

Physiological and psychological responses to an immersive virtual reality boxing exergame

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Published online: January 31, 2026

Accepted for publication: January 15, 2026

DOI:10.7752/jpes.2026.01005

Abstract

Immersive virtual reality exergaming is an increasingly common way to become physically active, yet its ability to provide vigorous exercise has not been well described. This exploratory study quantified the acute physiological responses of sixteen healthy young adults to fourteen-minute virtual reality boxing gameplay session. Participants completed five two-minute rounds separated by a minute rest period while oxygen uptake and carbon dioxide production were measured breath by breath using a portable gas analysis system. Heart rate was recorded continuously by a chest strap mounted monitor. From these recordings, metabolic equivalents and energy expenditure were calculated. Immediately after completing their session participants reported perceived exertion, Borg's Rating of Perceived Exertion, and enjoyment, Physical Activity Enjoyment Scale. On average, participants expended a total of 161.7 ± 18.0 kilocalories, 11.6 ± 1.3 kilocalories per minute and achieved 9.2 ± 1.8 metabolic equivalents, with the lower bound of the 95 percent confidence interval remaining above the American College of Sports Medicine threshold for vigorous intensity. Mean heart rate was reported as 163 ± 6 beats per minute corresponding to 93 ± 4 percent of age predicted maximal heart rate. Peak heart rate reached 186 ± 8 beats per minute. Participant perceptual responses reflected experiencing high effort and positive affect, the average perceived exertion rating was 17 ± 1 on the 6 to 20 scale and an enjoyment score of 4.0 ± 0.5 on a 5-point scale. Taken together, these findings indicate that as an exercise medium, upper body focused immersive virtual reality can produce vigorously intense physiological responses while remaining highly enjoyable for users. This suggests that this medium of interactive, immersive exercise may offer a time efficient and engaging option for individuals seeking alternatives to traditional exercise options. Larger and longer-term studies are needed to determine whether these acute observations are sustainable and whether this modality can be integrated into accessible, structured exercise programs.

Keywords: exercise intensity; energy expenditure; metabolic equivalents; heart rate; perceived exertion; enjoyment

Introduction

Exercise has been consistently proven as a means to improve physical health, reduce stress, and enhance cognitive function (Cassilhas et al., 2016). As technology advances, it continues to reshape the way people can approach physical activity, offering new ways to make it more personalized, accessible, engaging, and enjoyable. Exergaming is one recent innovation which blends the physiological demands of exercise with the motivation and enjoyment of interactive gameplay (Hu et al., 2021). Since the introduction of early exergaming systems such as the Nintendo Wii in 2006 and the Xbox Kinect, the field has evolved through advances in immersive virtual reality (IVR) technology. Utilizing head-mounted displays and room-scale tracking, IVR creates experiences that feel more realistic and have potential as a tool for delivering structured, time-efficient exercise outside of the traditional fitness setting (Sinclair et al., 2007).

IVR applications have demonstrated psychological benefits and high user satisfaction in short-term interventions (Xu et al., 2021), but far less is known about their ability to meet established physiological thresholds for exercise intensity. Enjoyment and motivation are critical to enhance long term adherence for any exercise modality, but the value of IVR in promoting activity promotion depends on whether it can deliver adequate cardiometabolic exertion. Existing research examining VR exercise as a viable medium has yielded inconsistent results. Some studies suggest a potential disconnect between cardiometabolic outcomes, with participants' cardiovascular responses failing to align with participants' caloric energy expenditure (Perrin et al., 2019), while others reported achieving moderate intensity during VR exercise sessions (Polechoński et al., 2024). Determining if the exertion experienced during an

exercise-focused IVR session reflects meaningful metabolic demand or merely the perception of intensity is vital for establishing the role IVR can play as a viable alternative to traditional exercise.

A common barrier to regular physical activity is the belief that exercise requires more time than can be realistically committed on a weekly basis (Trost et al., 2002). Exergaming activities such as IVR boxing present a potential solution to this time barrier by providing short, engaging sessions that demand sustained physical effort. During a gameplay session, players must coordinate repeated offensive upper-body movements, punching, faking, and striking, with defensive actions such as blocking, slipping, and head movement, while also making occasional adjustments in stance and balance. These movements are dominated by the upper body, but still require whole-body stabilization and rapid shifts in posture, which may influence both cardiovascular responses and overall metabolic expenditure. Preliminary evidence suggests that IVR boxing environments are a promising gateway into exercise, demonstrating that they can reduce anxiety and increase cognitive performance to a greater extent than video-guided exercise. Notably, IVR boxing settings can increase exercise intensity and overall enjoyment compared to non-immersive equivalents (Barbour et al., 2024; Cioffi & Lubetzky, 2023).

