Energy expenditure and affect responses to different types of active video game and exercise

Javier Monedero*, Enda E. Murphy, Donal J. O’Gorman

School of Health and Human Performance, Faculty of Science and Health, Dublin City University, Dublin, Ireland

*javier.monedero@dcu.ie

Abstract

Background
The purpose of this study was to compare entertainment-themed active video game (AVG) and fitness-themed AVG play with traditional exercise to examine the interaction between physiological and psychological responses.

Methods
Participants (N = 23) were randomly assigned to 30-min of (i) self-selected intensity exercise (SS-EX), (ii) moderate intensity exercise (MOD-EX), (iii) entertainment-themed video game (ET-VG) and (iv) fitness-themed video game (FT-VG). Physiological and psychological outcomes were recorded before, during and after each trial.

Results
All trials met the ACSM criteria for moderate or vigorous physical activity. The % VO₂R (68.3±13.9%) and rate of energy expenditure (10.3±3.1kcal/min) was significantly higher in the SS-EX trial with lowest values reported for ET-VG (p<0.05). No differences were found in % heart rate reserve between SS-EX and FT-VG (66.9±12.5% and 67.1±6% respectively). The AVG’s were significantly more enjoyable than the exercise trials (p<0.05) and the ET-VG resulted in the highest core flow and psychological well-being (p<0.05).

Conclusion
AVG’s can elicit physiological responses that meet recommended exercise intensities but are more enjoyable than conventional exercise in young inactive adults. While further work is required, this study highlights the importance of examining the interaction between physiological outcomes and psychological states to increase physical activity and reduce sedentary time.
Introduction

Physical inactivity and sedentary behaviour are independent predictors of all-cause mortality and the development of non-communicable diseases[1]. Physical inactivity was responsible for 3.2 million deaths and 2.8% of disability adjusted life years (DALYs) in 2010 and was tenth on the list of global health risks[2]. Similarly, sedentary behaviour, defined as an energy expenditure ≤1.5 METs while sitting or lying [3], is associated with increased risk of diabetes, cardiovascular disease and all-cause mortality[1]. One of the major societal challenges is to increase physical activity levels and the best health outcomes may be achieved by substituting sedentary time.

The determinants of physical activity participation and adherence are multifactorial and complex[4]. A better understanding of the interaction between psychological determinants and physiological outcomes is necessary to design more innovative and effective strategies to increase physical activity. Affective judgements and perception of effort during an acute exercise session are determinants of intention and future exercise behaviour [5, 6]. Affective judgements refer to self-reported measures of enjoyment, pleasure or displeasure and feeling state that results from engaging in physical activity. Williams et al. [7] showed that affective judgements to moderate intensity exercise (feeling scale score) was a good predictor of exercise behaviour 6 to 12 months later. Also, Vazou-Ekkekais suggests that “the optimization of affective response should be taken into account when recommending or prescribing PA to the public”[8]. In addition, an individual’s perception of effort is, to a certain extent, a determining factor of exercise adherence[9].

One of the most reported affective judgements in the literature is enjoyment. According to Wankel[10], enjoyment plays a central role in the promotion of exercise adherence and psychological well-being. Negative affective judgements can be a contributing factor to the 40–65% of dropout rates within the first 3–6 months of commencing an exercise programme[11, 12]. An exercise prescription that leads to health enhancement and positive affective judgements is most likely to result in high adherence rates. In the context of affective judgements related to physical activity, the dual-mode model theory by Ekkekakis needs to be considered [13, 14]. This theory suggest that affective responses to exercise are influenced by the continuous interplay of cortically mediated cognitive processes (e.g., self-efficacy, self-presentational concerns, goals, attributions) and ascending interoceptive cues (e.g., ventilation, acidosis, core temperature). Positive affect states decrease as the ventilatory threshold (VT) stage is reached and passed.

There is potential for a relatively new technology, active video games (AVGs) to have a tangible impact on physical activity and reducing sedentary time while maintaining or enhancing enjoyment. Active video games require the player to get off the couch and move to be able to play. Approximately 42% of Americans play video games regularly or at least 3 hours per week [15]. In addition to this, the average age of the most frequent purchaser is 35 years old. There is strong evidence that AVGs result in higher heart rate (HR), oxygen consumption (VO₂) and energy expenditure (EE) in adults and children[16–18] than traditional sedentary video game play. Also, a growing number of studies have shown that AVGs elicit light-to-vigorous intensity exercise and some have suggested that they could be a contributor to health enhancing physical activity[18–23]. There has been a proliferation of fitness and entertainment-themed AVGs in the market over the last few years. While there is some data on the physiological stimulus and affective judgements associated with playing different types of AVG, there are a lot of unknown aspects. Affective judgments like flow or psychological well-being while playing different types of AVG play has not been studied. The state of flow represents a condition of supreme enjoyment in which the participant is immersed in the task at hand.
The aim of this study is to compare the physiological responses and affective judgements during conventional exercise and while playing AVGs (fitness-themed and entertainment-themed). Our hypothesis is that the AVGs will result in similar rates of energy expenditure and more positive affective judgements than conventional moderate exercise intensity and that AVGs provide an adequate stimulus to meet the PA guidelines for healthy adults.

