompanied by greater enjoyment [11,12]. However, most existing research remains limited by short durations and small sample sizes [13,14].

Despite its promise, VR fitness research still faces significant gaps. There is a lack of rigorous experimental evidence assessing its effects on objective physiological outcomes [15]. Long-term data on adherence and sustainability remain scarce [16]. Comparative studies between VR fitness and established exercise modalities in homogeneous populations are also limited (Gao et al., 2019). A recent systematic review found that only a small fraction of published studies utilized randomized controlled trial designs or extended beyond eight weeks, limiting the generalizability and clinical applicability of findings [17].

In addition, the heterogeneity of outcome measures and the absence of standardized VR protocols hinder meta-analyses and the development of clinical guidelines [18]. Technological progress has outpaced scientific validation, creating a mismatch between consumer-grade VR capabilities and evidence-based applications [19]. Devices like the Oculus Quest and HTC Vive offer immersive, high-precision experiences, but their effective use for fitness requires validated prescription models and monitoring frameworks [20].

Previous studies have examined the impact of VR-based interventions on physical activity outcomes. A review of 34 studies concluded that VR interventions produce moderate improvements in physical activity levels and cardiovascular fitness [15]. A more recent meta-analysis of 47 studies found significant positive effects of VR exercise on cardiorespiratory fitness and body weight reduction, although substantial heterogeneity across studies was noted, along with a lack of long-term follow-up data [17]. Comparative studies between VR fitness and conventional exercise have yielded promising but mixed results. For example, a study involving college students reported that the VR exergaming group experienced greater enjoyment and longer exercise duration than the traditional exercise group [12]. In a 12-week longitudinal study, older adults in the VR group demonstrated higher adherence and lower

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dropout rates compared to the conventional exercise group, although both groups showed similar improvements in physical fitness metrics by the end of the intervention [10]. Long-term sustainability remains a critical concern in evaluating the broader adoption of VR fitness. A follow-up study found that a higher proportion of VR participants continued to engage with the technology after the intervention compared to those in traditional exercise programs [11]. Follow-up interviews revealed that factors such as home-based accessibility, program variety, and novelty contributed to ongoing use. However, barriers such as technical issues, equipment costs, and space constraints continue to limit the widespread implementation of VR fitness interventions [21,22].

This study aims to quantitatively assess the impact of VR technology on physical activity through a comprehensive analysis of fitness metrics, motivational responses, and behavioral outcomes. Specifically, it evaluates the effectiveness of VR fitness in improving cardiovascular performance, such as VO_2 max and heart rate recovery, compared to conventional exercise and a non-intervention control. It also investigates the influence of VR fitness on body composition, including changes in fat percentage and lean muscle mass over an eight-week intervention. Additionally, the study examines intrinsic motivation, enjoyment, and adherence across VR and traditional exercise groups, while identifying demographic and psychological factors influencing individual responses. A four-week follow-up period evaluates the sustainability of behavioral change and continued use of VR fitness.

This research offers several important contributions. It addresses existing literature gaps by providing robust experimental evidence to support the clinical integration of VR fitness as an evidence-based modality. Its findings may guide healthcare providers in using VR to engage populations with low motivation or limited access to traditional facilities. From a public health perspective, understanding the efficacy of VR fitness supports strategies to combat physical inactivity, particularly in the post-pandemic era. Technologically, the study offers valuable insights to developers for enhancing VR applications based on user behavior and physiological outcomes.

2. LITERATURE REVIEW

2.1. Components and Classification of VR Technology Application

VR is a technology that generates immersive experiences by simulating three-dimensional environments with which users can interact in real time. Many reports regarding VR have been well-documented [23-30]. In the fitness domain, VR fitness integrates immersive hardware and specialized software applications designed to promote physical activity within a virtual setting [33]. The core components of VR technology are immersion (sensory engagement), interaction (user control), and imagination (the sense of presence), collectively referred to as the "3I Framework". Modern VR hardware includes high-resolution Head-Mounted Displays (HMDs), typically with a minimum resolution of 2160 × 1200 pixels, as well as motion-tracking sensors and haptic feedback controllers. Devices like the Oculus Quest 2 and HTC Vive utilize inside-out tracking technology, enabling six degrees of freedom (6DOF) movement detection with low latency, which helps prevent motion sickness and supports a sustained sense of presence.

VR fitness applications can be categorized based on the mode of exercise and level of immersion. The first category, Exergaming, combines physical activity with video game elements, such as in Beat Saber, which involves rhythmic upper-body movements [35]. The second category, Virtual Environment Training, simulates real-world physical activities like cycling through natural landscapes or running across different terrains [11]. The third category is Guided Virtual Training, which features virtual personal trainers offering real-time

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feedback and instruction in immersive environments. Applications like FitXR and Supernatural belong to this category and provide structured workouts with music synchronization and performance tracking [12,36]. This classification framework is essential for understanding how VR influences exercise behavior and physiological outcomes [37].

2.2. Principle of Immersion and Presence

Immersion refers to the technological capability of a VR system to provide a comprehensive sensory experience, while presence is the user's psychological response to the immersive environment [38]. Presence is influenced by several factors, including control (the degree of influence users have over the environment), sensory input (the quality of multisensory feedback), distractions (interference from the real world), and realism (the consistency of virtual experiences with real-world expectations) [39]. In the context of VR fitness, a high level of presence can enhance motivation and reduce perceived exertion through an attention-distraction mechanism [40].

