

Energy Cost of Exergaming

A Comparison of the Energy Cost of 6 Forms of Exergaming

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Objective: To determine the relative effect of interactive digital exercise that features player movement (ie, *exergames*) on energy expenditure among children of various body mass indexes (BMIs; calculated as weight in kilograms divided by height in meters squared).

Design: Comparison study.

Setting: GoKids Boston, a youth fitness research and training center located at University of Massachusetts, Boston.

Participants: Thirty-nine boys and girls (mean [SD] age, 11.5 [2.0] years) recruited from local schools and after-school programs.

Main Exposure: Six forms of exergaming as well as treadmill walking.

Main Outcome Measures: In addition to treadmill walking at 3 miles per hour (to convert miles to kilometers, multiply by 1.6), energy expenditure of the following exergames were examined: Dance Dance Revolution, LightSpace (Bug Invasion), Nintendo Wii (Boxing), Cybex Trazer (Goalie Wars), Sportwall, and Xavix (J-Mat). Energy expenditure was measured using the CosMed K4B2 portable metabolic cart.

Results: All forms of interactive gaming evaluated in our study increased energy expenditure above rest, with no between-group differences among normal (BMI < 85th percentile) and “at-risk” or overweight (BMI ≥ 85th percentile) children ($P \geq .05$). Walking at 3 miles per hour resulted in a mean (SD) metabolic equivalent task value of 4.9 (0.7), whereas the intensity of exergaming resulted in mean (SD) metabolic equivalent task values of 4.2 (1.6) for Wii, 5.4 (1.8) for Dance Dance Revolution, 6.4 (1.6) for LightSpace, 7.0 (1.8) for Xavix, 5.9 (1.5) for Cybex Trazer, and 7.1 (1.7) for Sportwall. Enjoyment of the games was generally high but was highest for children with BMIs in the highest percentiles.

Conclusion: All games used in our study elevated energy expenditure to moderate or vigorous intensity. Exergaming has the potential to increase physical activity and have a favorable influence on energy balance, and may be a viable alternative to traditional fitness activities for children of various BMI levels.

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THE PREVALENCE OF OVER-weight children and adolescents has increased drastically over the past several decades.¹ This increase is troubling given the potentially numerous adverse health implications. In addition, childhood and adolescent obesity tracks into early adulthood, and children who are overweight through adolescence have a difficult time meeting weight recommendations as adults.²⁻⁴

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The positive and prevailing relationship between obesity and sedentary behavior among both adults and children is well documented.⁵⁻¹⁰ Sedentary behavior in children is expressed in a number of dif-

ferent ways, but the behavior that receives the greatest attention is screen time. Screen time includes activities such as watching television or videos, using a computer, surfing the Internet, and playing video games. Because of the sedentary nature of these activities, screen time has been positively associated with obesity.¹¹⁻¹³



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Although video gaming has been one aspect of screen time that has been at least partially blamed for the rapid increase in the prevalence of overweight children and ado-

lescents, there has recently been increased interest in activity-promoting video gaming or video games that require physical movement. *Exergames* is a relatively new term used to describe interactive video or electronic games that feature player movement, such as would occur in “real-life” exercise participation. Active video games have the potential to increase energy expenditure during otherwise sedentary video gaming and may provide a viable adjunct to more traditional exercise. These types of games are used primarily in the home setting but also have been deployed in fitness clubs, schools, community centers, and other settings. The use of exergaming as an adjunctive approach to traditional exercise stems from the assumption that interactive games would foster engagement in physical activities among children and adolescents who are at various levels of fitness and who are drawn to digital technology.