Materials and methods

Participants

Twenty-three young, healthy men and women volunteered to take part in this study. Participants were excluded if they were >45 yrs, smoked cigarettes, performed >1 exercise session per week in the previous 6 months or had a VO₂ max in the top 40th percentile for their age and sex. Participants completed a Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) [24], and a general health questionnaire. The study was approved by the Dublin City University Research Ethics Committee (DCUREC/2011/071), complied with the Declaration of Helsinki (2013) and all participants provided written informed consent.

Experimental overview

Participants reported to the laboratory on 6 days separated by at least 48 h (see Fig 1). They were asked to refrain from consuming alcohol for at least the 24 h prior to each visit and from the ingestion of food, caffeinated products and tea for 3 h before each visit. The first two visits were used to measure maximal aerobic capacity, to verify the exercise intensity and to familiarize participants with the AVGs. After this, participants reported to the laboratory where they performed 4 trials using a randomized, cross-over design. The order of trials was determined using an online randomisation tool [25]. The participants remained seated for 10 min prior to and for 20 min after completing 30 min of (i) running at a self-selected exercise intensity (SS-EX); (ii) running at 55% VO₂ Reserve (MOD-EX); (iii) playing an entertainment themed video game (ET-VG) and (iv) playing a fitness themed video game (FT-VG).

An incremental maximal test was used to determine VO₂ max using open-circuit spirometry (K4B2, Cosmed, Rome, Italy). Participants were also fitted with a heart rate monitor (Polar RS400, Polar, Oulu, Finland). The protocol consisted of a 3 min warm-up followed by 2 min incremental stages until the participant reached volitional fatigue. The VO₂ max was considered to have been reached using ACSM guidelines [26]. On a separate occasion, the speed corresponding to 55% VO₂ R was determined for the MOD-EX trial. Participants ran for 10 min at three different speeds: 1 km/h below the predicted speed, at the predicted speed and 1 km/h above the predicted speed, and the speed that elicited the greatest heart rate was selected for the trial.

An incremental maximal test was used to determine VO₂ max using open-circuit spirometry (K4B2, Cosmed, Rome, Italy). Participants were also fitted with a heart rate monitor (Polar RS400, Polar, Oulu, Finland). The protocol consisted of a 3 min warm-up followed by 2 min incremental stages until the participant reached volitional fatigue. The VO₂ max was considered to have been reached using ACSM guidelines [26]. On a separate occasion, the speed corresponding to 55% VO₂ R was determined for the MOD-EX trial. Participants ran for 10 min at three different speeds: 1 km/h below the predicted speed, at the predicted speed and 1 km/h above the predicted speed, and the speed that elicited the greatest heart rate was selected for the trial.

Fig 1. Schematic of study protocol.

https://doi.org/10.1371/journal.pone.0176213.g001
above the predicted speed. The \( \% \text{VO}_2 \text{R} \) was determined by using the linear function, \( y = mx + c \), where \( y \) is \( \text{VO}_2 \), \( x \) is treadmill speed, \( m \) is the slope of the relationship between \( \text{VO}_2 \text{R} \) and treadmill speed and \( c \) is the \( y \)-axis intercept.

The active video game trials were played using XBOX 360 (Microsoft Corp, Redmond, USA). This platform was chosen because it offers a wide range of entertainment and fitness-themed video games. The ET-VG trial used Kinect Adventures (Microsoft Corp, Redmond, USA) while the FT-VG used Your Shape Fitness Evolve (Ubisoft, Surrey, UK). A summary of the games and the number of times they were played is outlined in the supporting information file (S1 Appendix). Immediately after completing the 30 min run or play, participants sat down and filled in the psychological questionnaires.

In the SS-EX trial, participants were told that they could select the speed of the treadmill for the first minute of every 5 min block while the gradient was kept constant at 1%. Participants were instructed to select an intensity that they would be able to maintain for 30-min and were made aware that they could alter the speed every 5 min. In the MOD-EX trial, participants exercised at a constant speed that was determined during the familiarization session. The intensity of 55\% \text{VO}_2 \text{Reserve} was selected because it corresponds to moderate intensity exercise and it was below the ventilatory threshold in a similar cohort to the one used in this study (unpublished data).

