Original Paper

Comparing Exercise Intensity, Enjoyment, and Cybersickness Across Virtual Reality and Video Shadowboxing in Young Adults: Within-Subject Laboratory Study

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Abstract

Background: Virtual reality (VR) exergaming platforms are increasingly used to promote physical activity; yet differences in exercise intensity, enjoyment, and cybersickness remain unclear. Although prior work has examined VR exercise, no study has directly compared *Supernatural* and *FitXR*, with a semi-immersive video-based exercise condition under controlled laboratory conditions.

Objective: This study compared physical activity, enjoyment, and cybersickness across 2 immersive VR boxing exergames (*Supernatural* and *FitXR*) and a semi-immersive video-based shadowboxing condition in young adults.

Methods: A within-subject design with a randomized counterbalanced condition order was used. In total, 31 healthy young adults (age: mean 19.97, SD 1.02 years; n=19 female participants) completed three 20-minute exercise conditions (*Supernatural*, *FitXR*, and semi-immersive video shadowboxing) during a single laboratory session. Physical activity outcomes, including metabolic equivalents of task (METs), moderate-to-vigorous physical activity (MVPA), light physical activity, and step count, were assessed using wrist-worn accelerometry (ActiGraph GT9X Link). Enjoyment was measured using the Physical Activity Enjoyment Scale (PACES), and cybersickness was assessed using the Simulator Sickness Questionnaire (SSQ). One-way repeated-measures ANOVA was conducted with Greenhouse-Geisser corrections, followed by Bonferroni-adjusted pairwise comparisons (α=.05). Effect sizes were reported as partial eta-squared (ηp^2) and Cohen *d*. An a priori power analysis indicated that a minimum sample of 28 participants was required to achieve 80% power (Cohen *f*=0.25).

Results: A significant main effect of condition was observed for MVPA ($F_{1.45,43.08}$=5.40; *P*=.02; ηp^2=0.152). *FitXR* elicited greater MVPA (19.34 minutes, 95% CI 19.14-19.55) than *Supernatural* (17.43 minutes, 95% CI 16.43-18.43; *P*<.001; Cohen *d*=0.96) and semi-immersive video shadowboxing (17.87 minutes, 95% CI 16.72-19.02; *P*=.01; Cohen *d*=0.65), although the absolute differences were modest (1-2 minutes per 20-minute session). No difference was observed between *Supernatural* and semi-immersive video shadowboxing (*P*=.57; Cohen *d*=0.15). Enjoyment differed significantly across conditions ($F_{1.30,39.99}$=9.62; *P*=.002; ηp^2=0.243), with *Supernatural* rated highest (4.95, 95% CI 4.76-5.14), followed by semi-immersive video shadowboxing (4.74, 95% CI 4.58-4.89) and *FitXR* (4.30, 95% CI 4.04-4.55). *Supernatural* was rated higher than *FitXR* (*P*=.004; Cohen *d*=1.07) and semi-immersive video shadowboxing (*P*=.04; Cohen *d*=0.46). Despite moderate-to-large effect sizes, the absolute differences in enjoyment scores were small (approximately 0.65 points on a 7-point scale). No significant differences were observed in cybersickness across semi-immersive video shadowboxing (17.13, 95% CI 10.21-24.05), *Supernatural* (20.87, 95% CI 14.29-27.46), and *FitXR* (16.41, 95% CI 10.70-22.12; $F_{1.72,51.63}$=1.37; *P*=.26; ηp^2=0.044).

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Conclusions: This study is among the first to directly compare 2 commercially available immersive VR boxing platforms with a semi-immersive control condition in the same participants. Unlike prior studies that examined VR exergaming platforms in isolation, these findings suggest that platform-specific design features, rather than immersion alone, may drive differences in exercise intensity and enjoyment. These findings support flexible, user-centered approaches to physical activity promotion and exergaming-based exercise prescription.

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KEYWORDS

cybersickness; enjoyment; exercise intensity; exergaming; motion sickness; physical activity promotion; virtual reality; young adults

Introduction

Background

Young adults (aged 18-25 years) are particularly vulnerable to weight gain and declining physical activity during the transition to independent living, regardless of weight status [1,2]. National surveillance data from the United States indicate that approximately 24% of young adults are classified as overweight and 16% meet the criteria for obesity [3]; however, insufficient physical activity remains a broader public health priority across the weight spectrum [3]. Despite well-established physical activity guidelines recommending 150 minutes of moderate-intensity aerobic activity per week, current behavioral surveillance data from the National College Health Assessment indicate that only 22.7% of male and 18.6% of female college students meet these recommendations [3], underscoring a persistent and substantial gap between recommended and actual activity levels among this demographic.

Exergaming, which integrates full-body movement into interactive digital gaming experiences, has emerged as a promising strategy to promote physical activity and reduce sedentary behavior, particularly among digitally native populations [4]. Among various exergaming modalities, immersive virtual reality (VR) has received increasing attention due to its ability to create engaging, multisensory environments that enhance motivation and user engagement [5]. Immersive VR systems use head-mounted displays that embed users within 3D virtual environments, creating a sense of presence and embodiment that distinguishes immersive VR from conventional screen-based gaming [6]. Young adults represent a particularly receptive audience for immersive VR technologies; recent data indicate that approximately 60% of this demographic plays video games weekly, positioning VR-based exercise as a potentially accessible and appealing modality for this age group [7].

