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Exploring Energy Expenditure and Body Movement of Exergaming in Children of Different Weight Status

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Purpose: This study examined differences in energy expenditure and bodily movement among children of different weight status during exergames that varied in mode and intensity. ***Methods:*** Fifty-seven 8- to 12-year-old children including overweight/obesity (n = 28) and normal weight (n = 29) played three 10-minute interval Xbox One exergames (Fruit Ninja, Kung-Fu, and Shape Up) categorized based on predominantly upper-, whole-, or lower-limb movement, respectively. The authors measured bodily movement through accelerometry and obtained energy expenditure and metabolic equivalent (MET) via indirect calorimetry. ***Results:*** Energy expended during gameplay was the highest in Shape Up ($P < .01$) and higher in Kung-Fu than Fruit Ninja ($P < .01$). Absolute energy expenditure was significantly higher in overweight/obese children ($P < .01$), but not when controlling for body mass across 3 exergames ($P > .05$). Based on the MET cut-points, overweight/obese children spent more time at light intensity (<3 METs) for Fruit Ninja ($P < .05$) and Shape Up ($P < .01$), but less time at vigorous intensity (≥6 METs) for Kung-Fu ($P < .01$) and Shape Up ($P < .01$). Lower-limb movements during Shape Up were less in overweight/obese children ($P = .03$). ***Conclusion:*** Although children in both groups expended similar energy relative to their body mass during gameplay, overweight/obese children spent more time at light intensity but less time at vigorous intensity with fewer movements especially while playing a lower limb–controlled exergame.

Keywords: active video game, pediatric obesity, gameplay intensity, activity counts, oxygen consumption

The prevalence and severity of obesity continue to increase in children; currently, one third of children are overweight or obese in the United States (25). Children at a higher body mass index (BMI) are more prone to become overweight or obese adolescents and adults (23). Childhood obesity is associated with the development of early signs of metabolic syndrome, type 2 diabetes, and cardiovascular disease (40); impaired peer relationships, school experiences, and academic achievement (8); and a higher chance of early death in adulthood (6).

Physical inactivity appears to be a primary factor for increasing fat accumulation and adiposity (6). Given that more physical activities and fewer sedentary activities are known to be promising strategies for preventing childhood obesity (3,39), at least 1 hour of moderate- to vigorous-intensity physical activity (46) and less than 2 hours of screen time have been recommended for children on a daily basis (12,16). Only one in 5 children meets the physical activity recommendations and about one in 3 children meets the screen time guidelines (33). Furthermore, physical activity levels begin to decline (17) and differ by weight status (11) at age 7; thus, physical activity behavior should be enhanced, especially for preadolescent children around the ages of 8–12 years.

Perhaps unsurprisingly, overweight or obese children are frequently less physically active (15), especially at moderate- and vigorous-intensity levels in free-living conditions (43), and perform poorly on fitness tests (32) compared with their normal weight counterparts. As a new type of entertainment coupling body movements and video gaming, exergames (also known as active video games) are being used to provide additional opportunities for increasing children's energy expenditure and for reducing their sedentary pursuits (52). In the last decade, studies have increasingly utilized exergames for physical activity and health promotion (4,51). However, the relationship between energy expenditure and bodily movement in children of varying weight status using different modes of exergames is still relatively unknown (5,37).

The use of exergames capable of achieving a light- to vigorous-intensity level of physical activity (assessed via indirect calorimetry) through various platforms such as Xbox (10), Wii (36), and Dance Dance Revolution (1,55) has been reported in the literature.

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In comparing energy cost of exergaming activities between different weight groups, energy cost values were found to be higher in obese children and adolescents compared with their counterparts; however, these differences were inconsistent after adjusting for body size (2,36) or body composition (10,42,55). Furthermore, few studies to date have compared the results of whether moderate- or vigorous-intensity levels, based on the metabolic equivalent (MET) cut-points, were attained between weight groups (10,42). Those that have been done have reported conflicting results. Furthermore, exergames require bilateral movements in different directions (30,31); thus, the measure of both upper- and lower-bodily movements may contribute to the understanding of the relationship between body movement and energy expenditure during exergames played in different modes and at different levels of intensity. In addition, few studies have assessed bodily movement using the number of steps taken from an ankle-worn monitor (22,42). Given this methodological consideration, a more refined experimental approach with age- and sex-matched controls should be considered when comparing different weight status. Moreover, an assessment of the distinctive intensities and modes (upper, whole, and lower body) that exergames offer has not been extensively examined. These issues should be addressed because the influence of exergaming on energy expenditure and bodily movement may differ depending on the weight status of their players. Such information would contribute to the development and intervention of physical activity programs designed for overweight or obese children.