Because activity-promoting video games require movement, it should not be surprising that energy expenditure becomes elevated, especially in comparison to rest.¹⁴⁻²⁰ Previous research in exergaming has been limited to evaluating consumer-end products as a potential replacement for traditional seated game play. The potential of these games to promote fitness and extended periods of moderate to vigorous activity in normal and overweight youth has not been evaluated. In addition, very little is known about the commercial exergaming equipment that is currently being sold to fitness institutions as a means of promoting physical fitness in youth. Moreover, although the enjoyment or liking of some exergames has been evaluated (ie, Wii Fit and Wii Conditioning), the enjoyment of other systems has not been evaluated, nor has the enjoyment level between systems been compared.^{21,22} Enjoyment is important to understand, because children tend to participate in physical activity that they enjoy.²³ The purpose of our study was to evaluate the potential effect of 6 forms of exergaming (3 commercial products and 3 consumer products) on energy expenditure in children. An additional purpose of our study was to evaluate the perceived enjoyment of these exergames. Although not part of the original design of the study, we also compared energy expenditure and exergame enjoyment between children who were at or above recommended body weight.

METHODS

PARTICIPANTS

Thirty-nine children (19 boys and 20 girls) between the ages of 9 and 13 years (mean [SD] age, 11.5 [2.0] years) were recruited to participate in our study. Children were recruited from several public middle school after-school programs in Boston, Massachusetts, and included children from diverse races and ethnicities (57% African American, 11% white, 12% Hispanic, and 23% other). Participants were healthy, with an absence of any known or latent cardiopulmonary, metabolic, or orthopedic disease condition or ailment that would their limit physical activity. All participants were nonsmokers who were not taking any medications that could alter their metabolism and were not following any energy-restricted diets. Prior to participation in our study, informed written consent was obtained from the parent or guardian of the child, and written assent was obtained from the child. All

study procedures were approved by the institutional review board of the university.

PROCEDURES

Participants were invited to take part in a physical activity program at GoKids Boston, a youth fitness research and training center located at University of Massachusetts. The first 2 weeks were spent familiarizing the participants with the gaming equipment by playing the interactive games under the supervision of the research staff. During this period, participants came in twice a week for 90 minutes and rotated through each of the exergaming systems being evaluated in our study. Every participant spent 10 to 15 minutes on each system per day. During the introductory period and prior to measuring physical activity energy expenditure, the participant's body anthropometric measurements were assessed. Following this introductory period, energy expended during the various activities was measured by means of indirect calorimetry.

DESCRIPTION OF ACTIVITIES

Six exergaming systems were evaluated. These systems included Playstation (Dance Dance Revolution [DDR], Konami, Redwood City, California, using Sony Playstation, Sony Corporation of America, New York, New York), Nintendo Wii (Redmond, Washington), Xavix (SSD Company Ltd, Shiga, Japan), Cybex Trazer (Medway, Massachusetts), LightSpace (LightSpace Corp, Boston, Massachusetts), and Sportwall (Rolling Meadows, Illinois). The games chosen included 3 commercial products (Cybex Trazer, LightSpace, and Sportwall) and 3 consumer products (Sony Playstation [DDR], Nintendo Wii, and Xavix).

All of the game systems examined come with multiple games as well as multiple levels within each game. As part of our study, games and levels were selected on the basis of their potential effect on energy expenditure and potential enjoyment. We conducted pilot research with children to determine which games and levels to include in the study. We did this for Xavix, Cybex Trazer, DDR, Wii, and LightSpace. During this time, children played the different gaming systems and levels to determine which were the most aerobically challenging (using a rating of perceived exertion scale), while still maintaining the gaming experience. Gaming systems came with multiple games as well as multiple levels within each game that range from very easy and not very aerobically challenging to very difficult and frustrating for the children. The following games and levels were selected for inclusion in our study: Jackie Chan Alley Run at the “beginning” level for the Xavix gaming system; Thirteen on the “easy” level for DDR; Bug Invasions on the “intermediate” level for LightSpace; Goalie Wars on level 3 for the Cybex Trazer; and Boxing for the Wii entertainment system. The Sportwall was unique in that children were placed into groups of 4 to 5 participants and games were played competitively. These games were played in 4-minute blocks with 30 seconds of rest between each game. During these games, participants were placed roughly 15 ft from the wall and took turns running to the wall to score points.