Existing research demonstrates that VR-based exergaming can elicit moderate-intensity physical activity in young adults, with some reaching moderate-to-vigorous physical activity (MVPA) levels consistent with health promotion recommendations [8-10]. For example, Sousa et al [9] found that a fully immersive VR active video game elicited MVPA and improved cognitive performance in sedentary college students, while Craig et al [10] demonstrated that *Supernatural* produced energy expenditure consistent with moderate-intensity exercise, as measured using indirect calorimetry. Recent evidence further supports the ability of fully immersive VR exercise to elicit MVPA-level intensity across a range of platforms and populations [11,12]. Palmieri and Deutsch [11,12] demonstrated that competitive VR cycling elicited vigorous-intensity exercise and enhanced user experience in young adults across the lifespan, highlighting the capacity of platform design features to influence both physiological and affective responses.

Boxing-based exergaming represents a distinct modality within the broader exergaming literature, characterized by continuous upper extremity striking, coordinated rhythmic movements, and intermittent lower body engagement. These movement demands differ from those of commonly studied exergaming modalities such as cycling or stepping tasks, which are often more continuous and lower limb dominant. Consequently, boxing-based exergames may produce unique patterns of physical activity intensity, movement variability, and user experience. Within boxing-based exergaming specifically, *FitXR* has been used to examine energy expenditure and acute exercise responses [13], and *Supernatural* has been evaluated for its capacity to elicit moderate-intensity exercise through music-driven, immersive gameplay [10]. However, these platforms have largely been studied in isolation, limiting the ability to draw direct comparisons between their respective physiological and experiential effects.

Commercially available VR boxing platforms differ meaningfully in their instructional design and gameplay structure. *FitXR* emphasizes continuous instructor-led pacing, performance-based feedback, and sustained upper extremity movement, which may promote higher levels of continuous activity. In contrast, *Supernatural* incorporates music-driven pacing, greater movement variability, and immersive environmental engagement, which may influence both movement patterns and affective responses differently. Although these platforms differ substantially, no study to date has directly compared these 2 platforms with each other or with a semi-immersive control condition under controlled laboratory conditions [9,10,13]. These platform-specific differences provide a strong rationale for direct comparison under controlled conditions.

Prior research consistently identifies enjoyment as a key determinant of voluntary exercise participation and adherence, and evidence suggests that enjoyment and physiological intensity do not always align across exercise platforms and game designs; for example, some modalities elicit high enjoyment despite relatively lower physiological intensity, whereas others produce high intensity with lower perceived enjoyment [14-16]. Teixeira et al [14] demonstrated that enjoyment is a significant predictor

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of exercise habit and intention to continue exercising among young adults, underscoring its relevance as an outcome in exercise platform comparisons. In technology-based exercise interventions, platform-specific user experience factors, including enjoyment, comfort, perceived control, and tolerability, are especially influential in promoting engagement and sustained participation in physical activity, particularly when individuals have multiple platform options available and can readily switch between alternatives [17].

Although immersive VR may enhance engagement and enjoyment through sensory immersion, cybersickness-related nausea, dizziness, disorientation, and visual discomfort may reduce feasibility or willingness to participate [18]. Stanney et al [18] distinguished cybersickness from traditional simulator sickness, noting that the unique visual-vestibular conflict produced by head-mounted displays introduces symptom profiles that are particularly relevant in immersive VR exercise contexts. Despite advances in hardware, including improved refresh rates and motion tracking, cybersickness remains a meaningful barrier to VR exercise participation and warrants concurrent evaluation alongside physical activity intensity and enjoyment outcomes. Despite growing interest in VR-based exergaming, comparative evidence examining how platform-specific design features influence exercise intensity, enjoyment, and cybersickness tolerability across commercially available boxing platforms under controlled conditions remains limited [10,13,15].

A growing body of literature has demonstrated that immersive VR-based exercise can increase enjoyment and engagement compared to nonimmersive modalities, with recent meta-analytic evidence supporting these findings across diverse populations and exercise types [19,20]. In addition, prior empirical studies have examined immersive exercise across different modalities, including cycling-based VR tasks, highlighting the capacity of VR to influence both physiological and affective responses [11,12]. Within boxing-based exergaming, platforms such as *FitXR* have been used to examine energy expenditure, feasibility, and acute exercise responses, often using physiological measures such as heart rate or indirect calorimetry. More recently, research has begun to extend beyond proof-of-concept studies toward intervention-based applications of VR boxing [21].

Despite this growing body of work, limited research has directly compared commercially available VR boxing platforms under controlled conditions, particularly to isolate the effects of platform-specific design features, such as pacing, instructional style, and movement structure, on movement patterns and user experience. Consequently, it remains unclear whether observed differences in intensity and enjoyment reflect general properties of immersive VR exercise or result from specific platform design characteristics. Addressing this gap is necessary to better understand how different VR exercise platforms may differentially support physical activity and engagement.

Study Objectives

Therefore, the purpose of this study was to compare 3 exercise conditions—*Supernatural*, *FitXR*, and semi-immersive video shadowboxing exercise—to determine how these modalities differ in terms of physical activity outcomes, enjoyment, and cybersickness symptoms among young adults. We hypothesized that immersive VR conditions would elicit greater levels of MVPA and enjoyment than the semi-immersive video shadowboxing condition.

