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Utilizing Active Video Games for Accurate Energy Expenditure Assessment in Physically Active Adults

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Abstract: This study validated the energy expenditure (EE) reported by the active video game (AVG) *Fitness Boxing 2: Rhythm & Exercise* by comparing it with indirect calorimetry (MC) in 50 university students (21.2 ± 2.0 years). Participants attended the laboratory on two occasions. During the first session, height (165.6 ± 9.1 cm), body weight (68.5 ± 15.6 kg), and maximal oxygen consumption (42.2 ± 8.2 mL/kg/min) were assessed using a progressive treadmill test. In the second session, participants completed 15 minutes of free-mode exercise on the AVG while connected to the metabolic cart, allowing for simultaneous collection of EE from both the game and indirect calorimetry. Heart rate (162.0 ± 20.5 bpm), perceived exertion (11.5 ± 2.5), and enjoyment (73.3 ± 7.3) were also measured. The results showed significant gender differences in EE ($p = 0.049$). Specifically, EE estimates differed between devices in women (AVG: 110.3 ± 25.3 kcal vs. MC: 95.3 ± 25.3 kcal; $p = 0.003$). Although no significant differences were observed in men, the moderate correlation coefficient ($r = 0.60$) and the standard error of measurement (19.5 kcal), which exceeded the minimal detectable change (5.5 kcal), indicate substantial measurement error. Overall, these findings suggest that the AVG presents considerable inaccuracy when estimating EE and therefore should not be used in clinical or diagnostic contexts. However, it may still serve as a useful tool for promoting exercise participation and adherence.

Keywords: Exergaming, Fitness Boxing, Metabolic Cart, Enjoyment, Validation.

1. Introduction

Despite substantial evidence linking physical activity (PA) to various health outcomes, many people remain insufficiently active (Posadzki *et al.,* 2020). A recent report indicated that approximately 1.8 billion people did not comply with the PA guidelines in 2023 (World Health Organization, 2024). The guidelines recommend adults do at least 150 minutes of moderate-intensity activity per week, 75 minutes of vigorous-intensity activity, or an equivalent combination to confer many of these benefits (Bull *et al.,* 2020). Insufficient PA minutes per week can impose an economic burden on healthcare systems of almost $47.6 billion between 2020 and 2030 (Santos *et al.,* 2023). Therefore, increasing PA levels by any means possible has become a primary goal for health organizations and researchers.

The importance of PA becomes more significant when individuals transition from inactivity to a moderately active lifestyle (Rhodes *et al.,* 2017). In its simplest form, PA includes any body movement (e.g., gardening, walking, biking) that increases energy expenditure (EE). Although it might seem simple to accumulate PA throughout the day by simply moving, many barriers have been identified as major contributors to the prevalence of low PA (Koh *et al.,* 2022). These barriers can be classified as internal or external. Internal barriers include personal factors such as lack of time, enjoyment, social support, and fear of injury. External barriers include factors such as weather, infrastructure, and lack of resources (Herazo-Beltrán *et al.,* 2017; Koh *et al.,* 2022). Additionally, technological advances—including video games, smartphones, and laptops—encourage more screen time, particularly in children and young adults. This behavior may be associated with reduced PA levels (Davies *et al.,* 2012; Nagata *et al.,* 2023). Although this may seem contradictory, certain video games, specifically active video games (AVGs), can improve PA levels by encouraging players to physically manipulate and interact with the game.

AVGs incorporate a variety of body movements, such as jumping, squatting, running in place, and side-stepping, which could help improve PA (Huang *et al.,* 2017). Several studies suggest that AVGs can facilitate reaching moderate PA levels during exercise sessions ranging from 10 to 30 minutes (Dutta & Pereira, 2015; Peng *et al.,* 2011; Sween *et al.,* 2014). However, AVGs that are primarily seated reduce the likelihood of achieving moderate-to-vigorous PA intensities (Hygen *et al.,* 2022). AVGs offer a range of interactive and enjoyable elements (e.g., music, landscapes, characters), which appear to increase motivation, enjoyment, individualization, and adaptability. This adaptability allows them to be tailored to an individual's needs, enabling users to train at their desired intensity level (Benzing & Schmidt, 2018). For example, Moholdt *et al.* (2017) found that compared to a brisk walk, an AVG session resulted in longer exercise duration (44 min *vs.* 17 min, respectively), higher heart rate maximum values ([HR_{max}]; 73% *vs.* 57%, respectively), more minutes spent at high intensity (12.5 min at 80%–89% of HR_{max} *vs.* 0.7 min at 70%–79% of HR_{max}, respectively), and greater relative EE (7.6 kcal *vs.* 6.2 kcal). Interestingly, the enjoyment level was also significantly higher for the AVG compared to the brisk walk (8.7 *vs.* 3.9). These findings align closely with those from other studies (Berg & Moholdt, 2020; Soares *et al.,* 2021; Sween *et al.,* 2014) comparing AVGs with conventional PA methods (e.g., running, cycling, weightlifting).