MEASUREMENTS

The primary outcome in our study was energy expenditure during rest and exergame play. Exergame enjoyment and body composition were also assessed.

Energy Expenditure

Energy expenditure was measured by means of indirect calorimetry during physical activity and by means of a CosMed K4B2

portable metabolic cart (Rome, Italy) during rest. Participants were asked to abstain from any food or caloric beverages for 2 hours prior to assessing energy expenditure. On arrival at the research center, children were required to rest for 15 minutes. After 15 minutes of seated rest, seated energy expenditure was measured. Following the measurement of seated energy expenditure, energy expended during 7 activities (6 exergames and treadmill walking) was measured. Each activity was assessed for 10 minutes. Participants were given 5 minutes of seated rest between each activity. During this rest period, participants were allowed to drink water as needed. All tests were performed using equipment appropriate for children and adolescents.

Exergame Enjoyment

Immediately following participation in each exergame, enjoyment was measured using a 10-point discrete analog scale. Participants were asked the following question: "How much did you enjoy this activity?" The scale was anchored by "not at all" on the left and "very much" on the right. Analog scales have been used to successfully measure physical activity enjoyment in children.^{21,23}

Body Composition

Adiposity was estimated using body mass index (BMI; calculated as weight in kilograms divided by height in meters squared). Body mass was assessed using a digital scale (Tanita Corp, Arlington Heights, Illinois), accurate to the nearest ± 0.1 kg, and body height was measured barefoot, using a wall-mounted stadiometer (Tanita Corp) to the nearest ± 0.1 cm. During this assessment, participants wore a standardized T-shirt and shorts.

Body composition was assessed to allow for energy expenditure to be expressed in relative terms (ie, calories per kilogram lean body mass). Whole-body dual-energy x-ray absorptiometry (GE Healthcare, Pittsburgh, Pennsylvania) was used to determine fat-free mass, fat mass, and percent body fat.²⁴

DATA ANALYSIS

Means and standard deviations were calculated and reported for all independent and dependent variables. BMI percentile was calculated based on the Centers for Disease Control and Prevention 2000 growth charts.²⁵ Metabolic equivalent task values were calculated by dividing relative energy expenditure for each activity by $3.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Repeated measures analysis of variance was used to compare energy expenditure between activities and exercise enjoyment. Interactions between energy expenditure, BMI classification, and sex were evaluated. Covariates were used as needed to adjust for potentially confounding relationships and included age, sex, lean body mass, and BMI classification. We performed post hoc pairwise analysis using paired *t* tests. Bonferroni corrections were made when appropriate. All analyses were done using SAS version 9.12 (SAS Institute Inc, Cary, North Carolina), and the α level was set at $P \leq .05$.

RESULTS

Demographic data of all study participants are shown in **Table 1**. In general, girls had a higher body weight, BMI, and percent body fat than did boys. There was no difference in energy expended at rest between boys and girls.

All forms of interactive gaming evaluated in our study significantly increased energy expenditure above

Table 1. Demographic Data on 39 Children Recruited From Local Schools and After-School Programs in Boston, Massachusetts

Characteristic	Mean (SD) Values		
	Boys (n=19)	Girls (n=20)	Total (n=39)
Age, y	11.4 (2.0)	11.6 (2.1)	11.5 (2.0)
Body mass, ^a kg	53.5 (18.2)	56.8 (14.6)	55.2 (16.3)
BMI ^a	22.8 (6.5)	24.1 (4.3)	23.5 (5.5)
BMI percentile ^a	74.1 (27.5)	84.2 (19.3)	79.4 (23.7)
Body fat, ^a %	22.9 (13.2)	36.8 (10.2)	29.8 (13.6)
Energy expenditure at rest, kJ·d ⁻¹	1.17 (0.43)	1.02 (0.23)	1.09 (0.34)