Methods

Study Design

This study used a within-subject design with counterbalanced condition order to compare physical activity outcomes, enjoyment, and cybersickness across 3 exercise conditions: 2 immersive VR boxing exergames (*Supernatural* [Meta Platforms Inc] and *FitXR* [FitXR Ltd]) and 1 semi-immersive video shadowboxing condition. All participants completed all 3 conditions during a single laboratory visit. The order in which participants completed the 3 conditions was randomized using computer-generated random numbers to minimize order and fatigue effects; there were no between-subject group assignments.

Research Design Overview

This study used a within-subject, counterbalanced repeated-measures design to compare physical activity outcomes, enjoyment, and cybersickness across 3 boxing-based exercise conditions. A within-subject design was selected because it maximizes statistical power by controlling for individual differences in fitness, gaming experience, and baseline activity levels, which are known sources of variability in exergaming research. Counterbalancing of condition order was used to minimize carryover and fatigue effects. This design is consistent with prior immersive VR exercise research using comparable within-subject frameworks [6,9,11].

Setting

The study was conducted in a controlled laboratory setting at the University of Tennessee, Knoxville, Tennessee. Recruitment and data collection occurred during the 2025 academic year (September 2025 to December 2025). All data were collected Monday through Friday between 8:00 AM and 6:00 PM. Each session lasted approximately 2 hours.

All 3 exercise conditions were conducted within a marked 5×5 feet exercise area to ensure consistent spatial constraints and participant safety. For the VR conditions, Meta Quest 3 (Meta Platforms Inc) headsets with touch controllers were individually fitted and calibrated for each participant, including interpupillary distance adjustment and virtual boundary setup aligned with the marked exercise space. Research staff monitored participants throughout each condition for objective signs of cybersickness, including postural sway and visual irregularities observed via live gameplay casting from the Meta Quest 3 to an iPad (Apple Inc). Session termination criteria included any participant-reported severe symptom or staff-observed adverse event. Subjective cybersickness symptoms were assessed after each condition via the Simulator Sickness Questionnaire (SSQ).

Researcher Description

The research team consisted of 2 doctoral students, 1 postdoctoral researcher, and undergraduate research assistants, all affiliated with the Department of Kinesiology, Recreation,

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and Sport Studies. Team members had prior experience in physical activity measurement, exergaming research, and exercise psychology, including familiarity with VR exercise platforms and other exergaming modalities. All data collectors were trained by the postdoctoral researcher prior to data collection to ensure standardized session delivery across participants. Training included practice with headset fitting and calibration, protocol administration, and questionnaire procedures. To minimize the potential influence of prior platform familiarity on participant experience, all staff followed a standardized scripted protocol during each session and refrained from expressing preferences or opinions regarding any exercise condition.

Participants

Participants were young adults aged 18 to 25 years. Recruitment was conducted using a convenience sampling approach through email announcements, classroom recruitment, and posted flyers. The flow of participants through each stage of the study is presented in Multimedia Appendix 1.

Eligibility was determined using the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+), and participants were required to meet the criteria for safe participation in MVPA. Exclusion criteria included a self-reported history of severe motion sickness, cybersickness, migraines, epilepsy, or vestibular disorders due to the immersive nature of VR exposure.

Upon arrival, participants completed a demographic questionnaire assessing age, sex, general health status, and prior experience with immersive VR. Anthropometric measurements were obtained prior to exercise and included height (measured to the nearest 0.1 cm using a stadiometer), body weight (measured to the nearest 0.1 kg), and body fat percentage (measured using bioelectrical impedance analysis). Resting blood pressure was measured using an automated sphygmomanometer after 5 minutes of seated rest.

Participant Recruitment

Recruitment Process

Participants were recruited using a convenience sampling approach via email announcements distributed through departmental listservs, in-class announcements, and posted flyers displayed in campus facilities. Interested individuals contacted the research team directly to schedule a screening and eligibility assessment. Of the 33 individuals who expressed interest or underwent screening, 2 individuals were excluded. The primary reasons for exclusion included not meeting the PAR-Q+ criteria and/or having a self-reported history of motion sickness or a vestibular disorder. The remaining 31 participants enrolled in the study and completed all 3 exercise conditions. For more information, refer to the CONSORT (Consolidated Standards of Reporting Trials)–style flow diagram presented in Multimedia Appendix 1.

A target sample of 33 participants was established based on an a priori power analysis, accounting for an estimated 15% attrition rate; the final analytic sample consisted of 31 participants.

Participant Selection

Participants were selected based on the following inclusion criteria: age of 18 to 25 years, ability to safely engage in MVPA as determined by the PAR-Q+, and no self-reported history of severe motion sickness, cybersickness, migraines, epilepsy, or vestibular disorders. Participants were not required to have prior VR experience. This convenience sample was selected to reflect the target population of young adults most likely to engage with commercially available VR exercise platforms in naturalistic settings.

Ethical Considerations

This study involving human participants was reviewed and approved by the Institutional Review Board at the University of Tennessee, Knoxville (IRB #25-08839-XP). All procedures were conducted in accordance with institutional guidelines and ethical standards for human subjects research. Written informed consent was obtained from all participants prior to participation. Participants were informed about the study purpose, procedures, potential risks, and their right to withdraw at any time without penalty. All study data were deidentified prior to analysis to protect participant privacy and confidentiality. No personally identifiable information was included in the dataset used for analysis or reporting. No images or figures in this manuscript or the multimedia appendix contain identifiable information about individual participants. Participants received a US $20 e-gift card as compensation for their time and participation in the study.