Despite some promising initial findings, the physiological and psychological outcomes IVR exercise can achieve are not yet well characterized. Establishing whether IVR boxing can reliably achieve vigorous-intensity thresholds defined by the American College of Sports Medicine (ACSM) (American College of Sports Medicine, 2021) requires measurement of metrics such as metabolic equivalents (METs), energy expenditure (EE), and heart rate (HR). One MET is defined as the energy expenditure of sitting quietly, which corresponds to resting energy expenditure of approximately $3.5 \text{ mL O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (Ainsworth et al., 2011; Howley, 2001). ACSM classifies vigorous-intensity exercise as ≥ 6 METs or $\geq 77\%$ of age-predicted maximum HR (Howley, 2001; Mendes et al., 2018). EE further reflects the caloric cost of an activity and is a central determinant of the exercise's contribution to overall energy balance and weight regulation (Levine, 2004; Westerterp, 2013). Psychological metrics, including Borg's Rating of Perceived Exertion (RPE) and the Physical Activity Enjoyment Scale (PACES), are important complements to physiological data, given the roles perception and enjoyment play in exercise behaviors. RPE is a validated psychophysiological index measuring how intensely someone feels their body is working during a physical activity that correlates strongly with heart rate across aerobic and high-intensity modalities (Scherr et al., 2013; Williams, 2017). Alternatively, PACES has demonstrated reliability in assessing enjoyment of physical activity, with higher scores predictive of long-term exercise adherence (Chen et al., 2021; Kendzierski & DeCarlo, 1991; Raedeke, 2007).

While IVR exercise through boxing shows promise as a highly engaging exercise experience, its capacity to produce physiological outcomes associated with vigorous-intensity activity during real-time gameplay has not been clearly defined. Addressing this question requires direct measurement of metabolic output, cardiovascular strain, perceived exertion, and enjoyment during an actual bout of immersive boxing. The present exploratory study evaluates these responses during a single fourteen-minute session of IVR exercise using the game *Thrill of the Fight* (TotF) on the Meta Quest 3, which offers a continuous, upper-body-dominant boxing simulation suitable for examining physiological exertion. By assessing EE, METs, HR, % HR max, RPE, and PACES, we aim to characterize the acute physiological and psychological profile of IVR boxing and determine whether it can function as a stand-alone time-efficient, vigorous-intensity exercise modality. These descriptive findings provide an initial foundation for understanding the training potential of IVR boxing and for guiding future controlled studies on long-term feasibility and adaptation.

Material & Methods

Participants

Sixteen healthy adults (male, $n=12$; female, $n=4$) aged 18–23 years were recruited from the greater Los Angeles area. Inclusion criteria required the ability to perform moderate-to-vigorous exercise without medical restriction. Exclusion criteria included cardiovascular or pulmonary disease, musculoskeletal limitations, or a history of severe motion sickness with IVR. All participants provided written informed consent. This exploratory research was carried out in accordance with full ethical approval from the University of California, Los Angeles (IRB: 11-003190), in accordance with the Declaration of Helsinki. Given that this was designed as a single-session exploratory analysis, a formal α -priori power analysis was not conducted. The sample size was selected to provide stable estimates for key descriptive outcomes and to align with prior exergaming and exercise physiology investigations that typically recruited 9–17 individuals (Barbour et al., 2024; Hu et al., 2021; Perrin et al., 2019; Polechoński et al., 2024).

Procedure

Within this descriptive study, participant data was collected following the completion of a single 14-minute session of TotF using the Meta Quest 3S headset. The session comprised five, 2-minute rounds with 1-minute rest intervals, replicating a standard boxing format. Prior to testing, participants underwent anthropometric assessments, including height on the Physician's Beam scale and weight along with body fat percentages (BF%) were calculated using the InBody BIA scale (270; InBody Co., Seoul, South Korea). For

familiarization on the day before testing, participants were measured for anthropometry and then led through a safety demonstration of the gameplay and fitted for the head gear worn during gameplay.