We therefore examined the hypotheses that (1) exergames can increase energy expenditure to a moderate- to vigorous-intensity level, the specific levels of which would be dependent on different exergaming modes and the weight status of the individual playing; (2) children with higher BMIs would expend less energy after energy expenditure was adjusted for their body mass; and (3) children with higher BMIs would spend less time and use fewer lower-limb movements, especially in more intense exergames, compared with their counterparts. If our hypotheses are supported, such information could provide insight into feasible and effective strategies using exergaming technology for developing a successful physical activity regimen that may be used as part of childhood obesity prevention.

Methods

Participants and Design

In a cross-sectional study design, we recruited children of various ethnic backgrounds and of both genders from a community in the Greater Boston region through web advertisements and flyers. Participants had to be (1) between 8 and 12 years old, (2) free of attentional disorders or physical disability, (3) free of any medication that affected the central nervous system, and (4) had not previously engaged in the exergames used in our study. Among 421 individuals who responded, 81 were eligible and expressed interest in participating in this project. The remaining 340 who responded were either not eligible due to the age criteria or were excluded in order to balance either BMI percentile, gender, or race between the 2 weight groups. Of those eligible, 24 failed to attend their scheduled study sessions, leaving 57 participants in the present study. We conducted our study from March 2017 to May 2018 in a laboratory setting. This study was approved by the institutional review board at Northeastern University where the study was conducted. All participants and their parents provided written informed assent and consent for their participation.

Procedures

A single visit required for this study took approximately 90 minutes in the lab. Once a participant arrived at the lab, we provided the participant and his or her parent with an orientation regarding the study procedures after obtaining informed assent/consent. The participant completed a physical activity questionnaire, and then we assessed their anthropometric measurements. Next, we affixed devices to the children and carried out the exergaming sessions as described below.

Measures

Survey Instruments

Before the exergames, we used the Physical Activity Questionnaire for Older Children, which is a self-administered, 7-day recall questionnaire for children aged 8–14 years (13). The Physical Activity Questionnaire for Older Children is comprised of 10 items, 9 of which are structured to reflect moderate to vigorous physical activity. The questionnaire uses a 5-point Likert scale for each item (eg, 1 = no physical activity, 5 = 7 times or more physical activity) and then sums the scales of the 9 items and averages them as a composite score (56). Higher scores represent higher physical activity levels. We also queried previous game experience with a single question (ie, how much have you played Xbox Kinect games?) using a 3-point Likert scale (1 = little or no experience, 2 = some experience, and 3 = a lot of experience) (31). After the exergames, we evaluated the participant's enjoyment of each game using a 5-point smiley face Likert scale (1 = did not enjoy it at all and 5 = enjoyed it very much) (49).

Anthropometry

We measured stature (to 0.1 cm) using the ShorrBoard (Weight and Measure, LLC, Olney, MD) and body mass (to 0.1 kg) using the SECA scale (SECA Inc, Chino, CA) and then calculated BMI (kg/m^2) and BMI percentile using the Centers for Disease Control and Prevention (CDC) growth charts (35). Based on the participant's BMI percentile, we assigned each child to one of 2 groups: (1) the normal weight group (<85th percentile) or (2) the overweight/obese group (≥85th percentile) for analyzing differences between groups.

Heart Rate and Rating of Perceived Exertion

We placed a Polar H7 Bluetooth heart rate sensor (Polar Electro Inc, Lake Success, NY) on the chest with a soft textile strap to measure heart rate continuously during the testing session. Next, we downloaded heart rate data at 10-second intervals, and then values were expressed in beats per minute. We also collected their heart rates and children's OMNI scale of perceived exertion (category range: 0–10) (50) before and after each exergame.

Body Movement

We initialized 2 triaxial GT9X accelerometers (ActiGraph LLC, Pensacola, FL) at a 30-Hz sampling frequency with the ActiLife software (version 6.13.2; ActiGraph LLC) and set the Bluetooth wireless function for a wrist-worn GT9X to integrate with a Polar H7 Bluetooth heart rate sensor for continuous heart rate measurement. We then fitted the participant with 2 accelerometers on the nondominant wrist with a silicone wristband and at the anterior axillary line of the nondominant hip with a belt clip to measure upper- and lower-body movements, respectively, during the exergaming sessions (30).

