ARTICLE

Energy Expenditure and Cardiovascular Responses to Seated and Active Gaming in Children

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Objective: To examine energy expenditure and cardiovascular responses in children during seated and active gaming.

Design: Comparison study.

Setting: Children's Exercise Laboratory, University of Hong Kong.

Participants: Eighteen children (aged 6-12 years) recruited from local primary schools.

Main Exposure: Active and seated computer games played by all participants.

Main Outcome Measures: Resting energy expenditure and heart rate measured before gaming, during seated gaming, and during use of 2 active gaming formats (XaviX bowling and XaviX J-Mat; SSD Company Ltd, Shiga, Japan). We used repeated-measures analyses of variance to compare the outcome measures.

Results: The energy expenditure was significantly higher during seated gaming (mean [SD], 1.31 [0.19] kcal/min^{-1}; $P<.001$), XaviX bowling (1.89 [0.45] kcal/min^{-1}; $P<.001$), and XaviX J-Mat gaming (5.23 [1.63] kcal/min^{-1}; $P<.001$) compared with rest. The energy expended above rest was significantly higher for the 2 active gaming formats ($P<.001$ for both) compared with seated gaming. The heart rate was significantly higher during XaviX bowling (mean [SD,]102 [20] beats/min^{-1}; $P<.001$) and XaviX J-Mat gaming (160 [20] beats/min^{-1}; $P<.001$) compared with rest. Heart rate during the XaviX J-Mat gaming was significantly higher than during seated gaming ($P<.001$).

Conclusions: This study has shown that using active gaming media results in meaningful increases in energy expenditure and heart rate compared with the seated screen environment. Manipulating the gaming environment can provide children with appealing activity alternatives, and further development of "exertainment" interventions is warranted, in particular determination of sustainability.

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DESPITE MANY PREVENTAtive efforts, levels of obesity in children and adolescents continue to rise on a global scale. Exercise intervention strategies targeting weight loss in children have had limited results, and reported achievements have been small and transient.[1,2] Although conventional exercise provides additional energy expenditure for children, it must compete with the entertainment value of gaming media, which are rapidly becoming the preferred leisure-time activity of choice for most school-aged children.[3,4] In the last decade, computer and video game sales have grown by US$5.2 billion,[5] and more than 83% of US children and adolescents aged 8 to 18 years report having video game players in their bedrooms.[4] In a recent European comparative study, electronic games were reported to be used by more than 70% of the children in the survey group.[3] A report from the Data Resource Centre on Child and Adolescent Health compiled survey data from all 50 US states and showed that the highest number of overweight children reside in Washington, DC, which also had the highest proportion of children who spent more than 4 hours daily in front of their video games.[6] This should not be surprising, because the time children spend in screen activities such as television viewing, using computers, and playing electronic games is largely spent seated and has been shown

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to compete with time spent in otherwise active lifestyle pursuits.[7,8]

Recent data from Lanningham-Foster et al[9] showed that sedentary screen time can be made active and the energy expended from active gaming formats is sufficient in principle to have an effect on energy balance. Their findings showed a 2-fold increase in energy expenditure when active gaming replaced seated gaming. Clearly, sedentary video gaming needs to be replaced with a kinetic activity that children will enjoy. This may be the motivation for the gaming industry's newest introduction of "exertainment" gaming systems. Several exertainment platforms exist, for example, the Dance Dance Revolution active gaming device (SSD Company Ltd, Shiga, Japan) that involves following certain foot patterns on an electronic dance mat in time with a selection of songs. The Dance Dance Revolution device was recently shown to increase energy expenditure by 68% above seated energy expenditure.[9] Investigating the energy cost of the gaming unit, Unnithan et al[10] also found that overweight and nonoverweight children increased heart rate intensity levels enough to meet the recommendations of the American College of Sports Medicine for developing and maintaining cardiorespiratory fitness. The EyeToy Kinetic (Sony Computer Entertainment Europe, Ltd, London, England) uses motion capture technology to depict a player's image on a screen and in a virtual gaming environment, enabling a range of game applications to be made active. Examples of game applications include the EyeToy Knockout (boxing game) and EyeToy Homerun (baseball game), which have been shown to increase energy expenditure by 6.5 and 6.0 kcal/min^{-1} above resting levels and elicit heart rate values of 142 and 138 beats/min^{-1} in children aged 10 to 14 years, respectively.[11] A recent active gaming concept that allows players to experience various activities (eg, bowling, fishing, tennis, golf) in a virtual world is the XaviX gaming system (SSD Company Ltd, Shiga, Japan). In addition to the exercise gaming modalities, the XaviX system includes a gaming mat (XaviX J-Mat) that allows participants to travel the streets of Hong Kong at a walk or a run, avoiding obstacles and stamping out ninjas.