During gameplay, participant data was collected from a portable metabolic unit (Calibre, Wellesley, MA), a recently validated system for indirect calorimetry that demonstrated high accuracy relative to fourteen other stand-alone and portable cardiopulmonary exercise test (CPET) devices, worn throughout the session (Alcantara et al., 2022; Hu et al., 2021; Van Hooren et al., 2024). The lightweight (i.e. 50 gram) Calibre unit was attached to the participants head using two straps, one on the top and back of head, with the metabolic unit sitting in a slot on the face mask placed on the bridge of the nose and encompassing the mouth. The participant would breathe through a Thermal sensor (Sensirion, Stäfa, Switzerland) into the mask allowing for breathe-by-breathe oxygen consumption (VO₂) and carbon dioxide exhalation (VCO₂) measures using electrochemical (Angst Pfister, Switzerland) and thermal conductivity means (Sensirion, Switzerland), respectfully. Standard calibration occurred prior to testing according to the Calibre system manual. The device used Bluetooth connectivity to a smartphone and Calibre app, which enabled real-time visual graphs and derivation of EE using the Weir equation and derivation of MET values standardized to body mass (Byrne et al., 2005; Turell & Alexander, 1964). HR was continuously recorded every five seconds using a Polar RS400 chest strap (Polar Electro, Kempele, Finland) and was synchronized with gas exchange data (**Figure I**). Measurements were averaged between all the trials and were reported as mean value.



Figure I. Immersive VR exergaming gameplay showing Meta Quest 3S headset, Calibre metabolic unit and heart rate chest strap (under garment) used to assess physiological responses.

Following the session, participants were instructed to complete the Borg's RPE and the PACES assessment. RPE is a widely validated psychophysiological marker of exercise intensity, demonstrating a near-linear relationship with HR across aerobic and high intensity modalities, such that RPE multiplied by a factor of 10 approximates HR in beats per minute (Scherr et al., 2013; Williams, 2017). On this scale, 6 corresponds to "no exertion" while 20 indicates "maximal exertion. Enjoyment was assessed using PACES, which evaluates affective responses to physical activity on a 5-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"), with higher mean scores reflecting greater enjoyment (Chen et al., 2021; Kendzierski & DeCarlo, 1991). The PACES has demonstrated strong reliability and validity across adolescents, young adults, and clinical populations, and higher scores have been shown to predict long-term exercise adherence (Raedeke, 2007). Short-form versions have also been validated, but the full scale remains the standard for capturing multidimensional aspects of exercise enjoyment.

Statistical Analysis

All analyses were exploratory and descriptive. EE (kcal·min⁻¹; total kcal), METs (kcal·kg⁻¹·h⁻¹), HR (bpm; %HR_{max}), RPE (6–20 scale), and PACES (1–5 scale) are reported as mean ± SD and 95% confidence intervals (95% CI). Demographics (age, y; height, cm; weight, kg; BF%) were summarized using the same approach. No inferential tests were performed, as the study was designed to characterize responses within a

single cohort rather than compare between groups. 95% CIs were included to quantify the precision of descriptive estimates and provide greater transparency and replicability given the exploratory design. All analyses were performed in Microsoft Excel (Microsoft Corporation, Redmond, WA).

Results

Descriptive data for participant characteristics and all physiological and psychological outcomes are summarized in Table I. A young and generally healthy sample of sixteen participants completed the session (12 men and 4 women), with a mean age of 21 ± 1.3 years (95% CI: 20.3, 21.7), average height of 181.8 ± 9.1 cm (95% CI: 176.9, 186.7), body mass of 77.1 ± 11.5 kg (95% CI: 70.9, 83.3), and body fat of $13.2 \pm 3.9\%$ (95% CI: 10.9, 15.5). Participants averaged 161.7 ± 18.0 kcal (95% CI: 151.1, 172.3) burned during the 14-minute session and 11.6 ± 1.3 kcal per minute (95% CI: 10.9, 12.3) of exercise. Mean METs were 9.2 ± 1.8 (95% CI: 8.2, 10.2). Metabolic data recorded throughout the exercise reported an average HR of 163 ± 6 bpm (95% CI: 159.8, 166.2), with an average peak of 186 ± 8 bpm (95% CI: 181.7, 190.3), and a mean of $93 \pm 4\%$ predicted maximum (95% CI: 90.9, 95.1). The perceived intensity of the session was reported as a mean RPE of 17 ± 1 (95% CI: 16.5, 17.5), while their PACES enjoyment scores (1-5 scale) were 4.0 ± 0.5 (95% CI: 3.7, 4.3).

Table I. Participant Characteristics, Physiological, and Psychological Responses to a 14-Minute VR Exergaming Session Using Thrill of the Fight (n = 16).