AVGs have proven to be effective tools for increasing PA participation and improving health outcomes across the lifespan (Benzing & Schmidt, 2018; Douris *et al.,* 2012; Pasco & Roure, 2022). Their popularity may be attributed to their affordability (e.g., US$100–US$299), ease of use, minimal space requirements, and wide variety of available platforms. A recent report indicated that the Nintendo Switch sold approximately 19 million units worldwide between 2017 and 2022, making it one of the best-selling gaming consoles during that period (Statista, 2024).

Recent technological advancements have enabled AVGs to provide physiological estimates such as heart rate and EE. More broadly, advances in immersive technologies and consumer-based monitoring systems have expanded opportunities for home-based exercise. For example, virtual reality fitness platforms and wearable devices are increasingly capable of estimating physiological responses, PA intensity, and EE outside laboratory environments (Johansen *et al.,* 2023; Craig *et al.,* 2024; Howard *et al.,* 2025; Lampropoulos *et al.,* 2025). Despite these advances, concerns remain regarding the accuracy of consumer-generated physiological metrics, particularly when such estimates are used to guide exercise participation, monitor training load, or support weight-management decisions.

Historically, studies evaluating these outcomes relied on external devices, including heart rate monitors, metabolic carts, and accelerometers, while participants engaged in AVG-based exercise (Bailey & McInnis, 2011; Dutta & Pereira, 2015; Graves *et al.*, 2010; Gu *et al.,* 2023; Haddock *et al.*, 2012; Kim *et al.*, 2022; Lee *et al.,* 2017; Peng *et al.,* 2011; Sween *et al.,* 2014; Wu *et al.,* 2015). For example, one of the earliest studies examining AVG-derived physiological responses reported that 30 minutes of exergaming performed five days per week was sufficient to meet the American College of Sports Medicine PA recommendations (Haddock *et al.,* 2012). Since then, many AVG systems have incorporated proprietary algorithms to estimate heart rate and EE without external monitoring equipment. However, concerns remain regarding the accuracy of these estimates. For example, Borges Viana *et al.* (2019) reported that the EE provided by an exergame was nearly double that measured by indirect calorimetry. Their Bland–Altman analysis further revealed substantial bias, wide limits of agreement, and increasing disagreement between methods as EE increased. More recently, Kim *et al.* (2022) found that AVG-reported heart rate overestimated exercise intensity compared with electrocardiogram-derived values. These findings raise concerns because users may rely on inaccurate physiological feedback to guide exercise intensity, monitor caloric expenditure, or evaluate progress toward PA recommendations. Given that EE estimates from exergames may inform exercise programming, weight-management strategies, and dietary planning, establishing the validity of these measurements is essential before they can be confidently applied in health, fitness, or clinical settings.

Although new AVG systems provide EE readings, equipment such as the metabolic cart remains the gold standard for measuring many physiological parameters, including EE through indirect calorimetry. EE is an important variable to consider in daily life and during PA because it reflects the metabolic cost of movement, determines total daily energy balance, and is closely linked to weight maintenance, cardiometabolic health, and accurate exercise prescription (del-Cuerpo *et al.*, 2023; Smart *et al.*, 2018). Accurate EE estimates are particularly important when individuals aim to meet PA guidelines, regulate body weight, or monitor exercise load, as incorrect EE values can lead to inappropriate exercise intensities or misleading perceptions of training benefits (Howard *et al.*, 2025).

Therefore, equipment that provides a strong validity and reliability for quantifying exercise intensity and EE (Thiessen *et al.*, 2025) such as the metabolic carts COSMED Quark CPET or Parvo Medics TrueOne 2400 are important resources to consider when precise physiological measurements are required for clinical decision-making, exercise testing, or research applications involving oxygen consumption and cardiometabolic function. However, their accessibility is limited by high cost, the need for qualified personnel, regular calibration and maintenance, and limited availability outside laboratory or clinical settings (Alcantara *et al.*, 2022). This lack of accessibility contrasts with the widespread availability of AVGs, which cost less than US$300 and can be used at home without technical expertise, while simultaneously providing EE readings among their outcomes. Because these consumer-grade EE estimates are algorithm-based and do not rely on direct measures of metabolism, their accuracy remains uncertain and may vary according to user characteristics, game mode, or movement type (Kim *et al.*, 2022; O'Driscoll *et al.*, 2020).