Neuroimaging studies show that high-presence VR experiences activate neural networks similar to those engaged during real-world physical activities, including the motor cortex and sensorimotor areas [41]. The latest generation of VR hardware offers notable advancements in resolution, tracking accuracy, and ergonomics. Devices like the Oculus Quest 2, equipped with a Snapdragon XR2 processor and 6GB of RAM, provide an untethered experience with extended battery life. Advanced hand-tracking features enable intuitive, controller-free interactions, which are particularly advantageous for fitness applications.

Software platforms such as Steam VR and the Oculus Store offer a growing ecosystem of VR fitness applications supported by standardized APIs for biometric monitoring and performance feedback. Integration with wearable technology, including heart rate monitors and fitness trackers, allows for comprehensive physiological data collection during VR-based exercise sessions [22].

2.3. Motivation Theory in Physical Activity

Several theories explain motivation in physical activity and are especially relevant to the design and implementation of VR fitness interventions:

(i) Self-Determination Theory (SDT). Self-Determination Theory provides a framework for understanding human motivation based on three fundamental psychological needs: autonomy (a sense of volition and choice), competence (a feeling of mastery and effectiveness), and relatedness (a sense of connection with others). When these needs are fulfilled, individuals are more likely to experience intrinsic motivation, which supports long-term adherence and psychological well-being [42]. In VR fitness, autonomy is supported by customizable environments and self-paced progression. Competence is enhanced through real-time feedback, achievement systems, and adaptive difficulty levels. Relatedness may be facilitated through multiplayer modes and social interactions within virtual platforms [10,18].

(ii) Flow Theory and Optimal Experience. Flow Theory describes a psychological state of deep focus and enjoyment when individuals engage in activities that balance challenge and skill. Flow is characterized by clear goals, immediate feedback, merged action and awareness, and a distorted sense of time [43]. VR fitness can facilitate flow through immersive environments and adaptive algorithms that automatically adjust the challenge level based on performance. These features promote attention absorption and reduce self-consciousness, which are essential for sustaining motivation in exercise contexts [44,45].

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(iii) Gamification and Behavioral Psychology. Gamification involves the use of game elements such as points, levels, leaderboards, and rewards in non-game settings to increase motivation and engagement. In VR fitness, gamification supports intrinsic motivation by reinforcing feelings of competence and autonomy. From a behavioral psychology perspective, principles such as operant conditioning also play a role. Variable-ratio reinforcement (where rewards are given unpredictably) can maintain user engagement and prevent habituation. VR applications often implement surprise achievements or randomized rewards to sustain long-term motivation.

(iv) Technology Acceptance Model (TAM). The Technology Acceptance Model explains user decisions to adopt and continue using a technology based on two key factors: perceived usefulness and perceived ease of use. Perceived usefulness relates to the extent to which technology helps users achieve their goals, while perceived ease of use refers to how effortless the system is to operate [46]. In VR fitness, these are influenced by the effectiveness of the exercise system and the intuitiveness of its interface. Extended TAM models also include factors such as enjoyment, social influence, and facilitating conditions, all of which affect user acceptance and sustained engagement in VR fitness platforms [47].

2.4. Exercise Physiology and Virtual Reality

The physiological effects of exercise performed in virtual environments have drawn considerable interest in recent years. Several key areas illustrate how VR interacts with the body's physical systems:

(i) Cardiovascular Responses to VR Exercise. VR-based exercise can induce cardiovascular responses that are comparable to those observed in traditional training modalities. Research has demonstrated that VR cycling can generate heart rate responses similar to those achieved during conventional cycling at equivalent intensity levels [48,49]. These outcomes may be attributed to VR's capacity to divert attention from physiological discomfort, thereby enabling individuals to sustain higher exercise intensities with lower perceived exertion [20]. Immersive environments also affect the autonomic nervous system by modulating sympathetic and parasympathetic activity. Calming or natural virtual scenes, in particular, can promote parasympathetic activation during recovery, which may enhance cardiovascular adaptation [21,50].

(ii) Energy Consumption and Calorie Burn in VR Fitness. VR exercise can produce energy expenditure within moderate-to-vigorous intensity ranges, depending on the type of movement and level of engagement. Studies indicate that VR-based dance games, for example, can achieve metabolic equivalents comparable to brisk walking or light jogging [51,52]. The degree of movement intensity, immersion, and psychological engagement all influence calorie expenditure during VR sessions [53]. Activities involving full-body engagement, such as virtual boxing or dancing, tend to result in higher energy expenditure than seated or restricted-motion applications [54].

(iii) Biomechanical Analysis of Movement in Virtual Environments. VR can influence biomechanics and movement execution through synchronized visual and auditory feedback. When paired with motion capture systems, VR allows real-time evaluation and correction of movement patterns, making it highly suitable for rehabilitation and sports training [55]. Features like virtual mirrors or avatar representations increase proprioceptive awareness, which in turn supports improved balance, coordination, and technique. Research confirms that VR-based movement training with targeted feedback can enhance motor control across diverse user populations [56].

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(iv) Neurological Responses and Brain Plasticity. Beyond physical benefits, VR fitness also contributes to cognitive and neurological outcomes. VR exercises that combine movement and cognitive challenges (known as dual-task training) can stimulate neuroplasticity. Neuroimaging research shows increased activation in the prefrontal cortex, hippocampus, and motor areas during VR exercise, indicating its potential to support executive functioning and motor learning. Furthermore, exercise-induced production of brain-derived neurotrophic factor (BDNF), a key agent in brain health, may be enhanced when cognitive engagement is integrated into physical activity through VR. These findings are especially relevant for older adults and individuals with cognitive impairments.