Parameter		Mean $\pm$ SD	95% CI
Anthropometric	Age	21 ± 1.3	(20.3, 21.7)
	Height (cm)	181.8 ± 9.1	(176.9, 186.7)
	Weight (kg)	77.1 ± 11.5	(70.9, 83.3)
	Body Fat %	13.2 ± 3.9	(10.9, 15.5)
Energy Expenditure	kcal/min	11.6 ± 1.3	(10.9, 12.3)
	Total kcal	161.7 ± 18.0	(151.1, 172.3)
METS	kcal/kg/hr	9.2 ± 1.8	(8.2, 10.2)
Heart Rate	Average bpm	163 ± 6	(159.8, 166.2)
	Max bpm	186 ± 8	(181.7, 190.3)
	% HR max	93 ± 4	(90.9, 95.1)
RPE	6-20 scale	17 ± 1	(16.5, 17.5)
PACES	1-5 scale	4 ± 0.5	(3.7, 4.3)

Note: Figures present descriptive data mean, standard deviation (SD), and 95% confidence intervals (95% CI). No inferential statistical tests were applied given the exploratory design.

Discussion

The present study evaluated the physiological and psychological demands of the immersive VR boxing simulation through Thrill of the Fight. Although a majority of the gameplay is upper-body dominant, focused on repeated punching, guarding, and striking accuracy, successful gameplay requires whole-body participation. Core-focused defensive maneuvers, such as ducking and weaving and lower-body footwork to avoid strikes and reposition relative to the opponent, are required to defeat an opponent. These defensive gameplay mechanics activate the core and lower limbs, complementing the repeated punching, blocking, and guarding that formed the bulk of the physiological workload. With only short pauses between rounds, the continuous upper-body-focused gameplay and attentional demands of an immersive environment provide a plausible explanation for the elevated cardiovascular and metabolic demands observed.

Physiological Demand: METs, EE, and HR

The average metabolic intensity from the study indicates exercise through IVR boxing is capable of reaching levels of vigorous exertion. Participants averaged 9.2 ± 1.6 METs, well above the minimum METs needed for vigorous-intensity classification (≥ 6 METs) defined by ACSM (American College of Sports Medicine, 2021). The lower bound of the confidence interval, 8.2 to 10.2, remained well above 6 METs, suggesting that vigorous classification was not driven by potentially high-responding participants but rather reflected a consistent pattern across the sample.

This is an important distinction; it indicates that the metabolic demand of IVR boxing is likely robust across individuals within this demographic. Interpreting these values in relation to other exercises classified as vigorous helps clarify the physiological demand observed in IVR boxing. High-intensity functional training (HIFT) has been found to reach values near 12.2 ± 1.4 METs (Robinson et al., 2020), and VR resistance-based exercise studies have demonstrated similarly elevated metabolic outputs (Hu et al., 2021). IVR boxing approaching these levels is noteworthy because TotF relies primarily on rapid upper-body striking rather than full-body locomotion. The repeated punching actions, combined with trunk stabilization and continuous

engagement within the immersive environment, likely contributed to the metabolic cost. These findings indicate that VR boxing can elicit a level of metabolic intensity comparable to recognized vigorous activities, despite depending on a distinct movement profile.

The EE results further support this classification. Participants expended an average of 11.6 ± 1.3 kcal·min⁻¹, burning an average of 161.7 ± 1.3 kcal over the fourteen-minute gaming session. The average caloric burn rate per minute observed throughout the session is consistent with vigorous-intensity outputs reported in HIFT (Browne et al., 2020), VR resistance-based exergaming (Hu et al., 2021), and other commercial VR gaming platforms such as Supernatural (Craig et al., 2024). The total caloric cost is modest due to session length, though it is comparable to brisk treadmill walking at 5 to 6 km/h for the same duration (Ainsworth et al., 2011) or a short bout of aerobic dance (Howley, 2001). These findings imply that short sessions of VR exergaming may contribute meaningfully toward daily energy expenditure targets recommended for health maintenance and weight control (Levine, 2004; Westerterp, 2013).

HR responses further illustrate the cardiovascular load of this exercise modality. Participants averaged an HR of 163 ± 6 bpm, which corresponds to $93 \pm 4\%$ of age-predicted maximum HR. These results fall within the zone of vigorous intensity classification, mirroring patterns seen in other VR (Hu et al., 2021; Perrin et al., 2019) and traditional modalities (Achten & Jeukendrup, 2003; Guimarães et al., 2019; Swain & Leutholtz, 1997). Furthermore, they closely resemble HR trends reported during combat-sport activities that the game is intended to emulate. Prior research demonstrates that amateur boxing matches often produce average heart rates above 93% of maximum (Bruzas et al., 2023), and international-level boxers have recorded similar values ($93 \pm 3.3\%$) (Nassib et al., 2017). Sparring sessions have been found to produce peak HR values near 190 to 192 beats per minute (Ghosh, 2010). The peak rate recorded in this study, 186 ± 8 beats per minute, approaches this range. The similarity across these independent indicators suggests that IVR boxing can elicit comparable cardiovascular demands observed in intermittent high-intensity combat sports, despite more limited lower-body contribution. When considered alongside the metabolic and energy expenditure data, these heart rate patterns support the conclusion that immersive IVR boxing can produce physiological responses consistent with a vigorous intensity.