To date, only one study has directly validated EE estimates from a Nintendo Switch exergame against both a heart rate monitor and indirect calorimetry. Moreno *et al.* (2024) reported acceptable agreement among Ring Fit Adventure, a Polar FT7 heart rate monitor, and a COSMED metabolic cart, suggesting that some commercially available exergames may provide reasonably accurate physiological estimates. However, these findings may not generalize to other Nintendo Switch-based exergames because gameplay mechanics, exercise modalities, and motion-tracking technologies vary substantially (Benzing & Schmidt, 2018; Peng *et al.*, 2011). Ring Fit Adventure uses both handheld Joy-Con controllers and a lower-body leg strap equipped with motion sensors, enabling simultaneous detection of upper- and lower-body movements. In contrast, *Fitness Boxing 2: Rhythm & Exercise* relies primarily on handheld Joy-Con controllers to track punching movements and rhythmic exercise patterns. Because EE during exercise is strongly influenced by the amount and intensity of lower-body involvement (Reis *et al.*, 2017), differences in sensor placement and movement detection may influence the accuracy of calorie-expenditure algorithms. Moreover, the only previous Nintendo Switch-based validation study evaluated Ring Fit Adventure during moderate-intensity gameplay (Moreno *et al.*, 2024), whereas boxing-based exergames have demonstrated the capacity to elicit vigorous-intensity activity (Wu *et al.*, 2015). Because physiological demands may influence the accuracy of EE prediction algorithms, validation findings obtained from one exergame cannot necessarily be extrapolated to another. Consequently, the validity of EE estimates from *Fitness Boxing 2: Rhythm & Exercise* cannot be assumed based on findings from Ring Fit Adventure or other AVG platforms. Therefore, independent validation of *Fitness Boxing 2: Rhythm & Exercise* is warranted before its EE estimates can be considered accurate for research, clinical, or fitness applications. Accordingly, the purpose of the present study was to validate the EE reported by *Fitness Boxing 2: Rhythm & Exercise* against indirect calorimetry (COSMED) in men and women and to assess enjoyment and perceived effort. It was hypothesized that the EE values reported by *Fitness Boxing 2: Rhythm & Exercise* would not differ significantly from those obtained using the reference method (metabolic cart) in either men or women.

2. Material and Methods

2.1 Participants

An a priori power analysis conducted using G*Power for a repeated-measures t-test with 6 participants indicated that a minimum of 48 participants would be needed to achieve sufficient power (0.95) to detect differences. A small effect size of 0.43 (Cohen's d) and an alpha level of 0.05 were assumed. A sample of 50 physically active and healthy college students (25 male and 25 female) was recruited for this study (Table 1). All participants were asked to report their health status, and all were essentially healthy, with no known chronic disease or physical limitations that would be worsened by participating in the AVG. This study was conducted in accordance with the ethical guidelines of the Declaration of Helsinki. It was reviewed and approved by the Teaching Support and Research Department from the Autonomous University of Baja California, under IRB approval P-01-2023-1. After completing data collection for all 50 participants (post hoc), a new statistical power analysis was conducted using a repeated-measures ANOVA with a within–between interaction based on the EE data. Using an effect size of 0.35, an alpha level of 0.05, two groups (men and women), two conditions (active video game and metabolic cart), and a correlation coefficient of 0.708 between conditions, the analysis indicated a high statistical power of 0.99.

2.2 Fitness Boxing 2 Rhythm & Exercise

It is a Nintendo Switch game that combines boxing exercises with rhythm gameplay. The AVG has two modes, daily workout and free training. Daily workouts offer customized routines based on player-set goals (e.g., lower body, upper body, or whole body). The free training allows players to select specific exercises, intensities, muscular groups, and music. The workouts can range from 10 to over 40 minutes in duration (Krane, 2021; Scullion, 2020). The AVG has incorporated a *Joy-Con* system to track player movement on each hand. The game provides an estimate of calories burned (Scullion, 2020), which is understood as EE for research purposes. For this research, the free training mode was chosen, as it allows for consistent routines across subjects, unlike the daily workout, which can only be performed once per day.

2.3 Procedures

All participants voluntarily read and signed an informed consent. The participants attended the [concealed to ensure masked review] on two separate occasions with an interval of at least 48 hours. On the first day, body height (cm) was measured with a BSM 170 stadiometer (Gangnam, South Korea), and body weight (kg), body fat (%), and muscle mass (kg) was measured with an InBody bioimpedance equipment model 770 (Gangnam, South Korea). Subsequently, maximum oxygen consumption (VO^2max = $mL \cdot kg^{-1} min^{-1}$) and heart rate maximum (HR_{max}) were measured with a graded exercise treadmill test (GXT) using a breath-by-breath COSMED metabolic cart (Quark CPET model, Rome, Italy) and a COSMED treadmill, model T200 (Rome, Italy). To ensure accurate EE estimation, a profile for each player was created in the *Fitness Boxing 2: Rhythm & Exercise*, based on weight, height, age, and gender.

On the second day, the participants were fitted with a heart rate monitor (Polar FT7). Immediately after, the resting heart rate was recorded along with the rating of perceived effort (RPE) using Borg's 6 (no exertion) to 20 (maximum effort) scale (Borg, 1982). Participants then performed 15 minutes of *Fitness Boxing 2: Rhythm & Exercise* (Nintendo, Kioto, Japan) in the free mode while connected to the COSMED Quark CPET metabolic cart. The 15-minute exercise duration was selected because it falls within the range of commercially available *Fitness Boxing 2: Rhythm & Exercise* training sessions and is consistent with previous AVG studies evaluating physiological responses and EE (Bailey & McInnis, 2011; Haddock *et al.,* 2012; Graves *et al.,* 2010).