We downloaded steps and activity counts from 3 axes (x axis: anteroposterior, y axis: vertical, z axis: mediolateral) with a normal filter at a 10-second epoch length previously used for exergaming featuring intermittent physical activities and obtained vector magnitude from all 3 axes $(x^2 + y^2 + z^2)^{1/2}$ (31). We then averaged vector magnitude of each 10-minute exergame session to see the difference of the amount and pattern of upper or lower movement by weight status.

Energy Expenditure

After calibrating the metabolic analyzer in accordance with the manufacturer's manual, we fitted a rubber face mask (Hans Rudolph Inc, Kansas City, MO) and then tested to ensure that there was no leakage of air. After a 20-minute seated rest, we measured 5 minutes of resting metabolic variables (eg, oxygen consumption [VO_2], energy expenditure) while a participant rested in a chair and subsequently three 10-minute intervals of exergaming activity using the breath-by-breath method with an indirect calorimetry of the COSMED K4b^2 (COSMED, Rome, Italy). We downloaded the metabolic data at 15-second intervals, and then VO_2 and energy expenditure were expressed in milliliters O_2 per minute (mL/min) and in kilocalories per minute (kcal/min), respectively. We obtained MET values as VO_2 consumed during each 10-minute exergame per kilogram of body weight divided by VO_2 consumed at the 5-minute rest per kilogram of body weight (equal to one MET) (19,34). Based on the American College of Sports Medicine's cut-points (19), we computed time spent at light (1.5–2.9 METs), moderate (3–5.9 METs), and vigorous (≥6 METs) intensities.

Exergaming Sessions

In terms of movement patterns and intensities, we chose 3 exergames using a Kinect camera monitor sensor on an Xbox One console (Microsoft Inc, Redmond, WA) that included predominantly an upper limb–controlled game (slicing), Fruit Ninja; a whole limb–controlled game (punching, kicking), Kung-Fu for Kinect (Kung-Fu); and a lower limb–controlled game (running, jumping, skating), Shape Up. We selected 5 minigames from Fruit Ninja and Shape Up, and 3 minigames from Kung-Fu to ensure a 10-minute duration of each game session. After we confirmed that all instruments worked properly, a participant played the same sequence and game difficulty level (selected by an investigator) of the minigames in three 10-minute exergames with two 5-minute rests between the exergame sessions. The order of the exergames was randomized for Fruit Ninja and Kung-Fu but not for Shape Up. We observed that remaining fatigue (as indicated by higher resting heart rate and rate of perceived exertion) in our first 3 participants after their Shape Up play (even following the 5-min rest) likely interfered with the participant's performance on the next exergame; thus, we decided that Shape Up should be placed as the last exergame sequence for all gameplay.

Data Analysis

With regard to our a priori hypotheses, we conducted power analyses using G*Power program (http://www.gpower.hhu.de/en.html) with power ($1 - \beta$) and alpha (α) set at 0.9 and .05, respectively, (18), and the results of these analyses indicated that our sample size (N = 57) assured an adequate power to detect the group difference in primary variables (ie, energy expenditure [$d = 0.50$]; time spent in moderate to vigorous intensity [$d = 0.46$]; and body movements [$d = 0.40$]). Means and SDs were calculated and reported for all dependent variables. Of the 57 participants, we analyzed 56 metabolic data sets due to a technical error in one participant. We used an independent t test to see the differences in participant characteristics by weight status and a chi-square (χ^2) statistic to investigate whether distributions of categorical variables (ie, weight groups, sex, race) differed from one another. We employed a repeated-measures analysis of variance to compare between-weight groups: (1) changes in heart rate and rating of perceived exertion before and after each exergame; (2) upper- and lower-body movement (ie, activity counts) or metabolic variables (eg, VO_2, energy expenditure) across 3 exergames; and (3) exergaming intensity using METs (eg, light, moderate, vigorous) across 3 exergames. If we found a significant interaction or main effect, we performed a post hoc pairwise analysis using paired t tests with the Bonferroni adjustment for multiple comparisons. A log-linear mixed regression method was conducted to adjust for body mass in group comparisons of energy expenditure and VO_2 (58). Energy expenditure, VO_2, and body mass were log-transformed, and then a linear mixed regression model was constructed using log (energy expenditure or VO_2) as the dependent variable and log (body mass) as the independent variable. All statistical data analyses were conducted with SPSS (version 24.0; IBM, Armonk, NY). The criterion for significance was $P < .05$. We performed a Bonferroni correction for primary dependent variables and divided the critical P value (α) by the number of comparisons in 5 metabolic variables and 2 activity count variables, which were .01 and .03, respectively; thus, we reported the P values when generalizing results.