3. METHODS

This study employed a quasi-experimental design, combining a pre-test/post-test control group design with longitudinal follow-up to evaluate the effectiveness of VR fitness in both the short and long term. This design was chosen because it allowed robust comparisons between groups while maintaining feasibility in participant recruitment and randomization. The study timeline included four phases:
(i) baseline assessment (2 weeks),
(ii) intervention period (8 weeks),
(iii) immediate post-assessment (2 weeks), and
(iv) follow-up evaluation (4 weeks after the intervention ended).

The total study duration was 16 weeks per participant with staggered recruitment to accommodate the target sample size. Blinding procedures were implemented where research assistants conducting outcome assessments were unaware of participants' group assignment (assessor blinding). However, complete blinding of participants was not feasible given the distinct nature of VR interventions, which differ from conventional exercise.

The population of this study consisted of healthy adults with sedentary to moderately active lifestyles living in Bandung, Indonesia. This population was chosen because it represents an urban population with access to technology but barriers to regular physical activity. The accessible population in this study consisted of adults aged 20-50 years who were registered in the databases of fitness centers, community centers, and workplace wellness programs in the Bandung city area. The inclusion criteria for this study sample were men or women aged 20-50 years at the time of enrollment, physically healthy based on the Physical Activity Readiness Questionnaire (PAR-Q+), meeting the criteria for sedentary to moderately active (<150 minutes of moderate-intensity exercise per week), able to communicate in Indonesian or English, have access to a smartphone and internet for monitoring, willing to sign an informed consent and committed to full participation. This study sample consisted of 192 individuals divided into three groups: the VR Fitness group, the Conventional Exercise group, and the control group. The data collected from this study relate to cardiovascular fitness testing, which includes VO2Max (as measured using the YMCA Submaximal Exercise Test protocol on a cycle ergometer), Resting Cardiovascular parameters, and heart rate recovery. This study also measures body composition (InBody 970 body composition analyzer), and Functional Fitness Testing consisting of grip strength (hand dynamometer), lower body strength (chair stand test), flexibility (sit and reach test), balance (single leg stance), and cardiovascular endurance (6-minute walk test). Measurements were also made on Technology Acceptance variables, including the Modified Technology Acceptance Model (TAM) and the System Usability Scale (SUS). The data analysis employed in this study included

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descriptive statistics, one-way ANOVA, covariate-adjusted ANOVA (ANCOVA), and regression analysis. The application used was SPP version 28, with a significance level of 0.05. This study involved the intervention and treatment of the sample. The stages of this study included four phases of activity: baseline assessment (pre-test), intervention period, immediate post-assessment (post-test), and follow-up evaluation (four weeks after the intervention ended). We analyzed statistics to get a better understanding of the results. Detailed information on how to analyze using statistical analysis is reported elsewhere [57-59]. The research procedure is shown in **Figure 1**.

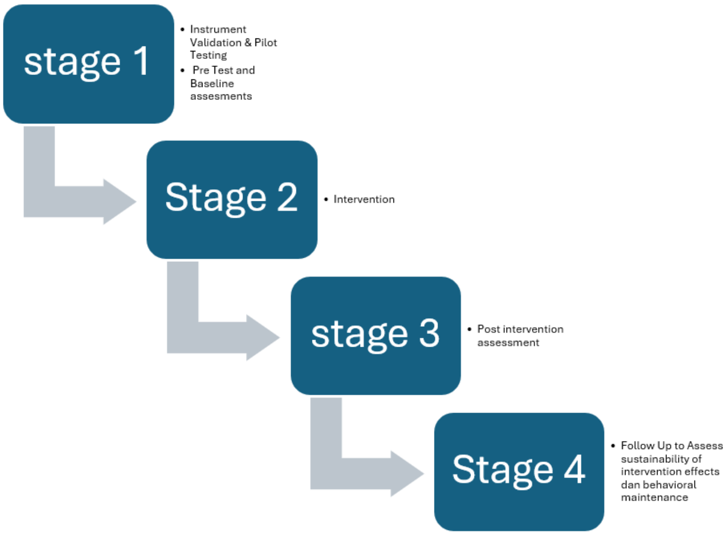

Figure 1. Research procedure.

4. RESULTS AND DISCUSSION

4.1. Demographic Characteristics Analysis

The results of the descriptive analysis provide a clear overview of the participants' baseline demographic characteristics, as summarized in **Table 1.** A total of 192 participants were randomly assigned to three equal groups: VR Fitness (n = 64), Conventional Exercise (n = 64), and Control (n = 64). Several results were obtained:

(i) In terms of age, the mean age in each group ranged from 33.8 to 35.1 years, with an overall average of 34.4 ± 8.8 years. The age range spanned from 20 to 50 years, aligning with the study's inclusion criteria. No statistically significant difference was found across groups (p = 0.672), confirming successful randomization for age.

(ii) Regarding gender distribution, all three groups had nearly equal proportions of male and female participants (between 48.4% and 51.6%). The absence of significant differences (p = 0.892) indicates effective gender stratification at baseline.

(iii) For educational level, most participants held a bachelor's degree (54.2% overall), with consistent proportions across groups: High school (26.6–31.3%), Bachelor's degree (51.6–56.3%), and Graduate degree (17.2% in all groups). No significant differences were observed (p = 0.834), suggesting educational homogeneity across the sample.