The objective of this study was to examine the energy cost and cardiovascular responses of active gaming using the XaviX bowling and XaviX J-Mat gaming systems in children. We hypothesized that playing the XaviX games would result in meaningful increases in energy expenditure and heart rate compared with the seated screen environment.

METHODS

The children in this study were recruited from local primary schools in Hong Kong. Parents were contacted by telephone and e-mail to confirm interest and to obtain initial consent. Of the 18 children (mean [SD] age, 9.6 [1.7] years) who agreed to participate in the study, none had any physical limitations or any chronic disease. All of the children were familiar with traditional seated computer gaming; however, the XaviX active gaming system was not commercially available at the time of this study, and none of the children had any experience playing the XaviX active games. In addition, none of the children reported having experience playing the seated bowling game before participating in this study. Informed written consent was obtained from their parents, and the research protocols were reviewed and approved by the institutional review board of our institution.

PROCEDURES

Resting Energy Expenditure

The measurement of resting energy expenditure occurred in a dimly lit, air-conditioned, quiet room. Resting energy expenditure was measured after a 12-hour overnight fast and abstinence from exercise. The children watched a self-selected video on a wall-mounted television screen while lying in a supine position. The children were observed throughout the testing period to ensure that their body position was maintained and they remained relaxed but conscious. A 20-minute protocol was used to measure resting energy expenditure, which included a 5-minute rest period followed by 15 minutes of measurement.

Seated and Active Gaming

Consistent with other gaming studies,[11,12] all interactive games were played for 5 minutes to mimic the short-duration play patterns common among primary school–aged children and allow enough time for the children to reach steady state oxygen uptake.[13] A computer-generated 10-pin bowling game was used for the seated gaming format. This game requires the mouse to be held down for a predetermined time and then released to complete a successful bowl. This game was played for 5 minutes seated at a computer desk. Two active game formats were chosen from the XaviX gaming system—XaviX bowling and XaviX J-Mat Jackie's Action Run. The bowling game includes a wireless bowling ball with wrist strap, game cartridge, and a XaviX port receiver connected to a television screen. Bowling was played in Challenge Games mode 3. To complete a successful bowl, participants stood 3 to 5 ft (to convert to meters, multiply by 0.3) away from the television screen and swung the wireless ball over the sensors in the XaviX port as performed in 10-pin bowling. Participants worked against the clock to knock down as many pins as possible in 5 minutes. The XaviX J-Mat gaming system also uses wireless technology to record game performance and the number of steps taken on a gaming mat and relay this to the XaviX port receiver, connected to a television screen. The XaviX J-Mat gaming system was set to play level 1 of Jackie's Action Run. The children were required to travel for 5 minutes through the streets of Hong Kong, occasionally dodging barriers in the road by sidestepping, squatting, jumping, and stamping out virtual ninjas. Participants were free to choose the intensity at which they completed the journey (walking or running) and the intensity of the jumps, squats, side steps, and stamps to destroy the ninjas or avoid the barriers.

After a 5-minute familiarization period to habituate the children to the gaming systems, each child completed a 25-minute gaming protocol. This consisted of the 5-minute seated baseline measure, 5 minutes of seated computer bowling, 5 minutes of XaviX bowling, 5 minutes of seated rest, and 5 minutes of XaviX J-Mat gaming. The gaming protocol order was arranged in an attempt to reduce energetic carryover between gaming formats. Energy expenditure was assessed throughout the protocol via indirect calorimetry.

Main Outcome Measures

Resting and gaming energy expenditures were measured using an indirect calorimeter (Oxycon Pro; Viasys Healthcare, Warwick, England). Before testing, gases of known concentra-

Table 1. Descriptive Characteristics of the Children

Patient No./ Sex/Age, y	Height, cm	Weight, kg	BMI
1/M/7.8	130.4	25.8	15
2/M/8.1	141.1	32.7	16
3/M/8.9	135.5	27.5	15
4/M/9.1	142.0	34.4	17
5/M/10.1	143.8	35.9	17
6/M/10.4	127.3	25.1	15
7/M/10.4	144.0	41.5	20
8/M/10.5	141.0	46.5	23
9/M/10.6	133.5	28.3	16
10/M/11.9	140.7	44.5	22
11/M/13.1	154.1	56.9	24
12/F/6.1	119.5	23.0	16
13/F/8.1	133.5	27.2	15
14/F/8.9	129.1	27.6	17
15/F/9.1	146.4	42.9	20
16/F/9.1	137.7	36.2	19
17/F/9.1	138.4	40.2	21
18/F/11.9	156.0	42.5	17

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

tions were used to calibrate the volumes of oxygen consumption and carbon dioxide output. Calibration of the turbine volume sensor was performed using a 3-l syringe. A pediatric-sized face mask (model 8950; Hans Rudolph Inc, Kansas City, Missouri) was fitted on the children with hook and loop fastener (Velcro; Velcro, Manchester, New Hampshire) straps and checked for proper fit and leakage. Data were integrated to an 8-breath average. Heart rate was measured using a commercially available heart rate monitor (Polar Inc, Lake Success, New York).