Results

Participant Characteristics

As shown in Table 1, 28 children with overweight/obesity and 29 children with normal weight completed this study. Age ($P = .19$); sex ($\chi^2 = 0.14$, $P = .71$); and race ($\chi^2 = 3.45$, $P = .49$) were balanced and similarly distributed between groups. A composite score of reported weekly physical activity level was not significantly different between groups ($P = .18$). However, game experience was significantly higher in children with overweight/obese than those of normal weight ($P < .01$). For the enjoyment of exergaming, all children reported the highest degree of enjoyment in Fruit Ninja (really good) and Kung-Fu (really good) and the least in Shape Up (good), $P < .01$, but we observed no difference between groups.

Heart Rate and Rating of Perceived Exertion to Exergames

Changes in heart rate and rating of perceived exertion before and after each exergame were not significantly different between groups after playing Fruit Ninja or Kung-Fu; however, the change in the rating of perceived exertion following Shape Up was significantly higher in children with overweight/obesity than those of normal weight ($P = .04$). In addition, continuous heart rate measured for each 10-minute exergame was not significantly different between groups (Table 2).

Bodily Movement to Exergames

Among 3 exergames, hip-measured activity counts ($P < .01$) were the highest in Shape Up and the lowest in Fruit Ninja, whereas wrist-measured activity counts ($P < .01$) were the highest in Fruit Ninja and the lowest in Shape Up. In comparing groups,

Table 1 Participants Characteristics

Characteristic	Normal weight	Overweight/obesity	*P*
Age	9.6 (1.4)	10.3 (1.4)	
Gender (boy/girl, n)	19/10	17/11	
Ethnicity, n (%)			
African American	5.0 (17.2)	8.0 (28.6)	
Asian	4.0 (13.8)	2.0 (7.1)	
White	15.0 (51.7)	10.0 (35.7)	
Hispanic/Latino	4.0 (13.8)	5.0 (17.9)	
Other (mixed)	1.0 (3.4)	3.0 (10.7)	
Grade in school	4.1 (1.4)	4.9 (1.1)	*
Height, cm	142.1 (12.2)	152.4 (9.5)	**
Weight, kg	33.8 (7.7)	61.8 (17.6)	**
BMI, kg/m^2	16.6 (1.8)	26.2 (5.0)	**
BMI percentile	42.8 (26.6)	95.9 (3.7)	**
Hour slept prior to the study	9.2 (1.3)	9.0 (1.7)	
Weekly physical activity level, scale[a]	2.5 (0.6)	2.8 (0.6)	
Xbox Kinect game experience, scale[b]	1.3 (0.5)	1.8 (0.7)	**
Enjoyment rate, scale[a]			
Fruit Ninja	4.3 (0.7)	4.1 (0.8)	
Kung-Fu	4.4 (0.7)	4.3 (0.8)	
Shape Up	3.7 (0.9)	3.4 (1.1)	

Abbreviation: BMI, body mass index. Note: Data are presented as mean (SD).
[a]Five-point Likert scale. [b]Three-point Likert scale.
*$P < .05$. **$P < .01$.

Table 2 HR and RPE of Exergaming

Variable	Normal weight	Overweight/obesity	*P*
Rest			
HR, bpm	88.64 (10.22)	90.61 (10.83)	
Fruit Ninja (upper)			
Pre-RPE, scale	1.3 (1.6)	2.2 (1.6)	
Post-RPE, scale	3.1 (2.4)	4.6 (2.0)	
Pre-HR, bpm	95.9 (12.7)	96.7 (12.3)	
Post-HR, bpm	144.1 (28.6)	145.4 (27.7)	
During HR, bpm	130.3 (21.4)	139.1 (20.4)	
Kung-Fu (whole)[a]			
Pre-RPE, scale	1.7 (1.7)	2.0 (1.8)	
Post-RPE, scale	3.2 (2.4)	4.3 (2.3)	
Pre-HR, bpm	95.8 (14.3)	94.6 (13.5)	
Post-HR, bpm	138.9 (22.4)	145.8 (18.3)	
During HR, bpm	152.8 (25.5)	152.3 (25.7)	
Shape Up (lower)[b]			
Pre-RPE, scale	2.1 (1.7)	2.6 (1.9)	
Post-RPE, scale	4.3 (2.9)	6.0 (2.4)	*
Pre-HR, bpm	100.4 (14.3)	103.3 (15.2)	
Post-HR, bpm	148.3 (23.7)	154.8 (19.1)	
During HR, bpm	163.8 (24.6)	163.1 (23.1)	

