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Running Title: Relative Exercise Intensity of Exergames

Investigating the Relative Exercise Intensity of Exergames in Pre-Pubertal Children

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Abstract

Objective:

Literature remains equivocal as to whether exergames elicit energy expenditure (EE) commensurate with physical activity guidelines. Such discrepancies may be attributable to a reliance on absolute exercise intensities which fail to account for differences in cardiorespiratory fitness levels.

Materials and Methods:

Thirty four pre-pubertal children (20 boys, 10.8±1.0 yrs) completed a 30 minute exergame (two 15 minute games; Kinect Adventures!; Xbox 360) and an incremental treadmill test to determine peak $\dot{V}O_2$ throughout which breath-by-breath gas exchange was measured.

Results:

Both games elicited moderate intensity (5.7±1.5 and 5.5±1.4 METs), with 36% demonstrating a mean EE in excess of 6.0 METs, commensurate with vigorous intensity. Furthermore, boys demonstrated higher EE during both games (Game 1: boys, 6.0±1.7 vs. girls, 5.2±1.0; Game 2: boys, 6.0±1.4 vs. girls, 4.9±1.2 METs; $P<0.05$). Hierarchical linear regression revealed sex, maturity and fitness to be significant predictors of EE, accounting for 24%: relative exergame $\dot{V}O_2$=24.53+(2.12*Sex)–(0.42*Maturity offset)–(0.16*relative peak $\dot{V}O_2$). There was no correlation between absolute $\dot{V}O_2$ during the exergames and peak $\dot{V}O_2$ but $\dot{V}O_2$ expressed as a percentage of peak $\dot{V}O_2$ was correlated with peak $\dot{V}O_2$ during both game 1 (r=-0.62, $P<0.01$) and game 2 (r =-0.59, $P<0.01$).

Conclusion:

The present findings provide further evidence that exergames can elicit energy expenditures commensurate with national physical activity guidelines and extend our understanding of the mediators of EE. Specifically, cardiorespiratory fitness and sex must both be considered in the design

and implementation of future interventions seeking to utilise exergames to enhance physical activity levels and/or cardiorespiratory fitness.

Introduction

Physical inactivity is recognised as a major public health challenge of the 21st century, with more than one third of children failing to achieve the recommended levels of 60 minutes of moderate-to-vigorous physical activity (MVPA) every day, defined as any activity eliciting an energy expenditure of at least 3.0 metabolic equivalents (METs).[1] Specifically, physical inactivity is associated with the development of serious health problems, such as cardiovascular disease and diabetes, the latter of which alone presently costs the National Health Service (NHS) over £14 billion per year.[2] Of concern, it has been highlighted that the current guidelines may not be sufficient to ameliorate, or indeed prevent, such associated health implications, suggesting that vigorous-intensity physical activity (i.e., an energy expenditure of at least 6.0 METs)[3, 4] is warranted.[5, 6] Moreover, physical activity has been displaced by sedentary behaviours,[7, 8] such as watching television and playing video games, which are independently, and additionally, associated with negative health consequences.[9-11] Indeed, recent reports suggest that children spend an average of 8 hours per week playing sedentary video games[12] and that this time is implicated as a risk factor for the rising prevalence of childhood obesity.[13] However, technological advances have led to the development of a new generation of video games that combine physical activity with game playing, frequently referred to as "exergames" and postulated to present a potential means of enhancing physical activity levels without requiring children to relinquish highly-valued behaviours.[14]

Although a promising concept, the literature remains equivocal as to whether exergames elicit energy expenditure levels commensurate with physical activity guidelines.[15] Specifically, whilst some exergame studies have reported energy expenditures equivalent to moderate intensity physical activity,[15-18] other studies refute this notion suggesting lower energy expenditures to be associated with exergames.[19-21] These discrepancies may be attributable a failure to account for potential sex differences and/or to a reliance on absolute exercise intensities to determine whether participants met physical activity guidelines, thus failing to account for differences in cardiorespiratory fitness levels. Specifically, whilst the majority of studies have pooled data from boys and girls, the validity of such analyses remains to be elucidated with contradictory findings reported by Maddison et al.,[17] who found no influence of sex, and Graves et al.,[20] who reported girls to demonstrate significantly higher