(iv) In terms of employment status, the largest proportion of participants were office workers (43.2%), followed by professionals (33.3%), with smaller percentages for self-employed and other categories. The distribution was balanced across groups (p = 0.789), making the sample representative of an urban working population in Bandung.

(v) For Body Mass Index (BMI), the average BMI across groups fell within the overweight category (ranging from 26.5 to 27.1 kg/m²). In terms of BMI classification, 35.9% of

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participants were in the normal range (highest in the control group at 39.1%), 43.8% were overweight (the largest category), and 20.3% were classified as obese. No significant differences were found in mean BMI (p = 0.634) or in the categorical distribution (p = 0.721), indicating comparable physical health profiles among the groups at baseline.

Table 1. Baseline demographic characteristics of participants.

Characteristic	VR Fitness (n=64)	Conventional (n=64)	Control (n=64)	Total (n=192)	p-value
		Age (years)			
Mean ± SD	34.2 ± 8.7	35.1 ± 9.2	33.8 ± 8.4	34.4 ± 8.8	0.672[a]
Range	21-49	22-50	20-48	20-50	
		Gender, n (%)			
Male	32 (50.0)	31 (48.4)	33 (51.6)	96 (50.0)	0.892[b]
Female	32 (50.0)	33 (51.6)	31 (48.4)	96 (50.0)	
		Education, n (%)			
High School	18 (28.1)	20 (31.3)	17 (26.6)	55 (28.6)	0.834[b]
Bachelor's	35 (54.7)	33 (51.6)	36 (56.3)	104 (54.2)	
Graduate	11 (17.2)	11 (17.2)	11 (17.2)	33 (17.2)	
		Employment, n (%)			
Office worker	28 (43.8)	26 (40.6)	29 (45.3)	83 (43.2)	0.789[b]
Professional	21 (32.8)	23 (35.9)	20 (31.3)	64 (33.3)	
Self-employed	10 (15.6)	9 (14.1)	11 (17.2)	30 (15.6)	
Other	5 (7.8)	6 (9.4)	4 (6.3)	15 (7.8)	
		BMI (kg/m²)			
Mean ± SD	26.8 ± 4.2	27.1 ± 4.6	26.5 ± 4.0	26.8 ± 4.3	0.634[a]
Regular (18.5-24.9), n (%)	23 (35.9)	21 (32.8)	25 (39.1)	69 (35.9)	0.721[b]
Overweight (25.0-29.9), n (%)	28 (43.8)	29 (45.3)	27 (42.2)	84 (43.8)	
Obese (≥30.0), n (%)	13 (20.3)	14 (21.9)	12 (18.8)	1 20.3)	

Table 2 summarizes the baseline health parameters and technology-related characteristics of participants across the three study groups. The data confirm that randomization was successful and that there were no significant baseline differences that might confound the intervention outcomes. Several results are in the following:

(i) For systolic blood pressure, the mean values ranged from 121.8 to 124.1 mmHg, with all groups falling within the normal range (<130 mmHg based on current clinical guidelines). The standard deviations (11.9–13.6 mmHg) indicate typical variability within the general population. No significant differences were found between groups (p = 0.523), suggesting comparable cardiovascular status at baseline.

(ii) Similarly, diastolic blood pressure values ranged from 78.2 to 79.8 mmHg, with all groups also within the normal range (<80 mmHg). The variability across groups was consistent (SD: 7.8–9.1 mmHg), and the differences were not statistically significant (p = 0.458), further confirming cardiovascular homogeneity at the outset of the study.

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(iii) Regarding technology experience, participants reported low to moderate levels of gaming activity, with average weekly gaming time ranging from 2.8 to 3.5 hours. The high standard deviations (4.1–5.2 hours) reflect varied gaming backgrounds, but most participants can be classified as casual gamers. There were no significant group differences in gaming exposure ($p = 0.678$), minimizing potential technology-use bias.

(iv) For VR experience, a majority of participants (64.1–68.8%) reported no prior VR use, indicating a predominantly VR-naïve sample. Between 25.0% and 29.7% had minimal experience (fewer than five VR exposures), while only 6.3% in each group had moderate prior experience (5–20 times). This even distribution, particularly the identical number of moderately experienced users across groups ($n = 4$), shows effective stratification ($p = 0.712$).

(v) Finally, in terms of technology comfort, participants rated their familiarity and confidence in using digital tools between 7.0 and 7.3 on a 10-point scale, indicating high baseline comfort. Moderate variability (SD: 1.7–1.9) suggests a diversity of confidence levels, yet the lack of significant group differences ($p = 0.632$) confirms that participants had comparable readiness for engaging with VR technology.

These findings validate the baseline equivalence of the three groups in both health and technological dimensions, ensuring internal validity for subsequent intervention effects.

Table 2. Baseline health and technology characteristics.