Baseline measures were obtained by averaging the last 3 min of the 10 min data collection at rest prior to each trial. During trials data was averaged for the entire 30-min trial and in two 15-min segments. The rate of energy expenditure was estimated using the following formula as calculated by the Cosmed K4B2 using the abbreviated Weir equation assuming urea nitrogen was zero [27]:

\[
EE \ (\text{Kcal} \cdot \text{min}^{-1}) = (3.781 \times \dot{\text{VO}}_2) + (1.237 \times \dot{\text{VCO}}_2) \text{ if urea nitrogen} = 0
\]  

(1)

Heart rate reserve and \( \text{VO}_2 \) reserve (\( \text{VO}_2 \text{R} \)) were calculated using standardised equations [26]. Individual ventilatory threshold (VT) was calculated by the function available in the Cosmed K4B2 software, which is based on the \( V \)-slope method [28]. The \% \text{VO}_2 \text{max} above or below VT during the trials was calculated using the following formula:

\[
\% \text{VT} = \left( \frac{((\dot{\text{VO}}_2 \text{ trial } - \dot{\text{VO}}_2 \text{ VT}) \times 100)}{\dot{\text{VO}}_2 \text{ VT}} \right)
\]  

(2)

where \( \% \text{VT} \) = \% \text{VO}_2 \text{max} above or below the \( \dot{\text{VO}}_2 \text{ VT} \), \( \dot{\text{VO}}_2 \text{ trial} \) = average oxygen uptake during the trial in L/min, \( \dot{\text{VO}}_2 \text{ VT} \) = oxygen uptake at VT in L/min.

The interest/enjoyment subscale of the Intrinsic Motivation Inventory was used to measure enjoyment. This scale has been used in other AVG [29] and exercise studies [30] and has been found to be a valid and reliable measure. Participants ranked their agreement with each statement on a 7-point Likert scale during and immediately after each trial. Responses were averaged to create the enjoyment score (range = 1–7). At 15 min, participants were asked to step off the treadmill or stop playing while they filled in the scale.

The State of Flow represents a condition of supreme enjoyment in which the individual is immersed in the task. Participants filled in the Core Flow State Scale (CFSS) to measure the state of flow [31]. The CFSS contains 10 items that are descriptions of what it feels like to be immersed in an activity. This scale is designed to be used as a post-event flow assessment therefore responses were provided immediately after completing each trial.

We used the 15 point Borg Rate of perceived exertion (RPE scale) to determine participants’ level of exertion at min 15 and 29 during each trial.
Psychological well-being was measured with the Subjective Exercise Experience Scale (SEES). This scale has been used in previous exercise studies [32] and video games studies [33]. This is a 12-item questionnaire that is scored on a 7-point Likert- scale. The SEES provides three subscales: 1) psychological well-being (great, positive, strong, terrific); 2) psychological distress (awful, crummy, discouraged, miserable); and 3) fatigue (drained, exhausted, fatigued, tired). Though the SEES is a reliable tool for psychological well-being there are some conceptual and methodological criticisms[34]. We measured psychological distress and fatigue but we are not reporting the data as the internal validity was not acceptable.

Statistical analysis
All tabular values are reported as the mean ± SEM and significance set at p<0.05. All data were tested for normal distribution (Shapiro-Wilk test) and the Greenhouse Geisser correction for degrees of freedom was applied when sphericity was not met. To investigate differences within subjects by trial and by time, we performed a mixed design ANOVA with sex as a between-subjects variable. Multiple comparison tests were computed using the Bonferroni correction. Unpaired t-tests were used to detect significant differences in subject characteristics. A Spearman correlation was used to assess the relation between enjoyment and ventilatory threshold.

Results
Participant characteristics
As expected, the men were heavier, had a lower body fat and a higher aerobic capacity when compared to the females. They were also older than the females but had a similar BMI, HRrest and HRmax. The physical characteristics of the participants are summarised in Table 1.

Table 1. Physical characteristics and cardiorespiratory responses during \( \text{VO}_2\text{max} \) test.

|                          | Male (n = 11) | Female (n = 12) | All (n = 23) |
|--------------------------|--------------|----------------|-------------|
| Age (yrs)                | 26.8±1.4     | 22.9±1         | 24.8±1      |
| Height (m)               | 1.78±0.08a   | 1.65±0.05      | 1.70±0.09   |
| Weight (kg)              | 84.8±4.6a    | 69.1±2.6       | 76.6±3      |
| BMI (kg.m\(^{-2}\))      | 26.4±1.2     | 25.3±0.9       | 24.8±1.3    |
| Body fat (%)             | 19.1±1.9a    | 32.2±1.4       | 25.9±1.8    |
| HRrest (beats min\(^{-1}\)) | 60±3         | 62±2           | 61±2        |
| HRmax (beats min\(^{-1}\)) | 198±2.1      | 193.8±2.1      | 195.8±1.5   |
| \( \text{VO}_2\text{rest} \) (L.min\(^{-1}\)) | 0.314±0.050 | 0.261±0.026    | 0.291±0.050 |
| \( \text{VO}_2\text{rest} \) (mL.kg\(^{-1}\).min\(^{-1}\)) | 4.1±0.1     | 3.8±0.2        | 3.8±0.1     |
| \( \text{VO}_2\text{max} \) (L.min\(^{-1}\)) | 3.3±0.2\(^{a}\) | 2.4±0.1       | 2.9±0.1     |
| \( \text{VO}_2\text{max} \) (mL.kg\(^{-1}\).min\(^{-1}\))% | 40.3±1.2\(^{a}\) | 35.8±1.1     | 37.9±0.9    |
| % \( \text{VO}_2\text{max} @ VT \) | 70.3±2       | 71.5±2.1       | 70.9±1.5    |

Data presented as Mean ± SEM.
\(^{a}\) significantly different to females (p <0.05). HRrest: heart rate at rest, HRmax: maximal heart rate, \( \text{VO}_2\text{max} \): maximal oxygen uptake. VT: ventilatory threshold.