HR during exergaming. Whilst there is presently no information regarding the influence of cardiorespiratory fitness on the energy expended during exergames in children, a recent study by Mellecker and McManus[22] investigated the relative exercise intensity during three exergames in young girls reporting that only the XaviX-Mat game elicited an energy expenditure equivalent to moderate intensity. However, this study utilised only 5 minute bouts of exergaming, which are unlikely to be representative of a sustained period of exergaming given that Rideout et al.[12] identified that children play video games for 1 hour 13 minutes, on average, every day. Caution is therefore required when extrapolating the findings of short-term gaming periods to assess their agreement with government guidelines. Furthermore, Mellecker and McManus[22] utilised a linear regression of heart rate (HR) as a function of oxygen uptake ($\dot{V}O_2$) to indirectly estimate the intensity during the exergames from HR recordings. It is also pertinent to note the potential confounding effects of non-physiological factors, such as players' skill levels and the specific protocols involved in playing different types of exergames, which may contribute to the lack of consensus regarding the intensity associated with exergaming. Therefore, these findings must be interpreted with caution and the relative exercise intensity of exergames in children remains to be elucidated.

Therefore, the purpose of the present study was to investigate the relative exercise intensity of exergaming in children and to investigate the modulatory influence of sex and aerobic fitness on this intensity during a typical 30 minute exergaming session. We hypothesised that the exergames would elicit an energy expenditure equivalent to moderate intensity and that cardiorespiratory fitness would be negatively associated with energy expenditure.

Materials and Methods

Sample Population

In total, 34 Caucasian children (20 male; 10.8 ± 1 years) were recruited to participate in this study (Table 1). The children were all recreationally active but none were engaged in formal, organised sports; only those children with physical ailments that would have precluded them from undertaking the exergames or incremental treadmill test were excluded from the study. All the participants were familiar with playing exergames and were asked to attend the laboratory in a rested state, at least two hours postprandial and to have avoided strenuous exercise and caffeine in the preceding 24 hours. Written informed consent and assent was obtained from parents and participants, respectively. The local research ethics committee granted ethical approval for this study.

Experimental Procedures

Participants attended the laboratory on one occasion during which anthropometric measures and peak $\dot{V}O_2$ were assessed and the exergames were conducted. Specifically, stature (Holtain, Crymych, UK) and sitting stature (Holtain, Crymych, UK) were measured to the nearest 0.01 m and body mass (Seca, Germany) to the nearest 0.1 kg. Age was calculated from the date of the first test, and maturity was estimated using the methods described by Mirwald et al.[23] and expressed as the estimated time in years from the age at peak height velocity (APHV). Participants subsequently completed two exergames in single-player mode (River Rush and Reflex Ridge; Kinect Adventures!, Xbox 360), in a randomly assigned order, for 15 minutes each, with 1 minute between. Finally, following a 15 minute rest, participants completed a continuous, incremental treadmill test. Due to the variation in biological age of the participants, the speeds utilised during the test were individually calibrated utilising Froude numbers (Fr), as described by Hopkins et al.[24]. The protocol required participants to complete 2-minute stages, beginning with a walking speed equivalent to Fr 0.25 and subsequently increasing to the equivalent of Fr 0.5 (Walk/run transition) after which successive increments were determined by the difference in the speed for stages 1 and 2 (~2 $km \cdot hr^{-1}$) until volitional exhaustion.