Table 1. Sample characteristic

Variables	Male	Female	Total
Age	21.4 ± 2.0	21.8 ± 2.2	21.2 ± 2.0
Height (cm)	172.1 ± 6.4	159.0 ± 6.1	165.6 ± 9.1
Weight (kg)	74.6 ± 15.1	62.4 ± 13.9	68.5 ± 15.6
BMI	25.1 ± 4.2	24.5 ± 4.3	24.8 ± 4.2
HR_{max} (BPM)	195.4 ± 8.5	189.6 ± 8.0	192.5 ± 8.7
VO^2max (mL*kg*min)	46.7 ± 7.8	37.8 ± 5.7	42.2 ± 8.2

Notes: BMI, body mass index; HR_{max}, maximal heart rate; VO^2max, maximal oxygen consumption.

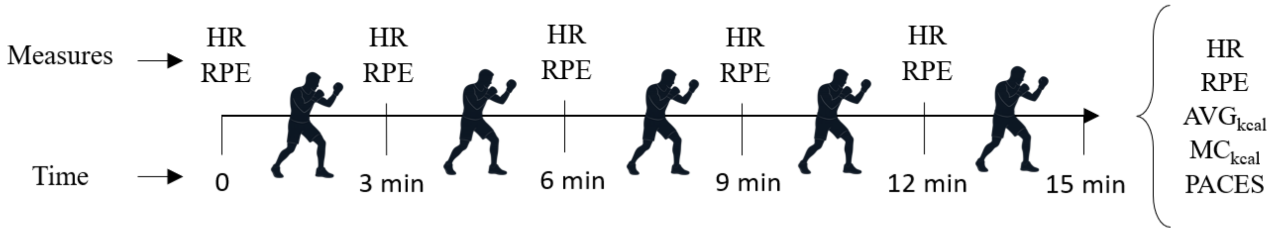

Figure 1. AVG protocol with the *Fitness Boxing 2: Rhythm & Exercise* (assessments every 3 minutes).

Notes: HR, heart rate; RPE, rating of perceived exertion; AVG$_{kcal}$, Active videogames kilocalories; MC$_{kcal}$, metabolic cart kilocalories; PACES, Physical Activity Enjoyment Scale.

Moreover, the primary purpose of the present study was to assess agreement between EE estimates obtained from the AVG and those from indirect calorimetry, rather than to evaluate compliance with PA recommendations.

Heart rate and RPE were recorded at 3-, 6-, 9-, 12-, and 15-minute intervals during the AVG. These values were used to calculate the heart rate mean (HR$_m$) and RPE mean (RPE$_m$). At the end of the exercise session, EE from the AVG (AVG$_{kcal}$) and the metabolic cart (MC$_{kal}$) were recorded. PA enjoyment was also assessed using the Physical Activity Enjoyment Scale (PACES) questionnaire (Moreno *et al.,* 2008) (Figure 1). This scale measures enjoyment during PA using 16 items; scores were summed (reverse-scoring for negative items) to yield an enjoyment score ranging from 16 to 80 (Carraro *et al.,* 2008). One researcher remained in the room throughout the session to assist participants and ensure correct exercise performance. It should be noted that none of the participants had previous experience with *Fitness Boxing 2* or other similar exergames.

2.4 Statistical Analysis

Data were analyzed using SPSS Statistics 23.0. Initial checks were conducted to identify outliers and assess the sampling distribution using the Kolmogorov-Smirnov test ($p < 0.05$). Descriptive variables, including age, height, weight, BMI, HR$_{max}$, VO^{2}max, HR$_m$, RPE$_m$, AVG$_{kcal}$, MC$_{kcal}$, and PACES, were expressed as the mean and standard deviation (mean±sd). A two-way mixed ANOVA was used to analyze gender (female and male) x measurements (AVG and metabolic cart), followed by Bonferroni correction for post hoc testing. The statistical significance was set at $p < 0.05$. For post hoc comparisons, Cohen's d effect sizes were calculated for male, female, and total groups, with interpretations as trivial (≤0.20), small (≤0.60), moderate (≤1.20), large (≤2.0), very large (≤4.0), and extra-large (>4.0). The intraclass correlation coefficient (ICC) was calculated to assess the reliability of AVG$_{kcal}$ and MC$_{kcal}$ using the following cutoffs: <0.50—poor reliability, 0.50-0.75—moderate reliability, 0.75-0.90—good reliability, and >0.90—excellent reliability (Koo & Li, 2016). Absolute reliability for AVG$_{kcal}$ and MC$_{kcal}$ was further evaluated through the typical error of measurement (TEM) and the smallest worthwhile change (SWC). The coefficient of variation (CV) and the mean absolute percentage error (MAPE) were also calculated, with thresholds defined as good (≤ 10%), moderate (10.1 - 20.0%), and poor (≥ 20%). Bland-Altman plots assessed measurement bias with 95% confidence intervals. Additionally, independent sample t-tests were conducted to compare AVG intensity, RPE, and PACES scores between genders.

3. Results

A two-way mixed ANOVA examining the effects of gender and measurement type on exergy expenditure revealed significant interactions (p= .049) and main effects for gender (female vs. male; p= .001) and measurement (AVG$_{kcal}$ and MC$_{kcal}$; p= .017). These findings indicate a gender-dependent difference in kilocalories across measurement methods, with females reporting different kilocalorie values between the AVG and the metabolic cart (Table 2).