DATA ANALYSIS

Means and standard deviations were computed for key variables. We compared the energy expenditure and heart rate during rest and during seated and active gaming using repeated-measures analysis of variance. We also compared the energy expended and the increase of the heart rate from resting during seated and active gaming with the repeated-measures analysis of variance. We computed post hoc pairwise comparisons using paired *t* tests with Bonferroni correction where necessary. A *P* value of .05 was set a priori.

RESULTS

Descriptive characteristics of each of the 18 children are shown in **Table 1**. The group had a mean body mass of 35.5 (9.2) kg and a mean height of 138.6 (9.1) cm. Five children (30%) were considered overweight as defined by body mass index (calculated as weight in kilograms divided by height in meters squared), although none were obese.[14]

Mean resting energy expenditure was 1376 (267) kcal/day^{-1}, whereas the mean resting heart rate was 81 (12) beats/min^{-1}. **Table 2** lists descriptive data for the energy expended and heart rate for the seated and active gaming formats. Energy expended in all game formats was significantly higher than resting values when expressed in kilocalories per minute ($F_{1,19}=132.32$; $P<.001$) or kilocalories per kilogram of weight per minute^{-1} ($F_{1,21}=268.46$; $P<.001$). Statistically significant mean differences of 0.35, 0.93, and 4.27 kcal/min^{-1} were found between rest and the seated, XaviX bowling, and XaviX J-Mat gaming formats, respectively (for all, $P<.001$). Likewise, statistically significant mean differences of 0.01, 0.03, and 0.12 kcal/kg^{-1} per minute^{-1} were found between rest and the seated bowling, XaviX bowling, and XaviX J-Mat gaming formats, respectively. The percentage increases in energy expenditure in kilocalories per minute^{-1} above the resting energy expenditure were 39%, 98%, and 451% for the seated bowling, XaviX bowling, and XaviX J-Mat gaming, respectively.

The energy expended above that of rest was higher for the 2 active XaviX games compared with the seated game ($F_{1,19}=126.49$; $P<.001$). The energy expended during XaviX bowling resulted in 0.58 kcal/min^{-1} more than seated gaming, whereas the energy expended during XaviX J-Mat gaming resulted in 3.92 kcal/min^{-1} more than seated gaming. A greater variance in energy expended during active gaming was apparent for the more intense XaviX J-Mat game (**Figure**). The energy expended above the resting expenditure was 3.34 kcal/min^{-1} higher ($P<.001$) for the XaviX J-Mat game compared with the XaviX bowling game.

Heart rate was also significantly higher during gaming than rest ($F_{2,37}=104.79$; $P<.001$) (Table 2). Subsequent pairwise comparisons revealed significant differences between rest and the XaviX bowling game (20 beats/min^{-1}; $P=.003$) and between rest and the XaviX J-Mat game (79 beats/min^{-1}; $P<.001$). A mean difference of 8 beats/min^{-1} was apparent between rest and seated bowling; however, this failed to attain significance ($P=.055$). An increase in heart rate during the XaviX bowling and XaviX J-Mat gaming, compared with seated gaming, is apparent (Table 2); however, this was significant only for the XaviX J-Mat game ($P<.001$).

COMMENT

The energy expended from playing the active XaviX games in our study is similar to that recently reported in 2 separate studies investigating the effects of video gaming on energy expenditure using single-game formats.[9,11] When sedentary screen time was compared with active screen time, Lanningham-Foster et al[9] found a 2-fold increase in energy expenditure from active gaming. Replacing seated gaming with the active XaviX bowling and XaviX J-Mat gaming increased energy expenditure by 0.6 and 3.9 kcal/min^{-1}, respectively. This translates into a more than 4-fold increase in energy expenditure for the XaviX J-Mat game. Preventing weight gain requires an energy adjustment of approximately 150 kcal/d.[15] The 4-fold increase in energy expenditure when playing on the XaviX J-Mat would fill the proposed energy gap, if this game was played for 35 minutes a day.