Experimental Measures

Throughout both exergames and the incremental treadmill test, heart rate (Polar S610, Polar Electro Oy, Kempele, Finland) and gas exchange variables (MetaMax 3B, Cortex, Biophysik, Leipzig, Germany), measured on a breath-by-breath basis, were displayed online. Prior to each participant, the gas analysers were calibrated using gases of known concentration and the turbine volume transducer was calibrated using a 3-litre syringe (Hans Rudolph, Kansas City, MO). The delays in the capillary gas transit and analyser rise time were accounted for relative to the volume signal, thereby time-aligning the concentration and volume signals.

Data Analysis

The peak $\dot{V}O_2$ was defined as the highest 10-s stationary average during the test. The Gas Exchange Threshold (GET) was determined using the V-slope method[25] as the point at which carbon dioxide production began to increase disproportionately to $\dot{V}O_2$ as identified using purpose-written software developed using LabVIEW (National Instruments, Newbury, UK). METs were calculated using a resting value of 3.5 ml $O_2 \cdot kg \cdot min^{-1}$, with the mean $\dot{V}O_2$ being determined over the entire duration of the game. The relative exercise intensity of each exergame was determined as a percentage of peak $\dot{V}O_2$ and compared to the GET in absolute and relative terms using paired samples t-tests. A two factor, repeated measures ANOVA was used to assess the influence of sex and exergame on energy expenditure, with subsequent independent and paired samples t-tests, where appropriate, to identify the location of significant differences. Pearson's correlations were used to examine the relationship between aerobic fitness and exergame responses with subsequent linear regression to assess the role of aerobic fitness in predicting energy expenditure during exergaming. All statistical analyses were conducted using PASW Statistics 21 (SPSS, Chicago, Il). All data are presented as means ± standard deviation. Statistical significance was accepted as $P \leq 0.05$.

Results

As shown in Table 1, there were no significant differences between boys and girls with regards to their anthropometrics or peak exercise responses, with the exception of girls being significantly closer to their age at peak height velocity and having greater peak heart rates.

Irrespective of sex, both exergames elicited a $\dot{V}O_2$ significantly lower than that associated with the GET when expressed in both absolute terms and as a percentage of peak $\dot{V}O_2$ (Table 2). In total, 100% of the current participants demonstrated a mean energy expenditure in excess of 3.0

METs with 36% of the total sample actually demonstrating a mean energy expenditure in excess of 6.0 METs (21% of girls and 48% of boys), in accord with vigorous intensity physical activity thresholds.

The two factor, repeated measures ANOVA revealed a main effect of sex on the mean $\dot{V}O_2$ during exergaming, irrespective of whether this was expressed in absolute or relative terms, with a similar sex effect also observed in the mean METs. When the $\dot{V}O_2$ during exergaming was expressed as a percentage of peak $\dot{V}O_2$ or the GET, there was a main effect of sex, with subsequent independent t-tests revealing that the relative $\dot{V}O_2$ was significantly higher in the boys, regardless of whether it was expressed as a function of peak $\dot{V}O_2$ or the GET. There were no differences between games when the data from boys and girls were pooled for analysis or within each sex, with the exception of mean exergaming heart rate which was higher during game 2 in both sexes.

Whilst the mean $\dot{V}O_2$ was strongly correlated[26] between games ($r = 0.62$, $P < 0.01$), there was no correlation between the $\dot{V}O_2$ during either game and peak $\dot{V}O_2$. In contrast, there was a strong inverse relationship between the peak $\dot{V}O_2$ and $\dot{V}O_2$ expressed as a percentage of peak $\dot{V}O_2$ during both game 1 ($r = -0.62$, $P < 0.01$) and game 2 ($r = -0.59$, $P < 0.01$). Conversely, there was a strong correlation between the absolute GET and the $\dot{V}O_2$ during game 1 ($r = 0.62$, $P < 0.01$) and game 2 ($r = 0.61$, $P < 0.01$), but no relationship when GET was expressed relative to peak $\dot{V}O_2$. Similarly, mean HR during each game was strongly related ($r = 0.83$, $P < 0.01$) but demonstrated no relationship with peak HR.