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

^aSignificant difference between boys and girls ($P \leq .05$).

rest ($P \leq .05$). The energy expenditures for all the activities are reported in **Table 2** and **Figure 1**. The energy cost was highest for Xavix Jackie Chan Alley Run and Sportwall, followed by LightSpace Bug Invasion, Cybex Trazer Goalie Wars, DDR, and Nintendo Wii Boxing. Energy expended while walking at 3 miles per hour (to convert miles to kilometers, multiply by 1.6) on a treadmill was similar to the Nintendo Wii Boxing and DDR but lower than the other 4 forms of exergaming (Figure 1).

Based on BMI percentile, 21 participants (54%) were either overweight (12 [31%]) or at risk for overweight (9 [23%]), and 18 (46%) were normal weight. There were 9 boys (mean [SD] age, 11.3 [2.0] years; mean [SD] BMI, $27.7 (6.3) \text{ kg m}^{-2}$) and 12 were girls (mean [SD] age, 11.2 [2.4] years; mean [SD] BMI, $26.3 (3.6) \text{ kg m}^{-2}$) who were overweight or at risk for overweight, and there were 10 boys (mean [SD] age, 11.5 [2.1] years; mean [SD] BMI, $18.5 (2.1) \text{ kg m}^{-2}$) and 8 girls (mean [SD] age, 12.0 [2.3] years; mean [SD] BMI, $20.6 (3.0) \text{ kg m}^{-2}$) who were in the normal BMI percentile range. As shown in Table 2, there was no significant difference in total energy expenditure measured in kilojoules per minute or metabolic equivalent task values between children who were in the upper BMI percentiles (≥ 85 th percentile) and children who were in the lower BMI percentiles (< 85 th percentile) for any of the exergaming activities ($P \leq .05$). When total lean body mass was controlled, children with a higher BMI expended significantly more energy than did normal-weight children during all activities except the Sportwall ($P \leq .05$).

Generally, boys enjoyed the exergames more than did the girls, but there were some specific sex differences. Boys enjoyed Wii Boxing and Xavix J-Mat significantly more than did girls ($P \leq .05$). Girls enjoyed DDR significantly more than did boys ($P \leq .05$). Enjoyment of the activities was similar between boys and girls for LightSpace, Sportwall, Cybex Trazer, and walking (**Figure 2**). These results were independent of BMI classification.

Overall, children in the higher BMI percentiles (≥ 85 th percentile) enjoyed the exergames more than did children in the lower BMI percentiles (< 85 th percentile). When comparing enjoyment of the various exergames,

Table 2. Energy Cost of Exergaming Activities by Body Mass Index Classification

Activity	Mean (SD) Total Energy Expenditure, kJ·min ⁻¹				Mean (SD) Metabolic Equivalent Task Value			
	BMI < 85th Percentile (n=19)	BMI ≥ 85th Percentile (n=20)	Total (n=39)	P Value	BMI < 85th Percentile (n=19)	BMI ≥ 85th Percentile (n=20)	Total (n=39)	P Value
	Rest	4.4 (1.5)	4.7 (1.7)	4.6 (1.6)	.65	1.2 (0.3)	1.1 (0.2)	1.1 (0.2)
Treadmill walking ^a	17.8 (4.3)	19.2 (4.8)	18.5 (4.6)	.42	5.0 (0.9)	4.8 (0.5)	4.9 (0.7)	.66
Wii Boxing	16.1 (5.3)	17.3 (7.1)	16.7 (6.2)	.58	4.3 (1.6)	4.1 (1.6)	4.2 (1.6)	.75
DDR Thirteen	18.6 (5.3)	22.4 (6.6)	20.5 (6.0)	.06	5.2 (2.0)	5.5 (1.6)	5.4 (1.8)	.59
Cybox Trazer Goalie Wars	22.1 (8.7)	23.8 (8.5)	22.9 (8.6)	.56	6.1 (1.6)	5.8 (1.4)	5.9 (1.5)	.53
LightSpace Bug Invasion	22.0 (6.1)	25.5 (6.3)	23.8 (6.2)	.13	6.5 (1.5)	6.3 (1.7)	6.4 (1.6)	.73
Sportwall	24.1 (6.5)	27.8 (9.3)	26.0 (7.9)	.22	7.5 (2.0)	6.9 (1.4)	7.2 (1.7)	.16
Xavix J-Mat	27.1 (9.3)	29.1 (7.7)	28.1 (8.5)	.49	7.1 (2.2)	7.0 (1.5)	7.0 (1.8)	.80