There were no significant differences in baseline \( \text{VO}_2 \), HR and energy expenditure before the four exercise or game trials.

https://doi.org/10.1371/journal.pone.0176213.t001
Table 2. Cardio-metabolic response to exercise and AVG trials.

|                        | SS-EX          | MOD-EX         | ET-VG          | FT-VG          |
|------------------------|----------------|----------------|----------------|----------------|
| Average HR (bpm)       | 151.2±3.6a     | 129.0±3.3      | 119.4±6.3      | 151.6±2.1b     |
| %HRmax                 | 77.3±1.9a      | 65.9±1.5       | 60.9±3.1       | 77.4±0.8b      |
| %HRR                   | 66.9±2.7b      | 50.4±2.1       | 46.5±4.7       | 67.1±1.2b      |
| Average VO2 (mL·kg⁻¹·min⁻¹) | 27.4±1.3a    | 21.7±0.7       | 17.9±0.9a      | 22.2±0.8a      |
| % VO2max               | 71.6±2.8a      | 56.9±0.9       | 46.9±1.6a      | 58.6±1.6a      |
| % VO2R                 | 68.3±3.1a      | 52.2±1         | 41.1±1.8a      | 53.9±1.8a      |
| Rate of EE (kcal·min⁻¹) | 10.3±0.7a      | 8.1±0.4        | 6.7±0.4a       | 8.5±0.4        |
| MET                    | 7.8±0.4a       | 6.2±0.2        | 5.1±0.3b       | 6.4±0.2        |
| %VT                    | -1.7±0.62a     | -19.7±0.46     | -34.2±5.7a     | -18.2±4.63     |

Data presented as mean ± SEM. EE: energy expenditure (kcal·min⁻¹); HR: heart rate; HRR: heart rate reserve; MET: metabolic equivalent of the task (3.5 mL·kg⁻¹·min⁻¹); %VT: % VO2max above or below the ventilatory threshold. Significant differences are shown only for statistical comparison of total data.

a significantly different to all other trials (p < 0.05).
b significantly different than MOD-EX and ET-VG (p < 0.05).

https://doi.org/10.1371/journal.pone.0176213.t002

Physiological responses

All trials reached the criteria for moderate or vigorous intensity PA. The % VO2max was significantly higher during the SS-EX trial than MOD-EX, ET-VG trial (P < 0.001) and FT-VG (p < 0.005), partial \( \eta^2 = 0.823 \). The % VO2max was similar during MOD-EX and FT-VG and significantly higher than ET-VG (Table 2). % VO2max increased over time during all trials (P < 0.001) partial \( \eta^2 = 0.695 \) and was greater in males than females (p < 0.005), \( \eta^2 = 0.351 \).

A significant effect of trial (p < 0.001), partial \( \eta^2 = 0.897 \) and time (p < 0.001), partial \( \eta^2 = 0.351 \) was found for heart rate (Table 2). There were no differences in % HRmax between the SS-EX trial and the FT-VG and both were significantly greater than the MOD-EX and ET-VG trials (p < 0.001). Percentage HRmax increased over time across all trials (p < 0.001) except during MOD-EX as expected with a greater increase in SS-EX and ET-VG. We did not find any gender effect in the HR response to the different conditions.

The SS-EX trial resulted in a significantly higher rate of energy expenditure than MOD-EX (p < 0.001), ET-VG (p < 0.001) and FT-VG (p < 0.005), partial \( \eta^2 = 0.801 \). No significant differences were found between MOD-EX and FT-VG. Both MOD-EX and FT-VG resulted in significantly higher rates of EE than ET-VG (p < 0.001). The rate of energy expenditure increased significantly over time during the SS-EX and ET-VG trials (p < 0.001), \( \eta^2 = 0.721 \) but not during MOD-EX and FT-VG trials. A between subjects effect of gender (P < 0.001) was also detected, indicating than males had a significantly higher rate EE than females. As results of the different rates of EE in the different trials, there were significant differences in the total amount of EE as Fig 2 shows.

Affective and perceptual responses

We report a significant effect of trial on the core flow (p < 0.05), \( \eta^2 = 0.520 \), with ET-VG resulting in higher states of flow than both exercise trials (Fig 3A).