A linear mixed model with sex as a fixed factor and maturity, peak $\dot{V}O_2$ and GET as covariates revealed a significant interaction between peak $\dot{V}O_2$ and sex and the GET and sex in determining the mean $\dot{V}O_2$ during exergames. Furthermore, an interaction was also evident between the GET and maturity with regards to mean $\dot{V}O_2$ during exergames. Finally, hierarchical linear regression revealed that sex, maturity and peak $\dot{V}O_2$ accounted for 24% of the variance in mean exergame $\dot{V}O_2$ according to the following model:

$$\text{Relative exergame } \dot{V}O_2 = 24.53 + (2.12 * \text{Sex}) - (0.42 * \text{Maturity offset}) - (0.16 * \text{relative peak } \dot{V}O_2)$$

Where 0 = girl and 1 = boy

Discussion

The purpose of the present study was to investigate the relative exercise intensity of two exergames in children and to investigate the modulatory influence of sex and fitness on this intensity. In accord with our hypotheses, we found that both exergames elicited moderate intensity physical activity (3.0 METs), with over a third of participants actually meeting the energy expenditure levels associated with vigorous intensity physical activity (6.0 METs). Furthermore, energy expenditure during exergaming was dependent on sex and the method of expressing aerobic fitness. Specifically, boys expended significantly more energy and, irrespective of sex, relative exergame energy expenditure was inversely related to peak $\dot{V}O_2$. These findings therefore provide further support to the notion of exergames as a tool to increase energy expenditure and decrease sedentary time in children, extending our understanding regarding the mediatory role of aerobic fitness in determining energy expended during exergames.

There remains considerable controversy within the literature regarding whether exergames elicit an exercise intensity commensurate with physical activity guidelines. Specifically, whilst some suggest that, in accord with the present findings, exergames engender an energy expenditure in excess of 3.0 METs,[27, 28] others report values significantly below this threshold.[16, 19, 29, 30] In contrast to the majority of these studies, over a third of the current participants demonstrated mean energy expenditure values associated with vigorous intensity physical activity. These equivocal findings may be attributable to the type and duration of the game played, as well as the cardiorespiratory fitness of the participants. A recent meta-analysis of the energy expenditure associated with exergaming concluded that games involving the lower or whole body were associated with a greater energy expenditure.[31] Given the range of movements required by the present exergames, the high energy expenditure observed is in accord with these conclusions. Methodological differences in the duration the exergames were played for may also contribute to the discrepancies in energy expenditure; short bout durations may have artificially constrained the energy expenditure measured by not allowing the dynamic $\dot{V}O_2$ response to reach a steady state. Furthermore, studies to date have almost exclusively relied on absolute measures of energy expenditure, thereby failing to account for the influence of aerobic fitness on the relative intensity of the exergame. Indeed, Maddison et al.[32] recently reported that aerobic fitness was a significant mediator of the relationship between exergames and body composition over a 24 week period; a finding supported by the present inverse relationship between relative energy expenditure and peak $\dot{V}O_2$. Finally, it is pertinent to note the substantial debate regarding the MET values associated with moderate-intensity physical activity in children, with suggestions that the observation of associated behavioural indicators (i.e. brisk walking) occurring at approximately 4.0 METs in children may raise questions regarding the applicability of the conventional 3.0 MET threshold.[4, 33, 34] Given the lack of consensus in the literature, the conventional threshold was utilised in the present study in accord with numerous calibration studies.[35, 36] However, applying the more stringent threshold of 4.0 METs to the present study still resulted in 93% of children surpassing the moderate intensity threshold. Irrespective of whether exergames are associated with the intensity required to contribute to physical activity recommendations, exergames are likely to contribute to reducing sedentary time, particularly sedentary screen time, which has been shown to demonstrate significant negative health effects, independent of physical activity levels.[37]