Assessments

Primary outcomes included physical activity metrics, enjoyment, and cybersickness. Physical activity was assessed using metabolic equivalents of task (METs), MVPA, light physical activity, and step count. Enjoyment was measured using the Physical Activity Enjoyment Scale (PACES), and cybersickness was assessed using the SSQ. Given the within-subject design, all participants served as their own controls. No additional predictors or confounders were included, as the within-subject design inherently controlled for between-subject variability.

Study Procedures

Supernatural (Immersive VR)

Participants completed a structured in-game familiarization session lasting 5 minutes to learn fundamental boxing movements, including jabs, crosses, hooks, uppercuts, ducks, and squats. Following familiarization, all participants engaged in a 20-minute, medium-difficulty, music-based boxing workout titled “Game Time,” selected to reflect a commonly used, commercially available session representative of typical *Supernatural* gameplay. This condition provided audiovisual feedback on punching accuracy and movement execution, with movement cadence guided implicitly by musical tempo rather than continuous instructor cueing.

FitXR (Immersive VR)

Participants completed a structured in-game familiarization session lasting 5 minutes to learn fundamental boxing movements identical to those introduced in *Supernatural*. Following familiarization, all participants engaged in a

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20-minute rhythm-based boxing workout titled "Good for You," selected to represent a standard, commercially available *FitXR* session at a medium difficulty level. This application combined continuous, instructor-led verbal cueing with game-selected electronic music, fixed pacing, and performance-based scoring mechanisms. Real-time feedback, competitive scoring elements, and sustained upper extremity striking were designed to promote consistent movement cadence and prolonged periods of higher-intensity effort.

Semi-immersive Video Shadowboxing

The semi-immersive control condition consisted of instructor-guided shadowboxing viewed on a flat-screen television positioned at participants' eye level, with the audio set to full volume. All participants viewed an instructional video introduction lasting 5 minutes and demonstrating basic boxing punches and defensive techniques, followed by a 20-minute guided shadowboxing workout. The instructional content was publicly available on YouTube (Alphabet Inc; "20 Minutes Shadowboxing with Coach Justin") and was not developed specifically for this study. Participants were instructed to mimic the demonstrated movements while maintaining a safe distance from the screen.

Across all conditions, exercise duration (20 minutes) and familiarization time (5 minutes) were standardized; however, platform-specific movement structure, cueing strategy, feedback, and pacing were intentionally preserved to reflect real-world use of commercially available boxing-based exercise platforms.

During the 10-minute recovery period following each condition, participants completed the PACES and the SSQ.

Data Sources

Physical activity was continuously measured during each exercise condition using wrist-worn accelerometers (ActiGraph GT9X Link; ActiGraph LLC) worn on the nondominant wrist at a sampling rate of 30 Hz. Raw accelerometry data were processed using ActiLife software (version 6.15.0; ActiGraph LLC) in 30-second epochs. Primary outcomes, including METs, MVPA, light physical activity, and step count, were derived from accelerometry data. MET values represent the average estimated MET across the 20-minute exercise bout.

The PACES is an 18-item validated instrument used to assess exercise enjoyment and affective responses, with items rated on a 7-point Likert scale (1="strongly disagree"; 7="strongly agree"). The PACES has demonstrated excellent internal consistency in healthy young adult samples, including college-aged populations (Cronbach $\alpha \approx 0.93$-0.96) [22].

Participants also completed the SSQ immediately following each exercise condition to assess cybersickness symptoms, including nausea, oculomotor strain, and disorientation. The SSQ consists of 16 items rated on a 4-point Likert scale (0="not at all"; 3="severe"), with individual symptom scores summed to create a total cybersickness score. The SSQ has demonstrated good internal consistency in healthy adult VR and simulator studies (Cronbach $\alpha \approx 0.80$-0.90) [23].

Blood pressure was measured before and after each condition solely to confirm participant safety and readiness to proceed to the next condition and was not used as an outcome variable.

Study Size

An a priori power analysis was conducted using G*Power (version 3.1; Heinrich Heine University Düsseldorf) for a 1-way repeated-measures ANOVA with 3 conditions (k=3; α=.05), and an assumed medium effect size (Cohen f=0.25, $\eta p^2 \approx 0.059$) based on prior VR exergaming literature. Results indicated that a minimum sample of 28 participants was required to achieve 80% power. Accounting for a 15% attrition rate, a target enrollment of 33 participants was established. The final sample of 31 participants provided adequate power for the primary outcomes (PACES, MVPA, and METs), whereas power for cybersickness was lower (power=0.726), suggesting reduced sensitivity to detect small between-condition differences.

Data Analysis

All data were screened for missing values, univariate outliers, and violations of ANOVA assumptions prior to analysis. No missing data were observed for any outcome variables, and all participants were included in all analyses. Descriptive statistics (means and SDs) were calculated for all demographic and outcome variables. Because each participant completed all 3 exercise conditions, outcome variables were analyzed using 1-way repeated-measures ANOVA. Dependent variables analyzed included METs, total MVPA, light physical activity, step count, PACES enjoyment scores, and the total cybersickness composite score.

Sphericity was assessed using Mauchly test; when violations were detected, Greenhouse-Geisser–adjusted degrees of freedom and corresponding P values were applied. Effect sizes were estimated using partial eta-squared (ηp^2), with values interpreted as small (ηp^2=0.01), medium (ηp^2=0.06), or large (ηp^2=0.14) [24].

Statistical significance was set at α=.05. Significant main effects were followed by Bonferroni-adjusted pairwise comparisons to identify specific differences between conditions.