The ICC indicated moderate reliability between the EE reported by the metabolic cart and the AVG (r= 0.703, p= .001) for both males (ICC= 0.595, p= .001) and females (ICC= 0.609, p= .001). However, the TEM was relatively high for both males (19.5 kcal) and females (13.7 kcal) compared with the SWC (5.5 kcal for males and 3.9 kcal for females), suggesting that the observed variation has practical significance (Table 3).

The CV (14.6%) and MAPE (17.0%) observed in the present study indicate that the AVG may misestimate EE by approximately one-sixth of the true value. From a practical perspective, this degree of error is substantial when caloric expenditure is used for exercise prescription, weight-management interventions, or clinical monitoring, as it may lead to inaccurate estimates of exercise dose. Although no universal cutoff exists for acceptable EE error, lower percentage errors are generally preferred for physiological monitoring, and the values observed in this study suggest insufficient accuracy for individual-level decision making. Conversely, in recreational exergaming, where the primary objective is to encourage PA rather than precisely quantify caloric expenditure, this degree of error may be less consequential (Table 4).

The Bland-Altman plot showed a constant and normal variance around the mean differences, suggesting that both equipment estimates kilocalories similarly between AVG_{kcal} and MC_{kcal} in males (Figure 2) and females (Figure 3).

No significant differences in mean heart rate were found during the AVG session between males (159.6 ± 22.4 bpm) and females (164.4 ± 18.2 bpm; p= .386; d= 0.148), indicating that all participants performed the exercise session with the AVG at the same intensity (male 81% and female 87% HR_{max}, See Table 4). Similarly, no differences were found in perceived effort during the AVG session between males (11.6 ± 2.3) and females (11.3 ± 2.7; p= .060; d= 0.156, Table 5). Lastly, PA enjoyment with the AVG was similar for males and females (74.0 ± 5.6 and 72.7 ± 8.8, respectively; p= .586, d= 0.174). The findings suggest that males and females demonstrated similar enjoyment of physical exercise with the AVG, at 92.5% and 91.3%, respectively.

Table 2. Pairwise comparison between conditions (AVG_{kcal} and MC_{kcal}) for males, females, and the total

	Males	**Females**	**Total**
AVG_{kcal}	133.8 ± 29.4	110.3 ± 25.3	122.0 ± 29.6
MC_{kcal}	132.3 ± 30.5	95.3 ± 25.3	113.8 ± 33.5
%Δ	1.1	13.6	6.7
p =	0.757	0.003	0.021
Cohen's d	0.050	0.593	0.259
	Trivial	Small	Small

Notes: AVG_{kcal}, Active videogames kilocalories; MC_{kcal}, metabolic cart kilocalories; %Δ, mean difference.

Table 3. Agreement analysis of energy expenditure for males, females, and the total sample of participants.

	ICC	**ICC 95%CI**	**TEM (kcal)**	**SWC (kcal)**
Males	0.60	0.26 - 0.80	19.5	5.5
Females	0.61	0.14 - 0.83	13.7	3.9
Total	0.68	0.49 - 0.81	17.2	4.9

Notes: ICC, Intraclass correlation; TEM, Technical error of measurement; SWC, Smallest worthwhile change.

Table 4. Percentage variation (CV% and MAPE%), and adjusted average ranges (CV_{kcal} and $MAPE_{kcal}$) of energy expenditure obtained with the AVG.

	CV%	**CV_{kcal}**	**MAPE%**	**MAPE% 95%CI**	**$MAPE_{kcal}$**
Male	14.5	114.4 - 153.2	16.4	12.17 - 21.01	111.9 - 155.7
Female	13.3	95.6 - 125.0	17.7	12.13 - 23.98	90.8 - 129.8
Total	14.6	104.2 - 139.8	17.0	13.4 - 20.71	99.2 - 144.8

Notes: AVG_{kcal}, Active videogames kilocalories; CV, Coefficient of variation; MAPE, Mean absolute percentage error.

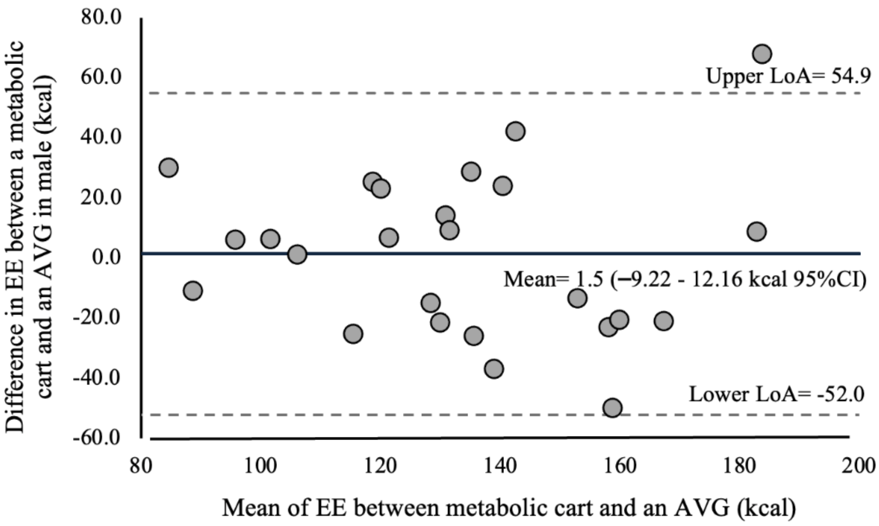

Figure 2. Bland-Altman plot for kilocalories estimated with the AVG and the metabolic cart in males.