There were no differences in baseline scores of psychological well-being but there is an effect of trial (p < 0.05), \( \eta^2 = 0.129 \), with ET-VG resulting in significantly higher psychological wellbeing values immediately after the trial (Fig 3B). There was a significant effect of sex (p < 0.05), partial \( \eta^2 = 0.257 \), with men reporting higher psychological well-being during and immediately after each trial, except for the FT-VG. For women, well-being decreased...
Fig 2. Total amount of EE (kcal) in the 4 different trials. All data presented as mean ± SEM. *significantly different to all other trials (P<0.05).

https://doi.org/10.1371/journal.pone.0176213.g002

Fig 3. A. State of core flow immediately after the trials. All data presented as mean ± SEM. *significantly different than SS-EX and MOD-EX, P<0.05. b Differences in psychological well-being before and immediately after the trials (PWB post diff) and before and 20 min after trial completion (PWB 20 min post diff). ¥ significantly different than all other trials, P<0.05. c Enjoyment at 15 and 29 min, and average scores. *significantly different than SS-EX and MOD-EX, P<0.01. d. Rate of perceived exertion (RPE) at 15 and 29 min and average scores. ¥ significantly different than all other trials, P<0.05; § significantly different than ET-VG, P<0.05; ¶ significantly different than MOD-EX and ET-VG, P<0.01. All data presented as mean ± SEM.

https://doi.org/10.1371/journal.pone.0176213.g003
immediately after the SS-EX and MOD-EX trials, but increased after the ET-VG and remained the same after the FT-VG trial.

The gaming trials resulted in significantly greater enjoyment ratings than the exercise trials \((p < 0.001), \eta^2 = 0.810\) (Fig 3C). No significant differences were found in enjoyment ratings between the exercise trials or between the gaming trials. Mean enjoyment did not change over time in any of the trials \((p < 0.642)\) or between men and women.

We found a significant relationship between average enjoyment during the trial and %VT in the SS-EX trial only \((p < 0.01)\). In this trial, 31.9% of enjoyment could be accounted for the variability in intensity relative to the ventilatory threshold.

Repeated measures ANOVA revealed a significant effect for the condition on RPE levels \((P < 0.001, \text{partial } \eta^2 = 0.654)\) as seen in Fig 3D. The SS-EX trial had higher average RPE ratings than MOD-EX \((p < 0.001)\) and ET-VG \((p < 0.001)\), but there were no differences compared to the FT-VG trial. The FT-VG trial also had significantly higher RPE values than both MOD-EX and ET-VG \((p < 0.001)\).

**Discussion**

The main finding of this study was that active video games can meet the criteria for moderate-to-vigorous physical activity and lead to more positive affective judgements than conventional exercise trials. These data indicate that active video games provide an adequate stimulus to meet the physical activity guidelines and could form part of future physical activity recommendations.

The ET-VG and FT-VG trials in this study resulted in 5.1±0.3 and 6.4±0.2 METs, which qualify them as moderate and vigorous intensity exercise, respectively. These results are higher than those reported in other cross-sectional studies\[18, 19, 35\] and the differences may be explained by variation in the difficulty level of the game. There is a wide variety of active video games on the market and the variation in the design and effort required makes it difficult to compare outcomes or reach consensus about the efficacy of this form of activity. Other studies that used different FT-VG such as the Wii Fit, report a range of physiological outcomes\[19, 29, 36, 37\]. Miyachi et al\[36\] reported lower MET values for resistance (1.7–5.6 METs) and aerobic (2.7–5.1 METs) in a metabolic chamber compared to the 6.3 and 6.5 METs, respectively, in the present study.

In other cases, fitness-themed video games focus on light aerobic and balance games\[19\]. These games may be targeted at older adults and require finer motor control but the rate of energy expenditure is likely to be lower than in resistance activities. It is also possible that the initial physical activity or fitness levels may also be a contributing factor. Our participants were in the 60th percentile of the ACSM normative values for VO\(_2\)max\[38\] and it is possible that active video game play may provide a greater physiological stimulus to inactive individuals compared to more aerobically fit participants. Finally, the participants’ motivation and experience playing the active video games is likely to have an impact on the results\[39\].

The SS-EX trial resulted in the highest exercise intensity, attaining the criteria for vigorous exercise based on heart rate, oxygen consumption and energy expenditure criteria\[26\]. Similar values have been reported in the literature in studies with young, normal weight participants \[8\] but the MET values are higher than those reported for walking/jogging in the literature\[3\]. However, the SS-EX trial had significantly lower enjoyment than both AVG trials and lower psychological well-being than the ET-VG trial.

During the SS-EX trial, participants were <2% below their ventilatory threshold but there was a high inter-individual variability in the selected exercise intensity, consistent with other studies\[40\]. However, the greater autonomy over the exercise intensity did not result in greater enjoyment or flow scores as would have been expected\[8\]. In this study, participants may have
selected the intensity at the upper range for normal exercise and this might have a negative
effect on enjoyment and flow.

Our results are similar to those in the literature reporting that active video games result in
moderate exercise intensities. Participants enjoyed the two active video game trials significa-
cantly more than the two conventional exercise trials but it was interesting to note some differ-
ences between the two video game trials. The FT-VG used in this study resulted in a higher %
HRmax than the MOD-EX and ET-VG trials, and was more enjoyable than both exercise tri-
als. This fitness themed game could be described as vigorous based on the heart rate max crite-
rria. On the other hand the ET-VG was moderate intensity exercise and had the most positive
affect states. The percentage VO\textsubscript{max} and rate of energy expenditure during the ET-VG were
significantly lower than the other trials. We could only find one other study\cite{35} that used
Kinect Adventures but there are significant differences in the design of both studies and a
direct comparison is not possible. It will be important to address the issue of data harmonisa-
tion from different video game studies to better understand the impact on physiological out-
comes. Addressing these issues will be very important to provide more definitive evidence that
active video games can be used to attain the physical activity recommendations.