Effect sizes for pairwise comparisons (Cohen d) were also calculated to quantify the magnitude of differences between conditions. Cohen d values were estimated using pooled SDs and should be interpreted cautiously given the within-subject design.

Power for the cybersickness outcome was lower (power=0.726), suggesting that the study may have been underpowered to detect small between-condition differences in cybersickness symptoms.

Results

Overview

A total of 31 young adults (age: mean 19.97, SD 1.02 years; n=19 female participants) participated in this study. Descriptive statistics for participant characteristics are presented in Table 1, and condition-specific means and SDs for all outcome variables are presented in Table 2. Results of the repeated-measures ANOVAs are summarized in Table 3 and

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Figure 1. The sample size was determined based on feasibility and consistency with prior within-subject immersive VR exergaming studies in young adults, which have reported adequate sensitivity to detect moderate effect sizes using repeated-measures designs with comparable sample sizes [6,9].

Table 1. Participant characteristics (N=31).

Characteristics	Participants
Age (years), mean (SD)	19.97 (1.02)
Sex, n	
Male	12
Female	19
BMI (kg/m^2), mean (SD)	22.86 (3.04)
Body fat (%), mean (SD)	23.36 (8.29)

Table 2. Mean (SD) scores of physical activity, enjoyment, and cybersickness outcomes across the 3 exercise conditions (N=31).

Outcomes	Semi-immersive video shadowboxing, mean (SD)	*Supernatural*, mean (SD)	*FitXR*, mean (SD)
Metabolic equivalents of task	3.19 (0.74)	3.16 (0.72)	3.29 (0.69)
MVPA[a] (min)	17.87 (3.13)	17.43 (2.74)	19.34 (0.57)
Light PA[b] (min)	1.28 (2.42)	1.60 (2.00)	0.66 (0.43)
Step count	1284.48 (291.16)	1182.32 (246.49)	1222.90 (111.13)
PACES[c] score (PA enjoyment)	4.74 (0.44)	4.95 (0.51)	4.30 (0.69)
Total cybersickness score	17.13 (18.87)	20.87 (17.96)	16.41 (15.56)

[a]MVPA: moderate-to-vigorous physical activity.

[b]PA: physical activity.

[c]PACES: Physical Activity Enjoyment Scale (7-point scale).

Table 3. Repeated-measures comparisons of physical activity, enjoyment, and cybersickness outcomes across the 3 exercise conditions (N=31).

Outcomes	Semi-immersive video shadowboxing, EMM[a] (95% CI)	*Supernatural*, EMM (95% CI)	*FitXR*, EMM (95% CI)	*F* test (*df*)[b]	*P* value	Effect size (ηp^2)[c]
Metabolic equivalents of task	3.19 (2.92-3.47)	3.16 (2.90-3.43)	3.29 (3.03-3.54)	2.30 (1.29, 38.68)	.13	0.071
MVPA[d] (min)[e]	17.87 (16.72-19.02)	17.43 (16.43-18.43)	19.34 (19.14-19.55)	5.40 (1.45, 43.08)	.02	0.152
Light PA[f] (min)	1.28 (0.39-2.17)	1.60 (0.87-2.33)	0.66 (0.50-0.81)	1.99 (1.40, 42.14)	.16	0.062
Step count	1284.48 (1177.69-1391.28)	1182.32 (1091.91-1272.74)	1222.90 (1182.15-1263.66)	1.68 (1.30, 39.00)	.20	0.053
PACES[g] score (PA enjoyment)[e]	4.74 (4.58-4.89)	4.95 (4.76-5.14)	4.30 (4.04-4.55)	9.62 (1.30, 39.99)	.002	0.243
Total cybersickness score	17.13 (10.21-24.05)	20.87 (14.29-27.46)	16.41 (10.70-22.12)	1.37 (1.72, 51.63)	.26	0.044

[a]EMM: estimated marginal mean.

[b]Greenhouse-Geisser corrections were applied when sphericity assumptions were violated.

[c]ηp^2: partial eta-squared.

[d]MVPA: moderate-to-vigorous physical activity.