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); DDR, Dance Dance Revolution.
^aFor 3 miles per hour (to convert miles to kilometers, multiply by 1.6).

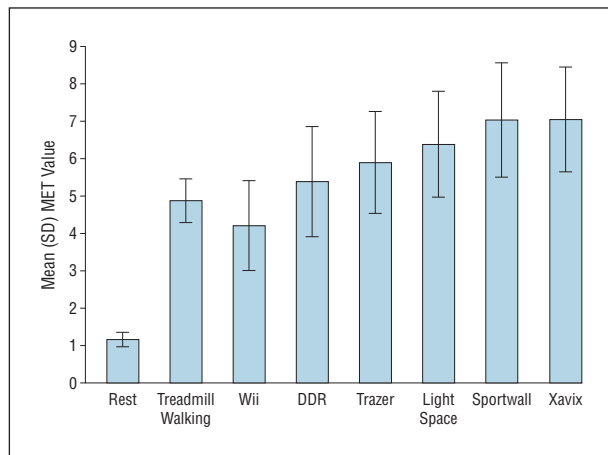


Figure 1. Mean (SD) metabolic equivalent task (MET) values for rest, walking, and exergaming for 39 children recruited from local schools and after-school programs in Boston, Massachusetts. There was a significant difference in energy expenditure during all forms of exergame play compared with rest ($P \leq .05$). There was a significant difference in energy expenditure during Trazer, LightSpace, Sportwall, and Xavix compared with treadmill walking for 3 miles per hour ($P \leq .05$). The MET value is the energy expended in the activity in relation to the energy expended at rest; 1 MET is equal to the energy expended at rest or $3.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. DDR indicates Dance Dance Revolution.

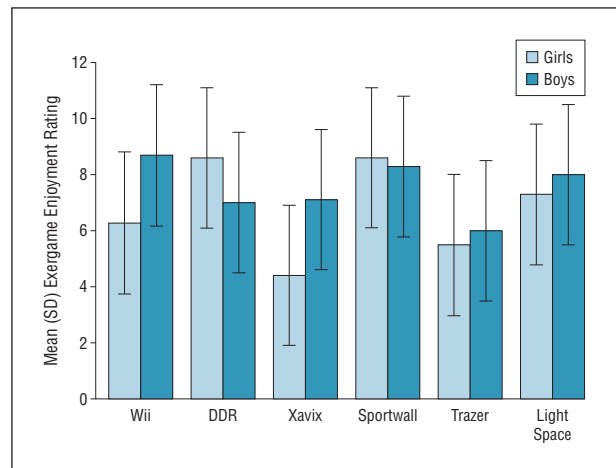


Figure 2. Mean (SD) enjoyment ratings by exergame and sex. Enjoyment was measured using a 10-point discrete analog scale. The ratings were given by 39 children recruited from local schools and after-school programs in Boston, Massachusetts. There was a significant difference in enjoyment between boys and girl regarding Wii, Dance Dance Revolution (DDR), and Xavix ($P \leq .05$).

children with higher BMIs enjoyed Sportwall to a greater extent than did children with lower BMIs ($P \leq .05$) (**Figure 3**). There was no difference in enjoyment for the other exergames. Sex did not alter these results.