Abbreviations: bpm, beats per minute; HR, heart rate; RPE, rating of perceived exertion. Note: Data are presented as mean (SD).
[a]Significantly greater in Kung-Fu versus Fruit Ninja in HR during gameplay; $P < .01$. [b]Significantly greater in Shape Up versus Fruit Ninja and Kung-Fu in HR during gameplay and post-RPE; $P < .01$.
*$P < .05$.

hip-measured activity counts ($P = .02$) were significantly higher for children with normal weight versus their overweight/obese counterparts only in Shape Up, indicating more movement in the lower limbs (Figure 1).

Metabolic Response to Exergames

As shown in Table 3, among the 3 exergames, absolute values in VO_2 and energy expenditure were the highest in Shape Up (vs Fruit Ninja and Kung-Fu; (all Ps < .01), and the values were higher in Kung-Fu compared with Fruit Ninja ($P < .01$). In comparing groups, children with normal weight (vs children with overweight/obesity) had lower absolute values in VO_2 and energy expenditure for 3 exergames (all Ps < .01) and lower absolute VO_2 value at rest ($P < .01$), whereas there was no significant difference in respiratory exchange ratio either at rest and for 3 exergames between groups. Although absolute energy expenditure is commonly used in exercise prescription, it is necessary to adjust for body mass to compare energy expenditure between different weight groups. After controlling for body mass, a log-linear mixed regression analysis revealed that the group effects on either VO_2 consumed or energy expended during any of the exergames were not statistically significant, whereas normal weight children spent less energy at rest compared with overweight/obese children ($P = .01$).

Time Spent in Different Activity Intensity Levels

Among 3 exergames, all children had the highest METs when playing Shape Up ($P < .01$) and higher METs when playing Kung-Fu than Fruit Ninja ($P < .01$). MET values were higher in normal weight children compared with overweight/obese children when playing any of the exergames (all Ps < .01) as shown in Table 3. Based on the MET cut-points, normal weight children compared with overweight/obese children spent more time (in minutes) at moderate- to vigorous-intensity activity for Fruit Ninja (5.7 [4.1] vs 2.9 [3.2]; $P < .01$), Kung-Fu (7.1 [3.6] vs 5.5 [3.2]; $P = .08$), and Shape Up (7.7 [2.3] vs 5.6 [2.7]; $P < .01$). Normal-weight children compared with their overweight/obese counterparts spent more time at vigorous intensity for Kung-Fu (1.2 [1.9] vs 0.0 [0.0]; $P < .01$) and Shape Up (1.8 [1.9] vs 0.4 [0.8]; $P < .01$) and at moderate intensity only for Fruit Ninja (5.3 [3.8] vs 2.9 [3.2]; $P = .01$) but less time at light intensity for Fruit Ninja (4.5 [3.8] vs 6.7 [3.2]; $P = .02$) and Shape Up (1.7 [1.4] vs 2.8 [1.6]; $P < .01$) (Figure 2; Supplementary Table 1 [available online]).

Discussion

This study aimed to explore energy expenditure, bodily movement, and intensity of playing three 10-minute interval exergames in preadolescents of different weight status. Children in both groups experienced similar energy expenditure relative to their body mass for all exergames. Based on the MET cut-points, time spent was similar at moderate-intensity level, but more at light-intensity level and less at vigorous-intensity level in children with overweight/obesity, which is apparent while playing a more intense, lower limb–controlled exergame such as the Shape Up. These findings suggest that the pattern in the intensity during gameplay may differ in children of different weight status while expending energy in a similar fashion.

Prior reports indicate that exergaming increases levels of energy expenditure from light to vigorous intensity, but this depends on the exergaming environment (eg, game choice and its level and mode) (1,5). Consistently, our findings suggest that all children expended energy at the level of moderate intensity for Fruit Ninja game and almost at the level of vigorous intensity for Kung-Fu and Shape Up games based on cut-points for the activity intensity level using activity energy expenditure (47,54). Furthermore, in terms of different exergaming modes based on limb movement patterns, we classified Fruit Ninja, Kung-Fu, and Shape Up as upper limb-, whole body-, and lower limb–controlled games, respectively, as indicated by the findings that movements (measured by activity counts) of the lower limb were the greatest in Shape Up and the lowest in Fruit Ninja, whereas those of the upper limb were the opposite. Furthermore, energy expended during gameplay was the highest in Shape Up and higher in Kung-Fu than Fruit Ninja. This finding can be attributed to the game mode (eg, running, jumping) of lower limb–controlled Shape Up, which engages weight-bearing activities using larger muscle mass and thus demands more energy expenditure than Fruit Ninja (predominately requiring upper-limb movements) and Kung-Fu (using both