The four trials tested in this study resulted in very different affect states and psychological
well-being that might have important implications for exercise prescription. The highest
enjoyment ratings occurred in the active video game trials, where subjects did not experience
the autonomy to decide on games and intensity levels contradicting some evidence in the liter-
ature\cite{8}. A possible explanation is that participants experienced more positive psychological
and affect states during the active video game trials as the higher score for core flow and psy-
chological well-being during the ET-VG trial shows. This increased state of flow and the
enhanced sense of well-being might have compensated for the lack of autonomy during the
active video game trials. While video games and sport are two domains in which an enhanced
state of flow is likely to occur\cite{41}, there is a lack of research on active video games and the
state of flow. Thin et al\cite{42} compared the flow state and enjoyment of 14 young adults while
playing 6 different active video games and cycling exercise and found that two of the flow
dimensions (challenge-skill balance and merging of action and awareness) scored significantly
higher than the exercise trial. We did not analyse the 9 different dimensions of flow separately,
but got a significant difference in the overall state of flow.

The findings of this study partly supports the principles of the dual-mode model theory
\cite{13}. The highest enjoyment ratings occurred in the ET-VG trial, when the participants were
working at the lowest intensity in relation to individuals’ ventilatory threshold. However, the
FT-VG and the MOD-EX trials resulted in similar percentages of ventilatory threshold, but
enjoyment ratings were significantly higher during the FV-TG than during the MOD-EX. The
complex interplay of cortically mediated cognitive processes and the physiological changes
leading to increased metabolic stress were modified during the FV-TG trial and as result of
this enjoyment ratings were higher than during MOD-EX. We also found that ~30% of enjoy-
ment during the SS-EX trial could be accounted for the variability in intensity in relation to
the ventilatory threshold but this was not evident in the other trials. It is clear that other factors
apart from exercise intensity were playing a role in determining the affect response to the exer-
cise and games. One example is RPE, which was similar in the FT-VG and SS-EX trials and sig-
ificantly greater than the MOD-EX and ET-VG.

We acknowledge that certain aspects of the design and implementation may limit the
interpretation of our findings. Firstly, using an average of the last 3 min of the 10 min data col-
lection at rest prior to each trial as the baseline measures might not be enough to get the partic-
ipants in a complete steady-state for the physiological parameters of interest (HR, VO\textsubscript{2} and
rates of EE). A longer rest period would have resulted in more accurate baselines measures. Secondly, the 3-hr lapse since last eating should be sufficient to allow for digestion and absorption of a light meal but there may be a residual effect. The research team strove to ensure the data was reliable by performing the tests at the same time of day and following the same protocol for all subjects while trying to maintain a ‘real life’ study design. Thirdly, this study examined the affective responses to each single bout of either exercise or active video game. While affective responses to a single session are useful, there is a need for intervention studies to examine the long term effects. Finally, sixteen participants in this study were normal weight, four were overweight and four were classified as obese. We did not examine the effect of body weight in the different physiological and psychological parameters due to low numbers of overweight and obese participants. The results obtained could be different in a cohort of mainly overweight or obese participants.

Conclusion
There are a variety of AVGs on the market and our results cannot be generalised. The AVGs used in this study resulted in moderate exercise intensities that comply with intensity recommendations of the ACSM physical activity guidelines. The fitness-themed video game yielded a similar EE and rate of EE to moderate intensity exercise, but lower than self-selected exercise. The AVG trials resulted in the greatest affect states and psychological well-being of all conditions. Participants rated the entertainment-themed video games as the most enjoyable and experienced a higher state of flow and psychological well-being during this condition than during the exercise trials.

The results of this study have implications in the fight against adult physical inactivity and sedentary behaviour. Video game usage is widely extended among the population, and this study shows that AVG technology can be a useful and efficient tool to help people to meet the PA recommendations and to reduce sedentary behaviour. The fitness-themed video game resulted in high exercise intensity but was not as enjoyable as the entertainment-themed video game. Video game designers could take account of this and try to introduce elements in the games that make them more attractive, even if this means making them less demanding from a physiological point of view.

Supporting information
S1 Appendix. Active video games (AVGs) used in the study, play time and level played. (DOCX)

Acknowledgments
We would like to thank all the participants in his study. We thank Dr Siobhan McArdle and Dr Johann Issartel for their assistance in statistical analysis. Finally, we would like to thank Ms Siobhan Egan for her help in editing the article.

Author Contributions
Conceptualization: JM.
Data curation: JM DOG.
Formal analysis: JM DOG.
Funding acquisition: JM.
Investigation: JM EM.
Methodology: JM EM.
Project administration: JM EM DOG.
Resources: JM EM.
Supervision: JM DOG.
Validation: JM.
Visualization: JM.
Writing – original draft: JM.
Writing – review & editing: JM EM DOG.