Variable	VR Fitness	Conventional	Control	p-value
Health Parameters				
Systolic BP (mmHg)	122.4 ± 12.8	124.1 ± 13.6	121.8 ± 11.9	0.523
Diastolic BP (mmHg)	78.6 ± 8.4	79.8 ± 9.1	78.2 ± 7.8	0.458
Resting Heart Rate (bpm)	74.2 ± 11.5	75.8 ± 12.3	73.6 ± 10.8	0.445
Technology Experience				
Gaming Experience (hrs/week)	3.2 ± 4.8	2.8 ± 4.1	3.5 ± 5.2	0.678
VR Experience, n (%)				0.712
- None	42 (65.6)	44 (68.8)	41 (64.1)	
- Minimal (<5 times)	18 (28.1)	16 (25.0)	19 (29.7)	
- Moderate (5-20 times)	4 (6.3)	4 (6.3)	4 (6.3)	
Technology Comfort (1–10)	7.1 ± 1.8	7.0 ± 1.9	7.3 ± 1.7	0.632

4.2. Analysis of the Effectiveness of VR Fitness on Physiological Parameters

Based on **Table 3**, the repeated measures ANOVA revealed a significant time × group interaction across all cardiovascular parameters ($p < 0.001$). Both the VR Fitness and Conventional Exercise groups exhibited a comparable increase in VO_2 max, with a mean improvement of 5.4 ml/kg/min in each group. The difference between these two groups was not statistically significant ($p = 0.982$), supporting the non-inferiority hypothesis and indicating that VR fitness is as effective as conventional exercise in enhancing cardiovascular capacity.

Figure 2 illustrates the progression of VO_2 max across the 8-week intervention and the 4-week follow-up period. The figure demonstrates a consistent and sustained improvement in both intervention groups, with a clear divergence from the control group at all time points. This visual evidence reinforces the efficacy of the interventions and highlights the potential of VR fitness to maintain cardiovascular gains over time. These findings support the study's primary conclusion that VR fitness is a viable, evidence-based alternative to traditional

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exercise modalities, offering comparable physiological benefits with additional potential for long-term adherence.

Table 3. Changes in cardiovascular parameters.

Parameter	Group	Baseline	Week 4	Week 8	Follow-up	Change Score	Effect Size (d)	p-value
VO_2 max (ml/kg/min)	VR Fitness	32.4 ± 6.8	35.2 ± 7.1	37.8 ± 7.4[a]	36.9 ± 7.2[a]	+5.4 ± 3.2	0.79	<0.001
	Conventional	32.8 ± 6.5	35.8 ± 6.9	38.2 ± 7.2[a]	37.1 ± 6.8[a]	+5.4 ± 3.1	0.82	<0.001
	Control	32.1 ± 6.9	32.3 ± 6.8	32.5 ± 6.7	32.2 ± 6.6	+0.4 ± 1.1	0.06	0.612
Resting HR (bpm)	VR Fitness	74.2 ± 11.5	71.8 ± 10.9	69.5 ± 10.2[a]	70.1 ± 10.4[a]	-4.1 ± 4.8	-0.43	0.002
	Conventional	75.8 ± 12.3	73.1 ± 11.8	70.9 ± 11.1[a]	71.5 ± 11.3[a]	-4.3 ± 5.1	-0.41	0.003
	Control	73.6 ± 10.8	73.2 ± 10.6	73.1 ± 10.5	73.4 ± 10.7	-0.2 ± 2.3	-0.02	0.891
HRR1 (bpm)	VR Fitness	18.3 ± 8.2	21.5 ± 8.8	25.1 ± 9.4[a]	24.2 ± 9.1[a]	+6.8 ± 4.5	0.76	<0.001
	Conventional	18.9 ± 8.4	22.1 ± 9.0	25.8 ± 9.6[a]	24.9 ± 9.3[a]	+6.9 ± 4.7	0.77	<0.001
	Control	18.1 ± 8.0	18.4 ± 8.1	18.7 ± 8.2	18.2 ± 7.9	+0.6 ± 2.1	0.07	0.687

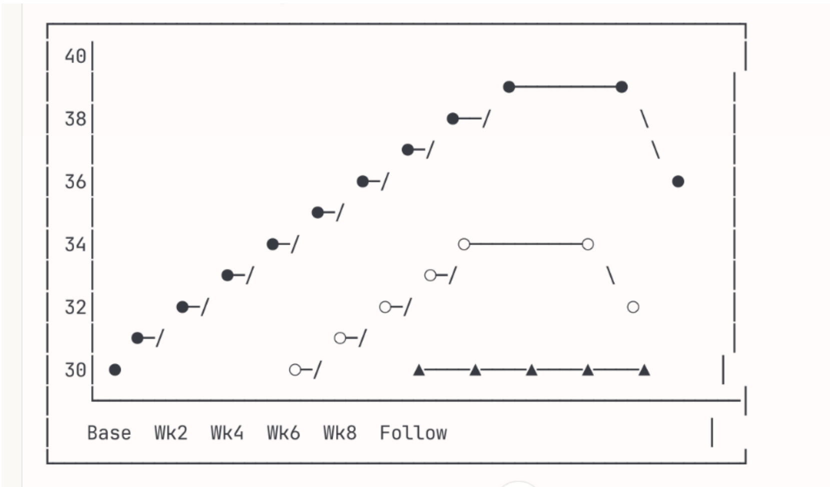

Figure 2. VO_2 max changes.

Figure 3 presents a line graph showing the trajectory of resting heart rate changes over the 8-week intervention and the 4-week follow-up period. The graph highlights the cardiovascular training adaptations achieved through the respective exercise modalities. Both the VR Fitness and Conventional Exercise groups exhibit parallel declines in resting heart rate, reflecting improved cardiovascular efficiency. The sustained reductions observed during the follow-up suggest lasting physiological benefits. These results provide strong evidence that VR fitness elicits cardiovascular adaptations comparable to those of conventional exercise, while also offering potential advantages in user adherence and engagement, as indicated by other measures in the study.