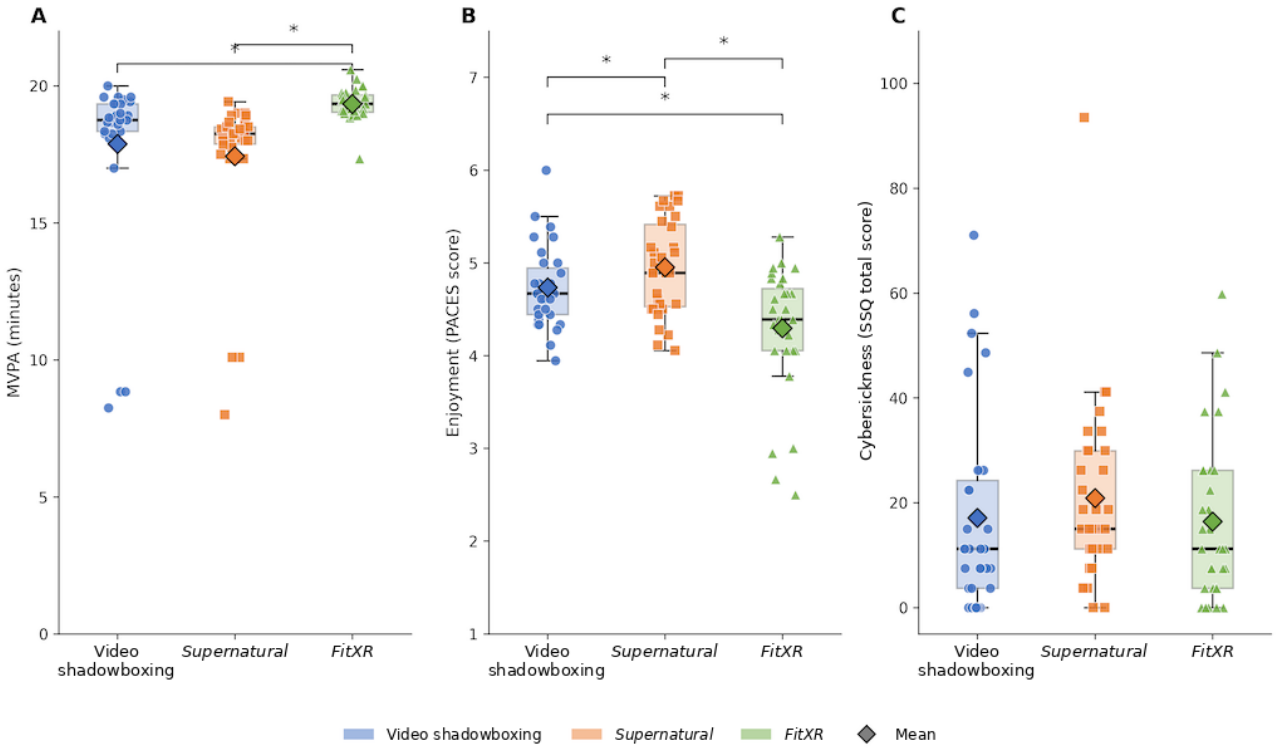
[e]Indicates a significant main effect of condition ($P<.05$) from repeated-measures ANOVA.

[f]PA: physical activity.

[g]PACES: Physical Activity Enjoyment Scale (7-point scale).

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Figure 1. Physical activity, enjoyment, and cybersickness across the 3 exercise conditions. (A) Moderate-to-vigorous physical activity (MVPA; minutes), (B) enjoyment (Physical Activity Enjoyment Scale [PACES] score), and (C) cybersickness (Simulator Sickness Questionnaire [SSQ] total score) during video shadowboxing, Supernatural, and FitXR. Individual data points represent participants. Diamonds indicate group means; boxes represent the IQR, with horizontal lines indicating medians; and whiskers extend to 1.5×IQR. *P<.05 (Bonferroni-adjusted pairwise comparisons).



Physical Activity Outcomes

Repeated-measures ANOVA revealed no significant main effect of exercise condition on METs ($F_{1.29,38.68}$=2.30; P=.13; ηp^2=0.071) or step count ($F_{1.30,39.00}$=1.68; P=.20; ηp^2=0.053).

There was a significant main effect of exercise condition on MVPA ($F_{1.45,43.08}$=5.40; P=.02; ηp^2=0.152). Post hoc pairwise comparisons indicated that *FitXR* elicited significantly greater MVPA than both semi-immersive video shadowboxing (P=.01) and *Supernatural* (P<.001), whereas semi-immersive video shadowboxing and *Supernatural* did not differ (P=.57). Estimated marginal means indicated that MVPA was highest during *FitXR* (19.34 minutes, 95% CI 19.14-19.55), followed by semi-immersive video shadowboxing (17.87 minutes, 95% CI 16.72-19.02) and *Supernatural* (17.43 minutes, 95% CI 16.43-18.43).

Pairwise comparisons indicated that the difference in MVPA between *FitXR* and semi-immersive video shadowboxing was moderate (Cohen d=0.65), that between *FitXR* and *Supernatural* was moderate to large (Cohen d=0.96), and that between semi-immersive video shadowboxing and *Supernatural* was trivial (Cohen d=0.15). Despite the statistical significance of some comparisons and the moderate effect sizes observed, the absolute differences in MVPA were modest (approximately 1-2 minutes across a 20-minute session).

Light physical activity did not differ significantly between exercise conditions ($F_{1.40,42.14}$=1.99; P=.16; ηp^2=0.062), indicating that lower-intensity movement patterns were relatively consistent across sessions.

The sum of MVPA and light physical activity did not account for the full 20-minute exercise bout during semi-immersive video shadowboxing (19.15 minutes) or *Supernatural* (19.03 minutes), with the remaining time representing epochs classified below the light physical activity threshold, consistent with brief sedentary transitions inherent to each platform's design. In contrast, *FitXR* accounted for the full 20 minutes of exercise time, consistent with its continuous, fixed-pacing structure, which minimized opportunities for sedentary transitions between movements.

PACES

Exercise condition had a significant effect on enjoyment ratings ($F_{1.30,39.99}$=9.62; P=.002; ηp^2=0.243). Post hoc pairwise comparisons revealed that *Supernatural* was rated significantly more enjoyable than both semi-immersive video shadowboxing (P=.04) and *FitXR* (P=.004). Additionally, semi-immersive video shadowboxing was rated more enjoyable than *FitXR* (P=.04).

Estimated marginal means indicated that enjoyment was highest for *Supernatural* (4.95, 95% CI 4.76-5.14), followed by semi-immersive video shadowboxing (4.74, 95% CI 4.58-4.89) and *FitXR* (4.30, 95% CI 4.04-4.55).