Sedentary media time has been associated with increased snacking behavior.[16] In addition, these snack foods contain high levels of fat and sugar.[17] It has been estimated that 1 hour of television viewing equates to a consumption of approximately 16% of total daily caloric in-

Table 2. Energy Expenditure and Heart Rate During Seated and Active Gaming Conditions[a]

Conditions (N=18)	Mean Energy Expenditure, Mean (SD)			
	Kilocalories per Minute^{-1}	Kilocalories per Kilogram per Minute^{-1}	Kilocalorie per Minute^{-1} Above Resting	Heart Rate, Beats/min^{-1}, Mean (SD)
Rest	0.96 (0.19)	0.03 (0.01)		81 (12)
Seated bowling	1.31 (0.33)[a]	0.04 (0.01)[b]	0.35 (0.24)	89 (13)
XaviX bowling	1.89 (0.45)[a]	0.06 (0.01)[b]	0.93 (0.34)[b]	102 (20)[b]
XaviX J-Mat gaming	5.23 (1.63)[a]	0.15 (0.03)[b]	4.27 (1.51)[b]	160 (20)[b,c]

[a] The XaviX gaming system, including the bowling game and the J-Mat device, are from SSD Company Ltd, Shiga, Japan.
[b] Significantly different ($P < .001$) from rest.
[c] Significantly different ($P < .001$) from seated bowling.

take.[18] Decreases in sedentary time are thought to be paralleled by changes in energy intake.[19] Fat intake and total energy intake decreased when targeted sedentary behaviors such as television viewing, using computers, and video gaming were decreased in nonoverweight adolescent youth. When targeted sedentary behavior was reduced for 100 minutes, a reduction of 300 kcal/d resulted. It is possible that active gaming would result in similar reductions in energy intake, making the energy adjustment from active gaming even more pronounced.

It is clear from the results of our study that the application of technology can encourage children to be highly active. When gaming on the XaviX J-Mat, the mean heart rate was equal to the cutoff for vigorous exercise,[20] and if children were to play this game regularly, they could more easily meet current activity recommendations[21] that are otherwise not being met.[22] Furthermore, if adhered to, this may provide various health benefits associated with high-intensity exercise.[23] High-intensity activity has been shown to increase resting energy expenditure,[23] decrease postexercise energy consumption,[24] and increase fat oxidation during and after exercise.[25] In children, intermittent bouts of vigorous physical activity have been found to be linked to higher levels of cardiovascular fitness and lower levels of body fat.[26,27]

There are also numerous health benefits associated with lower-intensity physical activity, similar to the intensity elicited by the XaviX bowling.[28] In adults, accelerometer measures of light-intensity daily activities such as washing dishes, cooking, and ironing were shown to have a significant effect on 2-hour plasma glucose levels, independent of time spent in moderate to vigorous activities.[29] These findings are of particular clinical importance to cardiovascular disease because of the relationship between cardiovascular health and glucose tolerance.[30] In children, light-intensity activity has also been shown to improve metabolic control.[31] If the light-intensity XaviX bowling game was played for 20 to 30 minutes daily, it may well provide a pronounced benefit for many diseases associated with physical inactivity,[32] and this lower-intensity activity is likely to be more sustainable over longer periods than more vigorous intensity games.

In this study, a basis for using 5-minute protocols was to mimic the sporadic short-duration activity patterns noted in children.[33] Our results are in agreement with previous findings that showed children will engage in vigorous bouts of activity during short-duration active gaming.[12] This previous study also showed that high-intensity gaming accounted for only 6% of total game time. It is well documented that children's activity levels are interspersed with brief intervals of high-, medium-, and low-intensity activities,[33] and it would seem that when gaming, children maintain this intermittent style of play.[12] Observational findings suggest that when offered a variety of different gaming modes in a video game center setting, children spent only half of their time in the game center playing active games followed by periods of lower-intensity walking.[12] If interactive gaming is enjoyable and interesting for children, then it is plausible that children would switch gaming modes from high-intensity to moderate- to low-intensity gaming and then back again. This gaming style would represent normal play patterns and could act as a replacement for time spent in seated gaming.