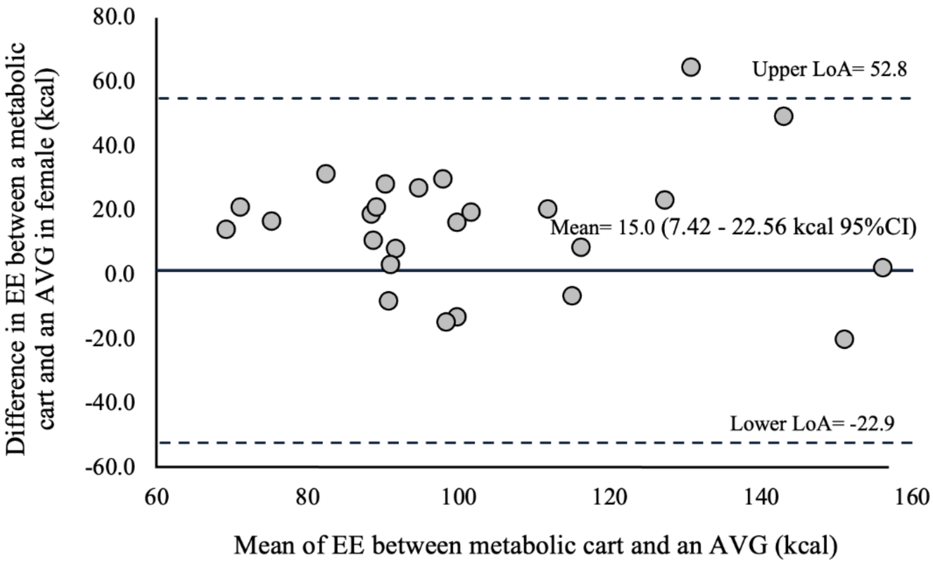

Figure 3. Bland-Altman plot for kilocalories estimated with the AVG and the metabolic cart in females.

4. Discussion

The main finding was that *Fitness Boxing 2: Rhythm & Exercise* demonstrated moderate agreement with indirect calorimetry when estimating EE in males and females. Although ICC values indicated moderate reliability, the relatively high TEM and moderate MAPE/CV values suggest that the game's EE estimates may lack the precision required for clinical, diagnostic, or research applications where accurate caloric expenditure is essential. However, *Fitness Boxing 2: Rhythm & Exercise* effectively enables high-intensity exercise while eliciting low perceived effort and high enjoyment.

Previous studies have shown that AVGs increase EE relative to baseline in children and young adults (Bailey & McInnis, 2011; Craig *et al.,* 2024; Siegel *et al.,* 2009). Our findings are consistent with this literature, even after 15 minutes of exercise with *Fitness Boxing 2: Rhythm & Exercise*. As in Siegel *et al.* (2009), males exhibited higher EE than females, which is expected given well-established sex differences in lean mass, body size, body composition, and hormonal influences on metabolism (Cunningham, 1980; Johnstone *et al.,* 2005; Wang *et al.,* 2000; Zunzer *et al.,* 2013). In our sample, however, females showed a statistically significant discrepancy of approximately 15 kcal between AVG-estimated EE and that measured by indirect calorimetry. Although this difference was statistically significant, its standardized magnitude was small (Cohen's d = 0.593), suggesting that the average discrepancy between methods was modest. Nevertheless, statistical significance alone does not determine the practical importance of a finding. When interpreted alongside the elevated TEM, CV, and MAPE values, even a relatively small standardized difference may have meaningful implications for applications requiring accurate caloric estimation, including exercise prescription, weight-management interventions, and clinical monitoring. This difference may reflect natural within-sex variability rather than a systematic sex effect, particularly given that our sample (n = 50) was substantially larger than that of Siegel *et al.* (2009); n = 13). It is also possible that unmeasured factors unique to females contributed to the observed variability in EE estimates. For example, estrogen and progesterone influence resting metabolic rate, substrate utilization, and exercise EE, with studies reporting differences of approximately 40–44 kcal between the luteal and follicular phases of the menstrual cycle (Dokumacı & Hazır, 2019; Löfberg *et al.*, 2024; Rogan & Black, 2022). Because the menstrual cycle phase was not standardized or recorded in the present study, participants were likely assessed at different hormonal stages, which may have increased within-group variability and partially contributed to the discrepancy observed between the AVG and the metabolic cart. However, our study design does not allow us to determine whether the menstrual cycle phase was responsible for these findings; therefore, this explanation should be interpreted with caution. Future validation studies should standardize or record the menstrual cycle phase to better isolate its potential influence on EE estimation. Furthermore, no recent studies have examined the validity of EE estimates generated by the AVG technology used in the present study against indirect calorimetry. Earlier investigations relied on gaming consoles and hardware developed more than a decade ago, which differ substantially from the system evaluated here. Although AVG technology has advanced considerably over time, our findings suggest that meaningful variability in EE estimation persists. Consequently, caution is warranted when using AVG-derived EE values in contexts that require precise estimates of caloric expenditure.