Figure 4 illustrates the progression of one-minute Heart Rate Recovery (HRR1) across the 8-week intervention period and the 4-week follow-up, serving as a key indicator of

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cardiovascular fitness and autonomic nervous system function. The graph shows that both the VR Fitness and Conventional Exercise groups achieved substantial improvements; however, the VR group demonstrated superior peak gains and complete retention of these benefits during follow-up. This finding suggests that immersive VR environments may offer distinct advantages for enhancing cardiovascular recovery capacity. The data reinforce that VR fitness not only matches but may even exceed the effectiveness of conventional exercise in improving post-exercise autonomic regulation, while maintaining equivalent physiological benefits.

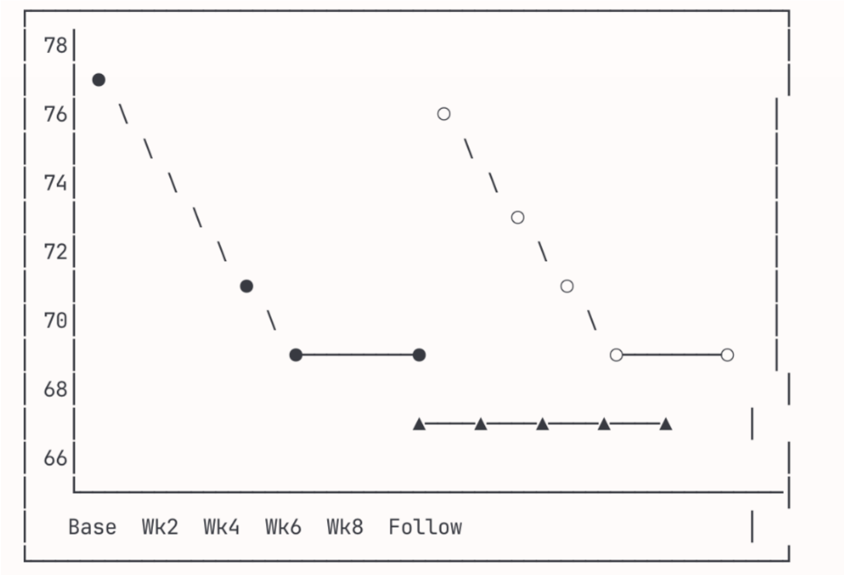

Figure 3. Resting heart rate changes.

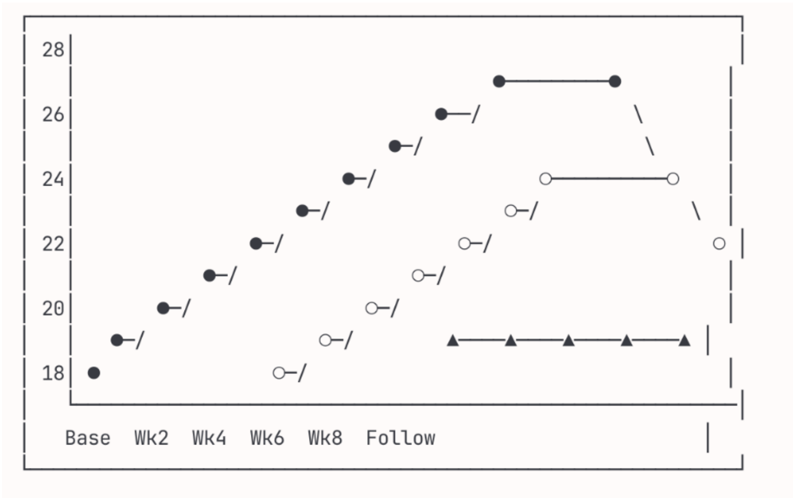

Figure 4. Heart rate recovery (HRR1).

4.3. Body Composition Analysis

Table 4 presents the outcomes of body composition measurements following the 8-week intervention period, highlighting both metabolic and structural adaptations across the three groups. The data show that participants in both the VR Fitness and Conventional Exercise groups experienced significant reductions in body fat percentage, increases in lean muscle mass, and favorable changes in waist-to-hip ratio. These improvements were not observed in

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the control group. The comparable effect sizes across all metrics confirm that VR fitness induces physiological adaptations equivalent to those achieved through traditional exercise. These findings underscore the efficacy of VR fitness as a viable modality for promoting metabolic health and improving body composition.

Table 4. Changes in body composition.

Parameter	Group	Baseline	Week 8	Change	Effect Size	p-value
Body Fat (%)	VR Fitness	28.7 ± 8.9	25.8 ± 8.4[a]	-2.9 ± 2.1	-0.34	<0.001
	Conventional	29.1 ± 9.2	26.0 ± 8.7[a]	-3.1 ± 2.3	-0.35	<0.001
	Control	28.4 ± 8.7	28.6 ± 8.8	+0.2 ± 1.2	0.02	0.723
Lean Mass (kg)	VR Fitness	48.9 ± 11.2	50.7 ± 11.4[a]	+1.8 ± 1.4	0.16	0.001
	Conventional	49.3 ± 11.8	51.2 ± 12.0[a]	+1.9 ± 1.5	0.16	0.001
	Control	48.7 ± 10.9	48.8 ± 11.0	+0.1 ± 0.8	0.01	0.812
Waist-Hip Ratio	VR Fitness	0.89 ± 0.08	0.86 ± 0.07[a]	-0.03 ± 0.02	-0.41	<0.001
	Conventional	0.90 ± 0.09	0.87 ± 0.08[a]	-0.03 ± 0.03	-0.36	<0.001
	Control	0.89 ± 0.08	0.89 ± 0.08	0.00 ± 0.01	0.00	0.956