Psychological Demand: RPE and Enjoyment

Perceptual response provides additional complementary context for the physiological findings. Participants rated their exertion at an average RPE of 17, consistent with vigorous workloads and reflective of substantial psychophysiological effort (Scherr et al., 2013; Williams, 2017). Interestingly, RPE values were slightly lower than expected given the recorded physiological strain. A similar discrepancy was also observed in other VR exergaming studies and may reflect the influence of attentional engagement or distraction from the novelty of interactive tasks in this medium (Hu et al., 2021; Sauchelli & Brunstrom, 2022). This is consistent with theories of distraction and active engagement, which propose that immersion and game engagement can lessen perceived effort despite high physiological output (Chen et al., 2021; Raedeke, 2007). Although perceived exertion may be somewhat attenuated, the close correspondence between mean HR and RPE reflects the established linear association between perceived exertion and cardiovascular load (Scherr et al., 2013; Williams, 2017), suggesting that when users are absorbed in gameplay, they may perceive effort as less taxing despite high physiological strain.

Importantly, enjoyment scores were high. PACES ratings averaged 4.0 ± 0.5 , with a confidence interval of 3.7 to 4.3, suggesting stable and positive affective responses across the sample. High enjoyment is particularly relevant because affective experience is a strong predictor of long-term exercise adherence (Raedeke, 2007). Findings from this study reinforce prior work showing that VR exercise can enhance enjoyment more than traditional modalities (Craig et al., 2024; Momosaki et al., 2025; Sauchelli & Brunstrom, 2022). The combination of vigorous physiological demand and positive response is notable; vigorous-intensity training often elicits discomfort or negative affect during traditional exercise formats (Frazão et al., 2016; Metcalfe et al., 2022). Exercise through IVR environments may offer help in mitigating these perceptions by maintaining engagement and attention throughout the workout.

Limitations

This study has several limitations. It is limited by a small, homogeneous sample of young, healthy adults, which restricts generalization to other groups and clinical populations. While not uncommon in exploratory work, the design was limited to a single-session, so the findings cannot determine whether the high intensity and positive psychological responses observed would persist with multiple sessions or translate into measurable training adaptations. While the Calibre metabolic unit has been validated, dynamic IVR exercise may still introduce calibration drift or motion artifacts. Similarly, perceptual measures such as RPE and PACES are well-validated but subject to bias from immersion or novelty. Additionally, exercise intensity was partially self-regulated through participant movement strategy and game mechanics, which introduces variability in physiological load and does not allow true exercise standardization for future trials. The absence of a comparison group restricts interpretation relative to conventional vigorous exercise. Future research should include multiple sessions, diverse samples, and head-to-head comparisons to clarify the long-term feasibility, physiological adaptations, and potential clinical relevance of IVR as an exercise modality.

Conclusion

This exploratory study demonstrates that exercise through IVR boxing can elicit intense physiological responses while maintaining high enjoyment among users. Participants exceeded ACSM thresholds across METs, heart rate, and energy expenditure, and reported perceived exertion consistent with vigorous workloads. These findings indicate that an upper-body focused IVR modality such as TotF can produce intensities that align with or approach those observed in traditional vigorous exercise. High PACES scores further indicate that the immersive format supports positive affect, which is an important determinant of long-term adherence. The combination of strong physiological responses and positive affect suggests that IVR boxing may appeal to individuals who struggle with motivation or adherence to more traditional exercise formats, or want a way to exercise effectively at home. These findings build on earlier work showing that exergaming can elicit vigorous-intensity workouts across several independent measures and that these outputs are consistent with values recorded in validated cardiopulmonary exercise testing research (Alcantara et al., 2022; Guimarães et al., 2019). Although the results are encouraging, the small sample and single-session approach limit their applicability. Future studies that include repeated sessions, larger and more diverse samples, and direct comparisons with established exercise modalities will be important for understanding whether these acute responses are sustainable and whether IVR boxing can be incorporated into structured training or intervention-based programs.

Conflicts of interest

We declare no conflicts of interest.

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