Our main hypothesis was that EE values reported by the video game *Fitness Boxing 2: Rhythm & Exercise* would not differ significantly from those reported by the gold-standard method (metabolic cart) in males and females. Although Bland–Altman plots showed consistent variance around the mean difference between measures, the moderate ICC and relatively high error indices (TEM, MAPE) contradicted this hypothesis and indicated low practical accuracy (See Table 3 and Table 4). This is consistent with the broader literature showing that exertion involving both upper- and lower-body movements leads to a higher metabolic cost (Graves *et al.*, 2008; Graves *et al.*, 2008, 2010). A key methodological factor that may explain the discrepancy is the configuration of the movement-tracking system. However, because the proprietary EE estimation algorithm used by *Fitness Boxing 2: Rhythm & Exercise* is not publicly disclosed, the extent to which movement-tracking data, participant characteristics, and exercise intensity contribute to the reported EE values remains unknown. Moreno *et al.* (2024) provided early evidence of acceptable validity for *Ring Fit Adventure* using *Joy-Con* sensors mounted on a resistance ring (upper body) and a leg strap with an accelerometer (lower body). In contrast, our study relied solely on handled *Joy-Con*s, which limits the detection of lower-body movements, and therefore affects readings of major contributions for EE during exercise (Reis *et al.*, 2017). Additionally, the Joy-Cons used in the present protocol lacked dedicated motion-capture accelerometers, further constraining the system's ability to quantify movement-derived kcal expenditure. Supporting this, Reis *et al.* (2017) demonstrated that even low-intensity half-squat movements produce higher metabolic costs than a wide range of machine-based upper- and lower-body exercises. Thus, the inability to capture lower-body movement likely contributed meaningfully to the underestimation of EE observed in our study, particularly among participants who engaged their legs more vigorously than the sensors could detect. The Bland–Altman analysis showed a relatively small mean bias, but the limits of agreement were wide (approximately ±53 kcal in males and ±38 kcal in females around the mean bias), indicating substantial individual variability in EE estimation. From a practical perspective, these limits suggest that the AVG may considerably overestimate or underestimate EE for a given user, despite acceptable average agreement at the group level. Such variability limits its clinical applicability for exercise prescription, weight-management programs, or situations where accurate caloric expenditure is required. Conversely, for recreational exercise or interventions primarily aimed at increasing PA participation and enjoyment, this degree of error may be less consequential because precise EE estimation is not the primary objective.

The findings from our study further demonstrate that *Fitness Boxing 2: Rhythm & Exercise* elicited high enjoyment and relatively low perceived effort, consistent with previous work in young adults (Hassan *et al.*, 2023; Moreno *et al.*, 2024). Participants reported a mean RPE of 11.5 on the RPE scale (Borg, 1982), despite exercising at vigorous intensity (84% HR_{max}, 162 bpm). This dissociation between physiological demand and subjective effort has been documented in traditional boxing contexts, where similar heart-rate intensities (79-83% HR_{max}) are typically associated with RPE values ranging from "very hard" (17) to "maximal exertion" (20). In line with ACSM guidelines emphasizing exercise intensity as a primary driver of cardiovascular adaptations (Armstrong, 2006; Liguori, 2020). These findings indicate that AVGs can deliver a substantial psychological stimulus while reducing perceived exertion. This effect mirrors results from studies comparing AVGs with traditional modalities such as treadmill walking (McDonough *et al.*, 2018) and stationary cycling (McDonough *et al.,* 2020), in which AVGs consistently produce lower RPE at a given workload.

High enjoyment further reinforces this pattern, as enjoyment is a key determinant of PA maintenance (Dunton & Vaughan, 2008; Williams *et al.*, 2006). Flow Theory provides a conceptual explanation for these results: immersive audiovisual cues and real-time feedback can absorb attention, narrowing perceived effort and promoting sustained engagement (Martin-Niedecken & Mekler, 2018; Nakamura & Csikszentmihalyi, 2014; Sweetser & Wyeth, 2005). The dynamic audio–visual environment of *Fitness Boxing 2: Rhythm & Exercise* likely contributed to this effect, consistent with evidence from exergames incorporating rhythmic or interactive features (Warburton *et al.,* 2007).