Graves et al.[20] reported that Wii boxing elicited a heart rate of 68% of age-predicted maximum heart rate in agreement with previous studies[19, 27, 28] which is suggested to be sufficient for the development or maintenance of cardiorespiratory fitness in youth.[19, 28] However, although the present study found a similar relative heart rate during exergaming, it is important to note that these American College of Sports Medicine recommendations are based on adults;[38] a meta-analysis by Baquet et al.[39] concluded that an intensity in excess of 80% maximum heart rate is required to elicit improvements in cardiorespiratory fitness in children. These findings therefore have significant implications with regard to the interpretation of previous studies which have sought to utilise exergaming as a tool to enhance cardiorespiratory fitness[40] and/or physical activity levels.[41-43]

In contrast to previous studies,[27, 28, 30] the boys demonstrated a higher energy expenditure during exergaming, irrespective of whether this was expressed in absolute or relative terms; boys evidenced a relative exercise intensity 10-15% higher than the girls. This discrepancy may be attributable to the relative gaming experience of the participants, with more experienced gamers demonstrating a depressed response due to a greater state of "training" or a reduced emotional response.[44, 45] However, all of the children in the present study reported a similar level of prior experience. Alternatively, the sex discrepancy may be related to the greater maturity of the girls, as energy expenditure associated with exergames is suggested to be significantly lower in adults compared to children, [15] or to the nature of the games selected in this study. Specifically, girls may be hypothesised to engender greater energy expenditure during different types of exergames, such as dance orientated games. It is noteworthy that prior to the resolution of the basis for the present sex difference, the influence of psychological factors such as enjoyment and intrinsic motivation needs to be elucidated.[15] Irrespective of the mechanistic basis, the hierarchical model derived in the present study highlights this modulatory role of sex and maturity in determining the response to exergames. A failure to account for these factors in the majority of previous studies may, at least in part, explain the equivocal findings and limits interpretation of such studies. Indeed, whilst accounting for sex, maturation and fitness, future studies are required to elucidate the remaining determinants of energy expenditure during exergames.

In the present study, a strong inverse relationship was observed between peak $\dot{V}O_2$ and the $\dot{V}O_2$ elicited during the exergames when expressed relative to peak $\dot{V}O_2$, suggesting that those with a lower peak $\dot{V}O_2$ were exercising at a greater relative intensity. Given reports that exergames are perceived as more enjoyable compared to traditional aerobic exercise modalities,[46] the current findings may imply that exergames could potentially represent a more potent intervention tool in less aerobically fit individuals. However, such conclusions must be tempered by reports that those exergames associated with greater energy expenditures are less enjoyable than more sedentary games[47] which questions the long-term sustainability of exergames as a physical activity intervention.

However, while the present findings provide further support to the notion of exergames as a tool to increase energy expenditure and decrease sedentary time in children, issues with the potential utility of such a tool are highlighted by a recent study which reported that although only 93% of children had access to an active video game console, 42% of these had not used it in the last 7 days.[48] Furthermore, it appears that amongst those who did utilise the consoles, the majority used them to engage in sedentary gaming.[48] Therefore, despite exergames being proposed as an active alternative to sedentary games and television viewing, unless the use of games such as those utilised in the present study can be encouraged, playing an exergame may merely be a sedentary alternative to a sedentary activity, rather than an active alternative.[48]

The current methodological design was associated with numerous strengths, such as the measurement of gas exchange parameters using indirect calorimetry to accurately determine energy expenditure. Furthermore, the present study is the first to account for the potential influence of maturation, and variations thereof, in determining the energy expenditure associated with exergames. Nonetheless, there are certain limitations which require consideration, such as the potential influence of a novelty effect and laboratory environment to artificially augment the energy expenditure observed. Indeed, whilst the present findings extend our current understanding regarding the role of cardiorespiratory fitness, sex and maturation in mediating the intensity associated with exergames, the utilisation of a single exercise bout necessitates caution when extrapolating such findings to a more sustained game playing environment. Furthermore, whilst estimating maturity according to the regression equations of Mirwald et al.[23] is well established, the limitations associated with such estimations must be considered when interpreting the present findings. Finally, although the metric of METs to define energy expenditure was used to enable comparisons to previous studies, it is important to highlight that individual resting energy expenditure was not determined in the present study.