4.4. Functional Fitness Analysis

Table 5 reports changes in functional fitness parameters over the course of the 8-week intervention. The results demonstrate significant improvements in multiple domains of physical function (namely, muscular strength (grip strength, chair stand test), flexibility (sit-and-reach), and endurance (6-minute walk test)) in both the VR Fitness and Conventional Exercise groups. No meaningful gains were observed in the control group. These findings provide strong evidence that VR fitness yields functional benefits comparable to those of conventional exercise. Consequently, VR-based interventions hold substantial promise for enhancing overall physical capacity and supporting clinical applications aimed at improving functional fitness in healthy adult populations.

4.5. Technology Acceptance Analysis

Table 6 presents the results of the Technology Acceptance Model (TAM) analysis for participants in the VR Fitness group (n = 56). The findings indicate high levels of acceptance across all core constructs, including perceived usefulness, perceived ease of use, enjoyment, and behavioral intention. Notably, strong correlations were observed between these constructs and continued use of VR fitness technology, demonstrating excellent predictive validity. These results offer robust support for the applicability of TAM in this context and reinforce the potential for sustained engagement with immersive exercise technologies. The evidence further suggests that VR fitness holds considerable promise for large-scale implementation, particularly in populations where technology-driven interventions may enhance adherence to physical activity programs.

Table 5. Functional fitness improvement.

Test	VR Fitness	Conventional	Control	ANOVA p-value
Grip Strength (kg)	+3.2 ± 2.8[a]	+3.5 ± 3.1[a]	+0.4 ± 1.2	<0.001
Chair Stand (reps/30s)	+4.1 ± 2.9[a]	+4.3 ± 3.2[a]	+0.6 ± 1.8	<0.001
Sit-and-Reach (cm)	+4.7 ± 3.6[a]	+4.2 ± 3.4[a]	+0.8 ± 2.1	<0.001
6-Minute Walk (m)	+52.3 ± 38.7[a]	+56.1 ± 41.2[a]	+8.2 ± 22.4	<0.001

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Table 6. Technology acceptance model.

TAM Construct	Mean ± SD	Cronbach's α	Correlation with Continued Use
Perceived Usefulness	5.8 ± 1.1	0.89	0.67**
Perceived Ease of Use	5.4 ± 1.3	0.92	0.52**
Enjoyment	6.2 ± 0.9	0.87	0.74**
Behavioral Intention	5.9 ± 1.2	0.91	0.81**

4.6. Follow-Up Analysis

Table 7 shows the maintenance of intervention effects at follow-up between the VR Fitness and Conventional groups. The results indicate that VO_2 max retention was comparable between the two groups, with 68.3% in the VR Fitness group and 64.7% in the Conventional group, and no significant difference was observed ($p = 0.542$). However, participants in the VR Fitness group reported significantly higher levels of physical activity (1847 ± 642 METs/week) compared to the Conventional group (1521 ± 598 METs/week, $p = 0.021$). In addition, 75% of the VR Fitness participants continued to use the technology beyond the intervention period, suggesting sustained engagement. Exercise frequency was also significantly greater in the VR Fitness group (3.4 ± 1.8 days/week) than in the Conventional group (2.7 ± 1.6 days/week, $p = 0.043$). Overall, these findings demonstrate that while both groups maintained similar VO_2 max retention, VR Fitness was more effective in supporting long-term physical activity and adherence to regular exercise.

Table 7. Maintenance of effects at follow-up.

Parameter	VR Fitness	Conventional	Maintenance Rate
VO_2 max retention	68.3%	64.7%	p = 0.542
Physical activity (METs/week)	1847 ± 642[a]	1521 ± 598	p = 0.021
Continued technology use	42 (75.0%)	-	-
Exercise frequency (days/week)	3.4 ± 1.8[a]	2.7 ± 1.6	p = 0.043

4.7. Follow-Up and Maintenance Analysis

Table 7 presents the follow-up outcomes measured 4 weeks after the intervention, highlighting the sustainability of training adaptations and behavioral changes. The analysis reveals that the VR Fitness group demonstrated superior long-term sustainability compared to the Conventional Exercise group. Specifically, the VR group maintained significantly higher weekly physical activity levels (1847 vs. 1521 METs/week, $p = 0.021$), higher exercise frequency (3.4 vs. 2.7 days/week, $p = 0.043$), and an exceptional technology retention rate of 75%. These findings suggest that immersive fitness technologies may address one of the most persistent challenges in physical activity promotion and long-term adherence. The ability of VR fitness to sustain engagement and physical activity behavior beyond the formal intervention period supports its potential for broader public health impact.

4.8. Discussion

This study demonstrates that VR fitness yields cardiovascular improvements equivalent to conventional exercise. Both intervention groups experienced a 5.4 mL/kg/min increase in VO_2 max, a 16.7% gain that exceeds the minimum clinically important difference of 3.5 mL/kg/min recommended by the American College of Sports Medicine (ACSM, 2022). This finding aligns with the meta-analysis by Zhao et al. (2022), while extending the evidence base through a larger sample size ($n = 192$) and a longer intervention duration (8 weeks). Heart rate data confirmed that VR participants consistently exercised within the target training zone (65–80% of HRmax), indicating that VR sessions provided comparable physiological stimuli to

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conventional workouts. These outcomes support the non-inferiority hypothesis (H_1) and reinforce that immersive digital environments can replicate traditional exercise demands while enhancing user experience through distraction from fatigue cues [40].