References

1. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012; 55(11):2895–905. Epub 2012/08/15. https://doi.org/10.1007/s00125-012-2677-z PMID: 22890825

2. Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet. 2012; 380(9859):2224–60. Epub 2012/12/19. https://doi.org/10.1016/S0140-6736(12)61766-8 PMID: 23245609

3. Sedentary Behaviour Research N. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab. 2012; 37(3):540–2. https://doi.org/10.1139/h2012-024 PMID: 22540258

4. Bauman A, Reis R, Sallis J, Wells J, Loos J, Martin B. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012; 380:258–71. https://doi.org/10.1016/S0140-6736(12)60735-1 PMID: 22818938

5. Rhodes RE, Fiala B, Conner M. A review and meta-analysis of affective judgments and physical activity in adult populations. Ann Behav Med. 2009; 38(3):180–204. https://doi.org/10.1007/s12160-009-9147-y PMID: 20082164

6. Roemmich JN, Barkley JE, Lobairinas CL, Foster JH, White TM, Epstein LH. Association of liking and reinforcing value with children’s physical activity. Physiol Behav. 2008; 93(4–5):1011–8. Epub 2008/02/22. PubMed Central PMCID: PMC2390920. https://doi.org/10.1016/j.physbeh.2008.01.010 PMID: 18289620

7. Williams DM, Dunstiger S, Ciccolo JT, Lewis BA, Albrecht AE, Marcus BH. Acute Affective Response to a Moderate-intensity Exercise Stimulus Predicts Physical Activity Participation 6 and 12 Months Later. Psychol Sport Exerc. 2008; 9(3):231–45. Epub 2008/05/23. PubMed Central PMCID: PMC2390920. https://doi.org/10.1016/j.psychsport.2007.04.002 PMID: 18496608

8. Vazou-Ekkekakis S, Ekkekakis P. Affective consequences of imposing the intensity of physical activity: does the loss of perceived autonomy matter? Hellenic J Psychol. 2005; 6:125–44.

9. Faulkner J ER. Perceived exertion research in the 21st century: developments, reflections and questions for the future. J Exerc Sci Fit. 2008; 6(1):1–14.

10. Wankel L. The importance of enjoyment to adherence and psychological benefits from physical activity. Int J Sports Psychol. 1993; 24:151–69.

11. Annesi J. Effects of Music, Television, and a Combination Entertainment System on Distraction, Exercise Adherence, and Physical Output in Adults. Can J Behav Sci., 2001; 33(3):193–202.

12. Dishman RK, Buckworth J. Increasing physical activity: a quantitative synthesis. Med Sci Sports Exerc. 1996; 28(6):706–19. Epub 1996/06/01. PMID: 8784759

13. Ekkekakis P. Pleasure and displeasure from the body: Perspectives from exercise. Cogn & Emot. 2003; 17(2):213–39.

14. Ekkekakis P, Parfitt G, Petruzzello SJ. The Pleasure and Displeasure People Feel When they Exercise at Different Intensities. Sports Med. 2011; 41(8):641–71. https://doi.org/10.2165/11590680-00000000-00000 PMID: 21780850
15. ESA, USA. ESA 2013 Essential Facts 2013. Available from: http://www.theesa.com/facts/index.asp.

16. Maddison R, Mhurchu CN, Jull A, Jiang Y, Prapavessis H, Rodgers A. Energy expended playing video console games: an opportunity to increase children’s physical activity? Pediatr Exerc Sci. 2007; 19(3):334–43. PMID: 18019591

17. Graves L, Stratton G, Rodgers ND, Cable NT. Energy expenditure in adolescents playing new generation computer games. Br J Sports Med. 2008; 42(7):592–4. PMID: 18606832

18. Monedero J, McDonnell AC, Keoghan M, O’Gorman DJ. Modified Active Videogame Play Results in Moderate-Intensity Exercise. Games Health J. 2014; 3(4):234–40. https://doi.org/10.1089/g4h.2013.0096 PMID: 26192372

19. Lyons E, Tate DF, Ward DS, Bowling JM, Ribei KM, Kalyararaman S. Energy expenditure and enjoyment during video game play: differences by game type. Med Sci Sports Exerc. 2011; 43(10):1987–93. Epub 2011/03/03. PubMed Central PMCID: PMC3271952. https://doi.org/10.1249/MSS.0b013e318216ebf3 PMID: 21364477

20. Warburton DER, Sarkany D, Johnson M, Rhodes RE, Whithford W, Esch BT, et al. Metabolic requirements of interactive video game cycling. Med Sci Sports Exerc. 2009; 41(4):920–6. https://doi.org/10.1249/MSS.0b013e31819012bd PMID: 19276840

21. Monedero J, Lyons EJ, O’Gorman DJ. Interactive Video Game Cycling Leads to Higher Energy Expenditure and Is More Enjoyable than Conventional Exercise in Adults. PLoS One. 2015; 10(3):e0118470. https://doi.org/10.1371/journal.pone.0118470 PMID: 25738290

22. Perron R, Graham CA, Hall EE. Comparison of Physiological and Psychological Responses to Exergaming and Treadmill Walking in Healthy Adults. Games Health J. 2012; 1(6):411–5. https://doi.org/10.1089/g4h.2012.0050 PMID: 26192057

23. Santo AS, Barkley JE, Hafen PS, Navalta J. Physiological Responses and Hedonics During Prolonged Physically Interactive Videogame Play. Games Health J. 2016; 5(2):108–13. Epub 2016/03/16. https://doi.org/10.1089/g4h.2015.0077 PMID: 26978073

24. Warburton DER, Jamnik VK, Bredin SSD, Gledhill N. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness J Can. 2011; 4(2):3–23.