COMMENT

The objective of our study was to examine the potential effect of interactive digital gaming activities (exergaming) on energy expenditure among middle school-aged children. Based on the finding of our study, energy expenditure was elevated to a moderate to vigorous intensity level for all the activities evaluated. There was a 4-fold to 8-fold increase in energy expenditure above rest for the various forms of gaming. Exergaming compared favorably with walking on a treadmill at 3 miles per hour, with 4 out of the 6 activities resulting in higher energy expenditure. This increase in intensity was similar be-

tween children in the higher (≥ 85 th percentile) and lower (< 85 th percentile) BMI percentiles. This level of intensity is consistent with current physical activity recommendations for children and can be used to alter energy balance.²⁶

Previous research in exergaming has demonstrated the potential of activity-promoting video games to increase energy expenditure when compared with traditional seated game play. Gaming systems that have been evaluated include Sony Playstation, Xavix, and Nintendo Wii. The studies that have evaluated these games have demonstrated that activity-promoting video games can increase energy expenditure when compared with sedentary video games. For example, Wii Sports has been evaluated and shown to increase energy expenditure 2.3 times above rest for Bowling, 2.5 times above rest for Tennis, and 3.0 to 4.2 times above rest for Boxing.¹⁶⁻¹⁸ Xavix has also been evaluated and has demonstrated energy expenditure that is 5.5 and 2.0 times above rest for the J-Mat and Bowling, respectively.¹⁴ The Sony Playstation EyeToy has also been evaluated, demonstrating energy ex-

penditure 2.1 times above rest.¹⁵ Dance Dance Revolution is an example of a game that is offered across multiple gaming platforms. Research assessing the energy cost of DDR has demonstrated an increase in energy expenditure that is 2.7 to 4.1 times above rest.^{15,17,20} These studies demonstrate the potential for activity-promoting video games to elevate energy expenditure when compared with traditional, seated video gaming, taking a relatively sedentary activity and increasing the energy expenditure 2 to 5 times above rest.

In contrast to previous research into exergaming, our study was designed to maximize energy expenditure from the various games in an effort to examine the potential therapeutic effect of exergaming. As a result, findings from our study demonstrate energy costs that are higher than seen previously on similar gaming systems. For example, the energy cost of playing Xavix J-Mat was 7 times above rest in the present study but only 5.5 times above rest in the Mellecker and McManus study.¹⁴ Dance Dance Revolution was 5.4 times above rest compared with 2.7 to 4.1 times above rest in other studies.^{15,17,20} Wii Boxing was 4.2 times above rest compared with 3.0 to 4.2 times above rest in previous research.¹⁶⁻¹⁸ These findings demonstrate that game choice and level selection, as well as the gaming environment, can influence how much energy is expended while playing exergames.

In addition, to our knowledge, previous research has not examined commercial exergaming equipment that is currently being marketed to schools and fitness facilities as an alternative form of exercise. The Sportwall, Cybex Trazer, and LightSpace all demonstrated a significant increase in energy expenditure and resulted in metabolic equivalent task values of 6.0 to 7.2. Children who played these games were getting moderate to vigorous activity.

Of the activities that were evaluated in our study, all were well tolerated, and self-reported enjoyment was very high. Sportwall was the most enjoyed activity, followed by DDR (Thirteen), LightSpace (Bug Invasion), Wii (Boxing), Cybex Trazer (Goalie Wars), and Xavix (J-Mat). It should be noted that these results apply to the specific game that was played, and it is likely that other games on the same gaming console would produce different results in enjoyment level.

Although the children generally enjoyed the games, there were some differences between boys and girls and between BMI classifications. Boys enjoyed Wii (Boxing) and Xavix (J-Mat) more than did girls. On the other hand, girls preferred DDR more than did boys. The commercial equipment was enjoyed to a similar extent between boys and girls.