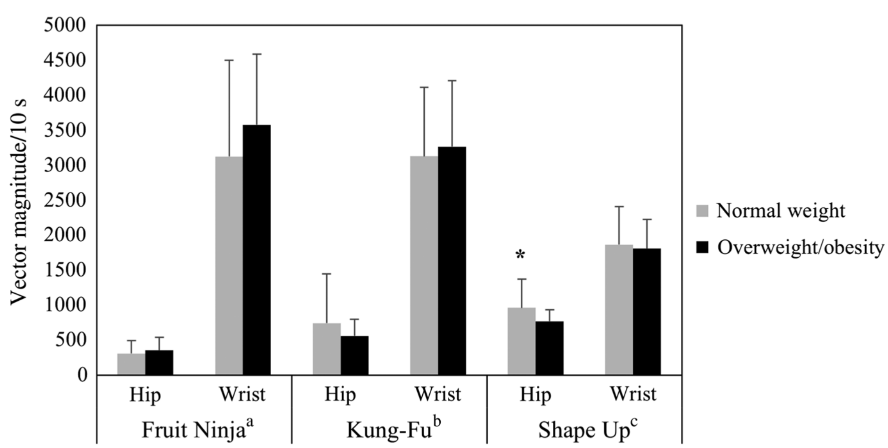

Figure 1 — Upper- and lower-limb movement. Activity counts obtained from a hip- and a wrist-worn accelerometers are presented for the three 10-minute interval exergames. Data are presented as mean (SD). [a]Significantly greater in Fruit Ninja versus Shape Up in wrist activity counts; $P < .01$. [b]Significantly greater in Kung-Fu versus Fruit Ninja in hip activity counts; $P < .01$. [c]Significantly greater in Shape Up versus Fruit Ninja and Kung-Fu in hip activity counts; $P < .01$. *$P < .05$.

Table 3 Metabolic Variables of Exergaming

Variable	Normal weight	Overweight/obesity	*P*
Rest			
VO_2, mL/min	246.33 (33.99)	381.24 (80.81)	**
Ln VO_2[a]	6.09 (0.43)	6.32 (0.35)	
EE, kcal/min	1.21 (0.16)	1.87 (0.41)	**
Ln EE[a]	0.18 (0.14)	0.60 (0.22)	*
RER (VCO_2/VO_2)	0.90 (0.05)	0.88 (0.07)	
Fruit Ninja (upper)			
VO_2, mL/min	722.91 (184.67)	971.47 (238.24)	**
Ln VO_2[a]	6.55 (0.26)	6.85 (0.25)	
EE, kcal/min	3.51 (0.90)	4.75 (1.21)	**
Ln EE[a]	1.22 (0.26)	1.52 (0.26)	
METs	3.54 (1.29)	2.58 (0.53)	**
RER (VCO_2/VO_2)	0.86 (0.05)	0.87 (0.05)	
Kung-Fu (whole)[b]			
VO_2, mL/min	887.60 (220.36)	1152.76 (246.71)	**
Ln VO_2[a]	6.75 (0.29)	7.03 (0.22)	
EE, kcal/min	4.26 (1.07)	5.63 (1.21)	**
Ln EE[a]	1.41 (0.29)	1.70 (0.21)	
METs	4.31 (1.44)	3.12 (0.63)	**
RER (VCO_2/VO_2)	0.86 (0.05)	0.87 (0.05)	
Shape Up (lower)[c]			
VO_2, mL/min	984.42 (233.48)	1317.06 (339.64)	**
Ln VO_2[a]	6.86 (0.25)	7.15 (0.27)	
EE, kcal/min	4.83 (1.17)	6.51 (1.72)	**
Ln EE[a]	1.54 (0.26)	1.84 (0.28)	
METs	4.74 (1.46)	3.53 (0.77)	**
RER (VCO_2/VO_2)	0.91 (0.10)	0.92 (0.07)	

Abbreviations: EE, energy expenditure; Ln, log-transformed values; MET, metabolic equivalent as the ratio of the exergaming metabolic rate to the resting metabolic rate; RER, respiratory exchange ratio; VCO_2, carbon dioxide output; VO_2, oxygen consumption. Note: Data are expressed as mean (SD).
[a]Log-linear mixed regression model was used to adjusted for body mass. [b]Significantly greater in Kung-Fu versus Fruit Ninja in all metabolic variables except for RER; $P < .01$. [c]Significantly greater in Shape Up versus Fruit Ninja and Kung-Fu in all metabolic variables; $P < .01$.
*$P < .05$. **$P < .01$.

upper- and lower-limb movements). This is consistent with a previous study (42) also showing greater energy expenditure during a Wii Jogging game than a Wii Boxing game.