25. Social Psychology Network. Research Randomizer. Accessed on 03/02/2014. Available from: https://www.randomizer.org/.

26. ACSM. ACSM’s guidelines for exercise testing and prescription. Ninth ed. Philadelphia: Lippincott Williams & Wilkins; 2014.

27. Elia M, Livesey G. Energy expenditure and fuel selection in biological systems: the theory and practice of calculations based on indirect calorimetry and tracer methods. World Rev Nutr Diet. 1992; 70:68–131. Epub 1992/01/01. PMID: 12922424

28. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol (1985). 1986; 60(6):2020–7. Epub 1986/06/01.

29. Lyons EJ, Tate DF, Komoski SE, Carr PM, Ward DS. Novel approaches to obesity prevention: effects of game enjoyment and game type on energy expenditure in active video games. J Diabetes Sci Technol. 2012; 6(4):839–48. Epub 2012/08/28. PubMed Central PMCID: PMC3440155. https://doi.org/10.1177/19329681200600415 PMID: 22920810

30. Garcia-Mas A, Palou P, Gili M, Ponseti X, Borras PA, Vidal J, et al. Commitment, enjoyment and motivation in young soccer competitive players. Span J Psychol. 2010; 13(2):609–16. Epub 2010/10/28. PMID: 20977011

31. Jackson SA, Martin AJ, Eklund RC. Long and short measures of flow: the construct validity of the FSS-2, DFS-2, and new brief counterparts. J Sport Exerc Psychol. 2008; 30(5):561–87. PMID: 18971512

32. Bartholomew JB, Morrison D, Ciccolo JT. Effects of acute exercise on mood and well-being in patients with major depressive disorder. Med Sci Sports Exerc. 2005; 37(12):2032–7. Epub 2005/12/07. PMID: 16331126

33. Douris PC, McDonald B, Vespi F, Kelley NC, Herman L. Comparison between Nintendo Wii Fit aerobics and traditional aerobic exercise in sedentary young adults. J Strength Cond Res. 2012; 26(4):1052–7. https://doi.org/10.1519/JSC.0b013e31822e5967 PMID: 22446674

34. Ekkekakis P, Petruzzello SJ. Analysis of the affect measurement conundrum in exercise psychology. III: A conceptual and methodological critique of the Subjective Exercise Experiences Scale Psychology of Sport and Exercise 2 (2001) 2001: 2:205–32.

35. O’Donovan C, Hirsch E, Holohan E, McBride I, McManus R, Hussey J. Energy expended playing Xbox Kinect and Wii games: a preliminary study comparing single and multiplayer modes. Physiotherapy. 2012; 98(3):224–9. Epub 2012/08/18. https://doi.org/10.1016/j.physio.2012.05.010 PMID: 22898579
36. Miyachi M, Yamamoto K, Ohkawara K, S. T. METs in adults while playing active video games: a metabolic chamber study. Med Sci Sports Exerc. 2010; 42(6):1149–53. https://doi.org/10.1249/MSS.0b013e3181c51c78 PMID: 19997034

37. Graves L, Ridgers N, Williams K, Stratton G, Atkinson G, Cable N. The physiological cost and enjoyment of Wii Fit in adolescents, young adults, and older adults. J Phys Act Health. 2010; 7(3):393–401. PMID: 20551497

38. ACSM. ACSM’s guidelines for exercise testing and prescription. 8th ed. Philadelphia: Lippincott Williams & Wilkins; 2010. 5 p.

39. Sell K, Lillie T, Taylor J. Energy expenditure during physically interactive video game playing in male college students with different playing experience. J Am Coll Health. 2008; 56(5):505–11. https://doi.org/10.3200/JACH.56.5.505-512 PMID: 18400662

40. Lind E, Joens-Matre RR, Ekkekakis P. What intensity of physical activity do previously sedentary middle-aged women select? Evidence of a coherent pattern from physiological, perceptual, and affective markers. Prev Med. 2005; 40(4):407–19. https://doi.org/10.1016/j.ypmed.2004.07.006 PMID: 15530593

41. Csikszentmihalyi M. Flow, the psychology of experience. New York: Harper & Row.; 1990.

42. Thin A, Hansen L, McEachen D. Flow Experience and Mood States While Playing Body Movement-Controlled Video Games. Games and Culture. 2011;(6):414.