Taken together, this inverse relationship between enjoyment and RPE has meaningful implications for long-term PA adherence, as positive affective responses strongly predict future participation (Dishman *et al.,* 2005; Williams *et al.,* 2008). Given the rising sedentary behavior among young adults and its associated health risks (Huang *et al.,* 2022), AVGs may serve as an accessible, enjoyable option for promoting engagement in moderate-to-vigorous PA. It is noteworthy that participants accumulated AVG_{kal} (122 kcal) and MC_{kal} (113.8 kcal) after only 15 minutes of gameplay. These values approached the lower bound of the American College of Sports Medicine's recommended EE for a typical exercise session in healthy adults (150-400 kcal) (Armstrong, 2006; Haskell *et al.,* 2007). These outcomes, which are consistent with those reported by Bailey and McInnis (2011) and Haddock *et al.* (2012), reinforce the potential of AVGs to help individuals achieve guideline-consistent activity doses.

To the best of our knowledge, the strengths of the current study lie in its novel assessment of EE in an AVG that elicited heart rate values resembling those of high-intensity exercise. Several limitations warrant consideration. First, the study did not standardize the menstrual cycle phase in female participants, which may have introduced additional variability in EE. Second, *Fitness Boxing 2: Rhythm & Exercise* is structured around rhythmic music that may influence movement tempo and exertion, yet its specific contribution was not isolated. Third, the proprietary algorithm used by *Fitness Boxing 2: Rhythm & Exercise* to estimate EE is not publicly available. Consequently, it is not possible to determine how variables such as body mass, age, movement frequency, exercise intensity, or controller-derived motion data contribute to the calculation of caloric expenditure. This limitation restricts the interpretation of the observed discrepancies between the AVG and indirect calorimetry and prevents the identification of the specific sources of measurement error. Fourth, participants were inexperienced with AVGs, which may have temporarily elevated enjoyment scores (i.e., PACES) due to novelty effects (Soltani *et al.,* 2021). Future studies should account for menstrual cycle phase, gaming experience, and game-specific design features to further improve the internal validity of AVG validation research. Fifth, the sample consisted exclusively of physically active, healthy university students, which may limit the generalizability of the findings to other populations. Therefore, future studies should examine the validity and user experience of *Fitness Boxing 2: Rhythm & Exercise* in sedentary adults, older individuals, and clinical populations before these findings are generalized beyond healthy, physically active young adults.

The present findings have several practical implications for fitness professionals, coaches, and exercise practitioners. First, *Fitness Boxing 2: Rhythm & Exercise* appears capable of eliciting vigorous-intensity exercise while maintaining high enjoyment and relatively low perceived exertion. Therefore, the game may serve as a useful tool to increase exercise participation among individuals reluctant to engage in traditional exercise modalities. Second, although the game provides EE estimates, practitioners should interpret these values with caution, as measurement error may limit their precision in exercise prescription, caloric tracking, or weight management. Although the standardized differences between methods were generally small, the observed measurement error indicates that these estimates should not be interpreted as clinically precise measurements of caloric expenditure. Instead, they may be better viewed as approximate feedback intended to motivate participation in PA rather than to support individualized clinical, nutritional, or exercise-prescription decisions. Consequently, *Fitness Boxing 2: Rhythm & Exercise* may currently be more appropriately used as a motivational and engagement tool rather than as a precise method for monitoring caloric expenditure. Finally, the high enjoyment scores observed in the present study suggest that exergames may represent a viable strategy for promoting long-term adherence to PA programs, particularly among healthy, physically active adults.

5. Conclusions

In conclusion, *Fitness Boxing 2: Rhythm & Exercise* showed moderate agreement with indirect calorimetry in estimating EE, but the observed measurement error suggests that its estimates should be interpreted with caution. Although the game may provide a general indication of caloric expenditure during exercise, its precision may be insufficient for clinical applications, research settings, or situations that require accurate EE monitoring. Nevertheless, the *Fitness Boxing 2: Rhythm & Exercise* elicited vigorous-intensity exercise, low RPE, and high enjoyment, supporting its potential as an enjoyable and accessible tool for promoting participation in and adherence to PA. Future studies should continue to evaluate the validity of EE estimates in other exergame platforms and exercise conditions, as findings from a single game should not be generalized to active video games as a whole. Additionally, future research should examine the validity and user experience of *Fitness Boxing 2: Rhythm & Exercise* in sedentary adults, older individuals, and clinical populations before these findings are generalized beyond healthy, physically active young adults.

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Authors' contributions

Jorge A. Aburto-Corona: Conceptualization, Methodology, Formal analysis, Investigation, Writing – Original Draft. Roberto Espinoza-Gutiérrez: Methodology, Investigation, Writing – Review & Editing. Juan J. Calleja-Núñez: Methodology, Investigation, Writing – Review & Editing. Miguel Betancor-León: Writing – Review & Editing. Antonio S. Almeida-Aguiar: Writing – Review & Editing. Kevin Vázquez del Castillo: Writing – Review & Editing. Daniel Rojas-Valverde: Writing – Review & Editing. José Trejos-Montoya: Writing – Review & Editing. Bryan Montero-Herrera: Conceptualization, Methodology, Writing – Original Draft. All authors read and approved the final versions of this manuscript.

Ethics approval and consent to participate

This study was performed following the ethical guidelines of the Helsinki Declaration. It was reviewed and approved by the Teaching Support and Research Department from the Autonomous University of Baja California, under the IRB approval P-01-2023-1.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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