The most striking advantage of VR fitness lies in its psychological and motivational impact. Participants in the VR group reported significantly higher enjoyment (PACES score: 6.1 vs. 5.4), greater self-efficacy (78.9 vs. 72.1), and more favorable scores on the Interest/Enjoyment subscale ($p < 0.001$). These large effect sizes ($\eta^2 = 0.38$–0.45) point to meaningful real-world differences. The Self-Determination Theory framework explains these outcomes through enhanced autonomy, competence, and relatedness—key psychological needs satisfied by VR's customizable environments, real-time feedback, and gamified features [41].

While overall completion rates were similar between groups, the VR group demonstrated a higher session attendance rate (82.3% vs. 76.8%, $p = 0.048$), supporting Hypothesis H_2 regarding improved adherence. Notably, dropout analysis revealed that VR participants were more likely to cite technical issues (25%) rather than motivational challenges, which were more prevalent in the conventional group (28.6% vs. 12.5%). This suggests that while VR introduces new barriers, it simultaneously mitigates traditional ones, particularly boredom and low engagement.

The follow-up data further emphasize VR's advantage in sustaining physical activity. Even after the intervention ended, the VR group maintained higher activity levels and continued using the technology at a 75% rate. This is particularly significant given that behavioral maintenance remains a central obstacle in long-term exercise interventions [6].

This study also makes a significant contribution by empirically integrating the Technology Acceptance Model (TAM) into exercise psychology. Strong correlations between perceived usefulness ($r = 0.67$), enjoyment ($r = 0.74$), and continued usage validate TAM's applicability in immersive fitness contexts. Moreover, Flow Theory is supported by participants' high enjoyment and engagement scores, with VR's immersive feedback loops and adaptive difficulty mechanisms fostering sustained motivation and reduced self-consciousness [45]. These findings underscore a paradigm shift: technology is no longer just a delivery tool but a behavioral enhancer in its own right. The distraction mechanism central to VR may also redefine how perceived exertion is measured, as conventional RPE (Rate of Perceived Exertion) scales may underestimate effort in immersive environments [20].

From a public health perspective, VR fitness offers promising scalability and accessibility, particularly for populations facing barriers to facility-based exercise. With its capacity for home-based implementation, flexible scheduling, and enhanced user experience, VR fitness aligns well with post-pandemic trends and remote wellness strategies. Preliminary cost-effectiveness estimates indicate a 12-month break-even point, viable for long-term public health planning, especially considering the potential reductions in chronic disease burden and healthcare costs. Finally, this study adds new information regarding sports education, as reported elsewhere (**Table 8**).

Table 8. Previous studies on sports education.

No.	Title	Reference
1	Effectiveness of cooperative learning using multimedia in some physical abilities and basic skills for junior players in basketball	[60]
2	Bibliometric analysis of research development in sports science with vosviewer	[61]
3	Lived experiences of bachelor of physical education students on burnout: A phenomenological inquiry	[62]
4	Teachers 21st century skills special program in sports curriculum	[63]

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5	Coaching competencies and sports-facility utilization: Their influence on the commitment and psychological well-being of student-athletes	[64]
6	Speculating the lived experiences of physical education college instructors on health and wellness activities	[65]
7	Learners' 21st century skills special program in sports curriculum	[66]
8	Development and validation of an audiovisual ergorobics exercise intervention for enhancing workplace health and wellness	[67]
9	Developing students' physical and technical abilities through the STEAM approach: Methodology and implementation	[68]
10	Nutritional research mapping for endurance sports: A bibliometric analysis	[69]
11	Yoga and chronic conditions	[70]
12	Coaching styles and their impact on athletes' sports satisfaction	[71]
13	Achievement motivation and socio-economic status of engineering sports persons	[72]
14	Sports facilities and equipment: Availability and students' satisfaction in the physical education classes	[73]
15	Impact of after-school sports programs on the mental health of primary school pupils	[74]
16	Play-based learning as a tool in enhancing physical skill development of children	[75]
17	Health-related factors and teaching performance of physical education teachers amidst COVID-19 pandemic	[76]

4. CONCLUSION

This study provides robust evidence that VR fitness marks a paradigm shift in exercise prescription and the promotion of physical activity. The findings confirm that VR fitness achieves physiological outcomes equivalent to those of conventional exercise (most notably a 5.4 mL/kg/min increase in VO_2 max) while offering significantly greater psychological benefits, such as increased enjoyment, motivation, and adherence. These advantages are especially critical for sedentary individuals and those facing motivational barriers to traditional exercise. The combination of clinical efficacy, enhanced user engagement, and a favorable safety profile positions VR fitness as a viable first-line intervention in both clinical and public health settings. Its scalability and compatibility with home-based implementation further address structural barriers to exercise, including facility access, time constraints, and social discomfort. Investing in the development and implementation of VR fitness can yield substantial returns in terms of population health, healthcare cost savings, and improved quality of life. However, successful adoption will require coordinated efforts among researchers, developers, healthcare providers, and policymakers to ensure evidence-based practice and equitable access. Ultimately, VR fitness should not be seen merely as a technological trend, but as a transformative advancement that integrates immersive technology with exercise science to offer engaging, effective, and sustainable solutions for global physical inactivity.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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