In comparing groups, absolute energy expenditure was significantly higher in children with overweight/obesity than those with normal weight for all of the exergames, consistent with prior reports (1,42,55). However, after controlling for body mass using a log-linear mixed regression method, the adjusted energy expenditure did not differ between groups for any of the exergames. This finding could be explained by the fact that children in both groups put similar effort into Fruit Ninja or Kung-Fu as indicated by no difference in activity counts on the hip or the wrist and heart rate between groups. Despite having similar energy expenditure during Shape Up gameplay in both groups, children with normal weight had more lower-limb movement than their overweight/obese counterparts. These findings suggest that energy cost might be more efficient in children with normal weight than those with overweight or obesity especially during intense and weight-bearing activities (29,41) such as our Shape Up gameplay. Similar to our findings, other studies (1,10,36,55) adjusting for body mass or fat-free mass have not found any significant differences in energy expenditure as a function of weight status. However, a previous study (42) measuring body composition showed higher energy expenditure after adjusting for fat-free mass in lean children compared with obese children while playing Wii Jogging. These researchers hypothesized that there might be more angular movement at the knee in children with normal weight than those with obesity. Such inconsistent findings might be due to differences in some methodological conditions including data analysis (ratio vs regression) (58); a relatively small sample size (36); a wide age range (eg, age-related body size in energy expenditure) (34); an uneven distribution of sample size in boys and girls (eg, more energy expended in boys than girls) (22); or a difference in energy expended between upper- and lower-limb movements during gameplay (30). These might be important factors in comparing energy expenditure between weight groups. In addition, individual differences in the game experience might affect energy cost when an individual performs a chosen exergame. Individual fitness and physical activity levels independent of weight status might impact oxygen uptake, thereby affecting energy cost as well (20). Our baseline data suggest that physical activity levels were not significantly different between groups, whereas previous Xbox Kinect

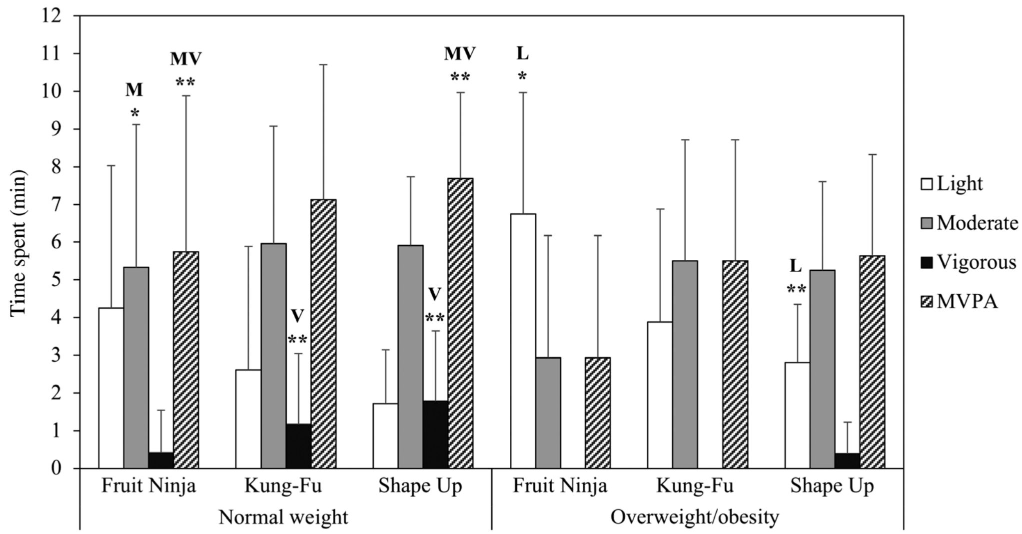

Figure 2 — Time spent in intensities of exergaming by MET. Time spent in L (1.5–2.9 METs), M (3–5.9 METs), and V (≥6 METs) in normal and overweight/obese children for each of three 10 minutes of exergames. 1 MET is equal to the metabolic rate while sitting at rest. Data are expressed as mean (SD). L, M, and V indicate light, moderate, and vigorous intensity, respectively; MET, metabolic equivalent; MVPA, moderate to vigorous physical activity. $*P < .05$. $**P < .01$.

game experience (unrelated to our chosen exergames) was more common in overweight/obese children than their normal weight counterparts. However, the results of energy expenditure or body movement remained even after controlling for the previous game experience as a covariate in the statistical model.