The pairwise comparisons yielded the following effect sizes: a small-to-moderate effect between *Supernatural* and semi-immersive video shadowboxing (Cohen d=0.46), a large effect between *Supernatural* and *FitXR* (Cohen d=1.07), and a

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moderate effect between semi-immersive video shadowboxing and *FitXR* (Cohen *d*=0.74). Notably, the comparison between *Supernatural* and *FitXR* demonstrated a large standardized effect (Cohen *d*=1.07), although the absolute difference in enjoyment was modest (approximately 0.65 points on the 7-point scale), indicating that the magnitude of change in practical terms may be limited despite the statistical and standardized differences.

Cybersickness

Total cybersickness symptoms did not differ significantly across both VR and semi-immersive video shadowboxing ($F_{1.72,51.63}$=1.37; *P*=.26; ηp^2=0.044).Cybersickness scores were similar across semi-immersive video shadowboxing (17.13, 95% CI 10.21-24.05), *Supernatural* (20.87, 95% CI 14.29-27.46), and *FitXR* (16.41, 95% CI 10.70-22.12).

When interpreted against established SSQ severity thresholds [24], total scores across all 3 conditions fell within the ranges described as significant (scores of 10-20) or problematic (scores >20), suggesting that despite the absence of statistically significant between-condition differences, cybersickness symptom burden was not negligible in any condition.

These findings highlight the importance of monitoring cybersickness symptoms during all forms of boxing-based exercise, including semi-immersive video shadowboxing, rather than solely during fully immersive VR exercise.

Discussion

Principal Findings

This study examined differences in physical activity, enjoyment, and cybersickness across 2 immersive VR boxing exergames (*Supernatural* and *FitXR*) and a semi-immersive video shadowboxing condition in young adults. Overall movement volume, as reflected by METs, step count, and light physical activity, was similar across conditions. However, wrist-detected MVPA differed by platform, with *FitXR* associated with higher values than those observed in the other conditions. In contrast, *Supernatural* was rated as the most enjoyable condition despite eliciting lower levels of wrist-detected MVPA. Cybersickness symptoms did not differ across conditions, indicating that all exercise modalities were similarly tolerated under short-term laboratory conditions.

Comparison With Prior Work

The similarity in overall METs and step count across exercise conditions aligns with prior research suggesting that individuals regulate effort during novel or cognitively demanding tasks to maintain a relatively stable workload [25-27]. Immersive VR environments introduce additional cognitive and motor demands that may influence movement pacing and effort regulation during early exposure, as individuals allocate attentional resources to navigating unfamiliar virtual environments while performing the exercise task itself [28,29]. These findings are also consistent with the constrained total energy expenditure model, which proposes that increases in effort during 1 portion of an activity are often offset by reductions elsewhere, resulting in relatively stable total energy expenditure over short durations [25,29,30]. This pattern has been observed across a range of exercise modalities and supports the interpretation that total movement volume may remain relatively stable even when platform-specific movement demands differ meaningfully [25,26].

Although overall movement volume was comparable, differences in wrist-detected MVPA were observed. *FitXR* was associated with greater wrist-detected MVPA, which may reflect its structured, continuous, and instructor-led gameplay that promotes sustained upper extremity movement. In contrast, *Supernatural* incorporates more variable movement patterns, including lower body engagement and rotational movements, which may be less consistently captured by wrist-worn accelerometry. As such, differences in MVPA likely reflect variation in detected movement patterns rather than definitive differences in physiological exercise intensity. This interpretation is supported by prior validation studies demonstrating reduced sensitivity of wrist-worn accelerometers to multiplanar and lower body–dominant activities [9,31-34]. Specifically, Montoye et al [31] and Hildebrand et al [32] demonstrated that wrist-worn accelerometers show reduced accuracy for activities involving significant upper extremity or multiplanar movement, which is particularly relevant when comparing platforms with differing movement structures, such as *FitXR* and *Supernatural*.

Although statistically significant differences in MVPA were observed, the absolute differences between conditions were modest over the 20-minute exercise bout. Together with the partial overlap between the CIs, these findings suggest that the practical magnitude of these differences may be limited. This reinforces the need to interpret platform-specific differences in intensity with caution, particularly when using a single measurement modality.

Enjoyment differed across conditions, with *Supernatural* rated highest. Although standardized effect sizes ranged from moderate to large, the absolute differences in enjoyment scores were relatively small, indicating generally high enjoyment across all conditions. Affective models of exercise behavior suggest that enjoyment is influenced by sensory engagement, attentional focus, and perceived autonomy [17]. *The* immersive environments and rhythm-based structure of *Supernatural* may promote attentional absorption and reduce self-monitoring, contributing to more positive affective responses, consistent with prior work demonstrating that music-driven and environmentally immersive exercise contexts can enhance positive affect during physical activity [17,35].

Self-determination theory (SDT) [36] further supports this interpretation, as sustained engagement in physical activity is influenced by the satisfaction of autonomy, competence, and relatedness. *Supernatural* may have supported greater perceptions of autonomy by allowing greater self-regulation of movement, whereas the externally paced and performance-driven structure of *FitXR* may constrain autonomy despite supporting competence. This distinction is consistent with SDT-based research in exercise contexts demonstrating that externally regulated exercise environments are associated with lower autonomous motivation and less positive affective responses than more self-directed conditions [17]. Prior research

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indicates that externally imposed pacing and higher perceived exertion may be associated with less favorable affective responses during exercise [14,16].