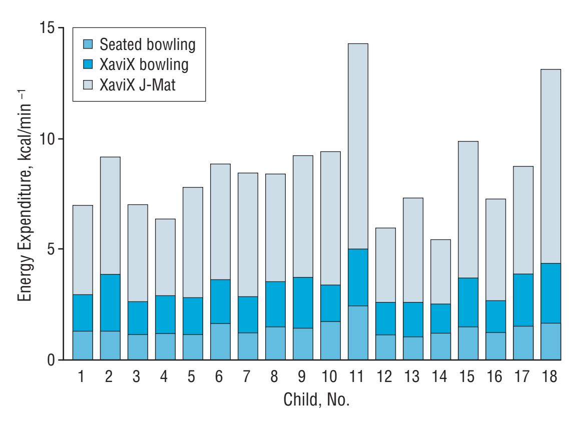

Figure. Energy expenditure during all gaming conditions for each child. The XaviX gaming system, including the bowling and J-Mat device, are from the SSD Company Ltd, Shiga, Japan.

The significant variance around the mean in energy expended while playing the XaviX J-Mat game suggests that the amount of energy expended is highly dependent on the user. This disparity was not as notable when users played the lower-intensity XaviX bowling game. It has been suggested that when children are given free choice, there is an overall preference for lower-intensity physical activity.[34,35] A child's perception of control appears to be higher when exerting free choice, which results in greater levels of self-reward and more reinforcement to participate in their preferred activity.[36] Various reports indicate that intensity preferences are mediated by sex, age, and weight differences. Girls have been found to participate in more lower-intensity activities than boys,[37] intensity of participation tends to decrease with age,[38] and lean children have been found to engage in more moderate to vigorous activity than their obese counterparts.[39] In a longitudinal study of physical activity habits, intensity preferences appeared to be a strong predictor of overall change in physical activity for 20 months.[40] Epstein et al[41] suggest that the preference for intensity of activity is dependent on the accessibility of the competing sedentary activity. In a later randomized control trial, Epstein et al[36] used rewards to decrease sedentary behaviors and increase physical activity or both. After 1 year, those who were provided positive reinforcement for reducing sedentary habits lost significantly more weight and had a bigger decrease in body fat percentage than the activity reinforcement or combined group. The noted behavior changes, which were shown to be related to the accessibility of activity, were also significant. When schedules were changed to limit the access of sedentary activities, the children in the sedentary group chose active instead of sedentary options. According to Epstein et al,[41] activity choice can be manipulated by modifying environmental constraints. The argument to support the substitution of inactive time with active time proposed by Epstein et al[36] has been explained using the behavioral economics model, which suggests that active behaviors can be achieved if access to sedentary behaviors that compete with being active are altered.[42]

The key to promoting sustainable activity in childhood is enjoyment. Children initiate and sustain video game playing because it is fun, exciting, and challenging.[43] Level of enjoyment appears to be a mediating factor when choosing to allocate time to sedentary or active leisure pursuits.[44] In preliminary studies involving male adults playing video games, dopaminergic responses, a physiological marker of enjoyment, were increased.[45] All of the children in this study verbalized their enjoyment of the gaming experience and were keen to continue gaming.

Data from the present study should be qualified within the limitations of this study. The 5-minute protocol we used did not allow for investigation into the sustainability of active gaming. However, our intention was to compare the energy expended and cardiovascular responses during active and seated gaming. Furthermore, we believed that prolonging the gaming time would have increased the gas collection process beyond the tolerance level of the children. Previous studies have shown that energy expenditure is highly variable between lean and obese adults.[46] Non–exercise activity thermogenesis is the energy expended for all nonsporting activities such as fidgeting and walking. In recent studies, lean adult subjects have been shown to participate in more non–exercise activity thermogenesis activities than their obese counterparts.[46] The subject characteristics in our study did not allow differences in active gaming energy expenditure between lean and obese children to be explored; however, gaming style and resultant energy expenditure might differ substantially between lean and obese children. In addition, single-game formats such as those provided for by XaviX may result in reduced compliance as children become overfamiliarized with the games. A gaming system capable of including multigaming formats, or access to multiple exertainment platforms may increase adherence and compliance. Clearly future research should determine sustainability of single-game formats.

Our data demonstrate that the 2 active gaming formats result in meaningful increases in energy expenditure compared with the seated screen environment. The next step is to test whether active gaming interventions can provide sustainable increases in childhood physical activity.

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Author Contributions: Dr McManus had full access to all of 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:* Mellecker and McManus; *Acquisition of data:* Mellecker and McManus; *Analysis and interpretation of data*: Mellecker and McManus; *Drafting of the manuscript*: Mellecker and McManus; *Critical revision of the manuscript for important intellectual content:* Mellecker and McManus; *Statistical analysis:* Mellecker and McManus; *Obtained funding:* McManus; *Administrative, technical, or material support:* Mellecker and McManus; *Study supervision:* McManus.

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> You send your child to the schoolmaster, but
> 'tis the schoolboys who educate him.
> —Ralph Waldo Emerson