In summary, the present study provides further evidence that exergames can elicit energy expenditures commensurate with national physical activity recommendations. Furthermore, the current findings extend our understanding of the mediators of energy expenditure, suggesting that cardiorespiratory fitness and sex must both be considered in the design and implementation of future interventions seeking to utilise exergames to enhance physical activity levels and/or cardiorespiratory fitness.

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Table 1. Participant anthropometric and peak exercise responses.

	Total (*n* = 34)	**Boys (*n* = 20)**	**Girls (*n* = 14)**
Age (years)	10.8 ± 1.0	10.7 ± 1.0	10.9 ± 1.1
Stature (m)	1.45 ± 0.08	1.45 ± 0.08	1.44 ± 0.09
Body mass (kg)	38.62 ± 10.18	39.10 ± 8.35	38.02 ± 12.3
Maturity offset (years)	-1.9 ± 1.1	-2.5 ± 0.8	-1.1 ± 1.0 *
Peak $\dot{V}O_2$ ($l \cdot min^{-1}$)	1.68 ± 0.55	1.68 ± 0.57	1.68 ± 0.55
Relative peak $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	44.86 ± 13.01	42.69 ± 12.25	47.28 ± 13.76
Peak RER	1.24 ± 0.48	1.43 ± 0.51	1.04 ± 0.37
Peak HR (beats$\cdot min^{-1}$)	202 ± 10	197 ± 5	206 ± 11 *
GET ($l \cdot min^{-1}$)	1.23 ± 0.32	1.29 ± 0.30	1.16 ± 0.32
Relative GET (% peak $\dot{V}O_2$)	61 ± 8	59 ± 8	64 ± 8

Means ± SD. $\dot{V}O_2$, oxygen uptake; RER, respiratory exchange ratio; HR, heart rate; GET, gas exchange threshold. * Significant difference between sexes.

Table 2. Mean energy expenditure responses to two different exergames

	Total		Boys		Girls	
	Game 1	**Game 2**	**Game 1**	**Game 2**	**Game 1**	**Game 2**
$\dot{V}O_2$ (l·min^{-1})	0.75 ± 0.24	0.74 ± 0.24	0.81 ± 0.28	0.82 ± 0.25	0.68 ± 0.17	0.64 ± 0.19
Relative $\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	19.8 ± 5.1	19.4 ± 4.9	20.9 ± 5.8	21.0 ± 4.9	18.3 ± 3.6	17.1 ± 4.2
METs	5.7 ± 1.5	5.5 ± 1.4	6.0 ± 1.7	6.0 ± 1.4	5.2 ± 1.0	4.9 ± 1.2 #
$\dot{V}O_2$ % peak	50 ± 25	49 ± 22	56 ± 31	54 ± 25	42 ± 10	41 ± 16
$\dot{V}O_2$ % GET	60 ± 14	59 ± 14	63 ± 15	64 ± 14	57 ± 13	52 ± 11
HR (beats·min^{-1})	124 ± 17	131 ± 18 *	122 ± 17	131 ± 22 *	125 ± 17	131 ± 12 *
Relative HR (% max)	62 ± 9	66 ± 9 *	63 ± 9	68 ± 10 *	61 ± 8	64 ± 7 *

Mean ± S.D. $\dot{V}O_2$, oxygen uptake; METs, metabolic equivalents; GET, gas exchange threshold; HR, heart rate. * Significant difference between game 1 and game 2 within sex; # Significant difference between sexes within game