Enjoyment has been identified as a key predictor of future exercise participation among young adults [14]. In the present study, *Supernatural* elicited higher enjoyment despite slightly lower wrist-detected MVPA, suggesting that affective response and intensity represent distinct dimensions of the exercise experience. This finding aligns with prior work by Sousa et al [9] and Craig et al [10], who demonstrated that immersive VR exercise platforms can elicit both physiological and affective benefits, and with broader evidence suggesting that immersive VR exercise enhances motivation and enjoyment relative to less immersive conditions at comparable exercise intensities [11,12]. A recent review reported that immersive VR exercise can enhance motivation, engagement, and enjoyment relative to less immersive conditions at comparable intensities [20]. These findings are consistent with prior work demonstrating both psychological and physiological benefits of immersive VR exercise [37].

Cybersickness symptoms did not differ across conditions, indicating that immersive VR exercise was well tolerated during short-duration exposure. This is consistent with prior work by Stanney et al [18] and Kennedy et al [38], who noted that symptom burden during brief, room-scale VR exposure tends to be lower than that during seated or artificially locomoted VR experiences, likely due to reduced visual-vestibular conflict. These findings are consistent with prior work demonstrating low symptom burden during brief VR exercise sessions [34]. Advances in hardware, including improved refresh rates and motion tracking, as well as the use of room-scale movement without artificial locomotion, may reduce sensory conflict and mitigate cybersickness risk [39]. Notably, however, cybersickness scores across all 3 conditions, including the semi-immersive video shadowboxing condition, fell within the ranges classified as significant to problematic on the SSQ [38], suggesting that cybersickness symptom burden is not exclusive to fully immersive VR and warrants monitoring across all boxing-based exercise modalities. However, cybersickness remains influenced by multiple design factors, including movement type and visual feedback, and should continue to be considered in future intervention studies [39].

Limitations

Several limitations should be considered when interpreting these findings. First, this study used an acute, time-matched exercise protocol, which may limit generalizability to longer-term participation. Movement efficiency and intensity regulation may change with repeated exposure due to motor learning and task familiarity [34,39,40]. Second, the sample consisted of healthy young adults, which may limit generalizability to older adults or clinical populations. This is particularly relevant given that exergaming interventions are increasingly applied in older and clinical populations [41]. Participants were also prescreened for cybersickness susceptibility, which may underestimate symptom burden in broader populations. Third, all exercise intensity outcomes were derived from wrist-worn accelerometry [42] without concurrent heart rate monitoring or ratings of perceived exertion. This limits the ability to confirm whether observed differences in wrist-detected MVPA reflect true differences in physiological intensity. Wrist-worn accelerometers demonstrate reduced accuracy for multiplanar and upper extremity–dominant activities, which is particularly relevant in immersive VR exercise contexts [31,32]. Future studies should incorporate multimodal assessments of exercise intensity [38]. Fourth, the SSQ includes items such as sweating, which may reflect exercise-induced responses rather than cybersickness-specific symptoms. This represents a potential source of measurement confounding in exergaming contexts. Finally, only a single standardized session was used for each platform. Variation in content, difficulty, and instructional style may influence both intensity and enjoyment, and the findings may not be generalizable to all available sessions within each platform.

Conclusions

This study is among the first to directly compare 2 commercially available immersive VR boxing platforms alongside a semi-immersive shadowboxing condition within the same participants, providing a more comprehensive evaluation of exercise intensity, enjoyment, and cybersickness than prior platform-specific investigations. Unlike previous studies that have largely examined VR exergaming platforms in isolation, the present findings suggest that platform-specific design characteristics, rather than immersion alone, may influence exercise intensity and user experience.

Although differences in wrist-detected MVPA and enjoyment were modest, the findings highlight that exercise intensity and affective response represent distinct dimensions of the exercise experience, with potentially different implications for long-term physical activity engagement. These results contribute to the growing VR exercise literature by supporting flexible, user-centered approaches to physical activity promotion and exergaming-based exercise prescription. From a real-world perspective, commercially available VR and semi-immersive boxing platforms may represent accessible and engaging tools for promoting physical activity among young adults. Future longitudinal research is needed to determine whether these acute responses translate into sustained exercise adherence and long-term behavioral change across diverse populations.

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Data Availability

The datasets generated during this study are available from the corresponding author upon reasonable request.

Generative AI Use

The authors confirm that no generative AI tools were used in the writing or analysis of this manuscript.

Authors' Contributions

ZA led the data analysis and drafted the manuscript. JO and JM assisted with data collection and manuscript editing. JG and JAS assisted with the development of the original idea and manuscript editing. ZG supervised the study and provided critical revisions. All authors approved the final manuscript.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Participant flow through enrollment, assignment, follow-up, and analysis. Of 33 individuals assessed for eligibility, 31 met inclusion criteria and were enrolled. Using a within-subject, counterbalanced design, all participants completed 3 exercise conditions (video shadowboxing, Supernatural, and FitXR) during a single laboratory session lasting approximately 2 hours. Condition order was randomized and counterbalanced using computer-generated random numbers. No participants were lost to follow-up or excluded from analysis. JARS: Journal Article Reporting Standards; PAR-Q+: Physical Activity Readiness Questionnaire for Everyone.
[PNG File , 119 KB-Multimedia Appendix 1]

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Abbreviations

CONSORT: Consolidated Standards of Reporting Trials
MET: metabolic equivalent of task
MVPA: moderate-to-vigorous physical activity
PACES: Physical Activity Enjoyment Scale
PAR-Q+: Physical Activity Readiness Questionnaire for Everyone
SDT: self-determination theory
SSQ: Simulator Sickness Questionnaire
VR: virtual reality

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