Children at risk of becoming overweight or who were overweight enjoyed the exergames to a greater extent than did children with a BMI below the 85th percentile. However, the follow-up analysis demonstrated that the only significant difference between BMI classifications was that children with higher BMIs enjoyed Sportwall to a greater extent than did children with lower BMIs. Sportwall was unique in that it was played in teams, and the activity was intermittent and of a high intensity. Thus, the social interaction and intermittent high-intensity nature of the activity may be why the children with higher BMIs

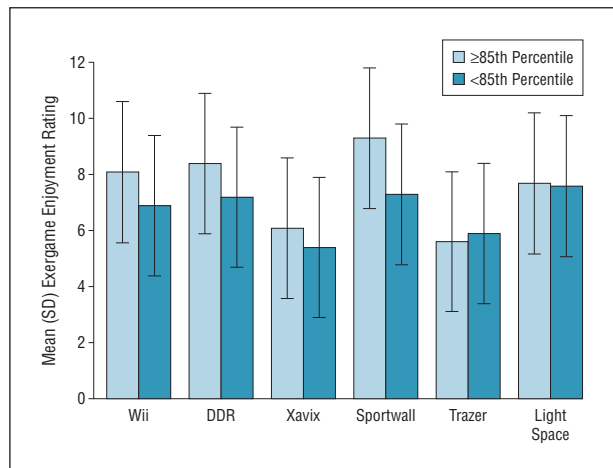


Figure 3. Mean (SD) enjoyment ratings by exergame and body mass index (BMI) classification. Enjoyment was measured using a 10-point discrete analog scale. The ratings were given by 39 children recruited from local schools and after-school programs in Boston, Massachusetts. There was a significant difference in enjoyment between children with a BMI in the ≥ 85 th percentile and children with a BMI in the < 85 th percentile regarding Sportwall ($P \leq .05$). DDR indicates Dance Dance Revolution.

enjoyed the activity more than did the children with lower BMIs. The enjoyment for those children in the higher BMI percentiles was seen despite a relative increase in exercise intensity, as demonstrated by an elevated energy cost per kilogram lean tissue compared with the normal-weight children.

Although these results address important gaps in the literature, there are some limitations that should be addressed. Energy expenditure was measured for only 10 minutes and likely overestimates the energy cost of exergaming compared with free game play. However, our goal was to evaluate the potential of these games to increase energy expenditure. Another limitation was that the fasting period for the study was only 2 hours. This may have resulted in a slightly elevated metabolism but was necessary so that children were not so hungry during testing as to limit their ability to participate effectively in the activities. In addition, there was no attempt to match children in the higher and lower BMI percentiles. The decision to make this comparison was done post hoc, and the results should be interpreted with this limitation in mind. Finally, the games and levels that were examined were chosen a priori; thus, choice was not evaluated in our study. Future research should address what children will choose to do if given the opportunity to freely play.

Although exergaming is most likely not the solution to the epidemic of reduced physical activity in children, it appears to be a potentially innovative strategy that can be used to reduce sedentary time, increase adherence to exercise programs, and promote enjoyment of physical activity. This may be especially important for at-risk populations, specifically children who carry excess body weight. Future research should longitudinally evaluate the impact of exergaming on physical activity patterns in youth. In addition, more research is needed to evaluate how prolonged participation in exergaming alters energy balance and adiposity.

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Author Contributions: Dr Bailey had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Bailey and McInnis. Acquisition of data: Bailey. Analysis and interpretation of data: Bailey. Drafting of the manuscript: Bailey. Critical revision of the manuscript for important intellectual content: Bailey and McInnis. Obtained funding: Bailey and McInnis. Administrative, technical, and material support: Bailey.

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Additional Information: The Department of Exercise and Health Sciences, University of Massachusetts, Boston, was the institution where our study was conducted.

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