With regard to exercise intensity (19), we found that children with normal weight spent more time in vigorous intensity (>6 METs) and less time in light intensity compared with children who were overweight/obese, whereas children in both groups spent a similar amount of time in moderate-intensity activity (3–5.9 METs). Our results are consistent with a previous study (10) demonstrating that there was similar time spent at moderate intensity between different weight groups, whereas lean adolescents had more time spent at vigorous intensity (>6 METs) compared with obese adolescents over a 1-hour period engaged in Xbox Boxing. While other studies (1,36) reported no differences between weight groups, some methodological constraints may have accounted for the lack of group differences. For instance, the standard adult MET value (3.5 mL/kg/min) used in a previous study (1) is inappropriate for use in children because resting metabolic rate differs based on age-related body size (ie, higher in children than adolescents and adults) (34). Furthermore, children aged 8–12 years typically possess a resting metabolic rate of about 6 mL/kg/min (26). Therefore, the use of an individual's actual resting metabolic rate as one MET for children (the measure used in our study) is likely to generate more accurate results for the MET categorization of exercise intensity. Furthermore, most studies in an exergame setting indicated the use of average MET values to determine exergaming intensity, thus limiting the ability to quantify time in exergaming intensities that meet activity guidelines (1,42,55). Assessing time spent in different intensities while exergaming is of significance for identifying the inconsistent results from assessments of metabolic activities during exergaming play (10) because exergaming typically results in spontaneous and intermittent movements (31).

Our findings suggest that children with normal weight engage more in vigorous-intensity activity than those with overweight/obesity during Kung-Fu or Shape Up gameplay (requiring more movement in the lower limbs), which may account for some physiological and psychological factors in children of different weight status. For instance, children with overweight/obesity in the present study reported a greater rating of perceived exertion, especially in Shape Up gameplay, which required the most intense level of lower-limb movements. This finding may indicate more fatigue and discomfort (7), which together with less exercise tolerance (48) and a greater amount of oxygen consumption across all exergames, suggests more burden incurred by the metabolic cost associated with excess body mass (41). Furthermore, other studies (14,45) showed inverse relationships between fatness and performance on weight-bearing activities (eg, fitness test items) in children. The poor performance we observed in overweight/obese children on Shape Up play as a type of weight-bearing activity is probably due to the fact that their excess body mass requires extra effort in order to move during weight-bearing activities (14) and consequently causes increased loading on weight-bearing joints (eg, the knee) (27). These constraints might restrict such children's performance on weight-bearing activities, especially at vigorous-intensity levels. Another possible explanation could be that such individuals might be less motivated to play exergames at vigorous-intensity levels due to a lack of motor competence and motor skills (9) or enjoyment (53). However, the enjoyment levels throughout our gameplay sessions were not significantly different between groups.

Furthermore, we observed that exergames requiring more movement in the lower limbs (ie, the most on Shape Up, less so far on Kung-Fu, the least on Fruit Ninja) induced additional engagement in moderate to vigorous physical activity, resulting in a greater amount of energy expended. Our findings herein have clinical and practical implications for health professionals, teachers, and parents such that if exergames are being considered, they should choose those emphasizing lower-limb and low-impact weight-bearing activities (eg, cyber cycling) capable of achieving a moderate- to vigorous-intensity level, especially for overweight or obese children in the early stages of their physical activity programs. Once their fatness and/or fitness levels have favorably improved, such children should be encouraged to engage in more intense exergames primarily requiring lower-limb movements that elicit greater amounts of energy expenditure at vigorous-intensity levels since physical activity at this level is more likely to improve cardiorespiratory fitness and lower body fat (24). In addition to the choice of game mode and intensity, varied selections of exergames should be offered for these children. This can provide a balance of different activity modes, leading to the acquisition and development of motor skills (44). Our findings also suggest that game designers/developers should develop a game environment (eg, a built-in series of storytelling) to keep individuals motivated and continuously engaged (31,38) since long-term engagement in exergaming may be difficult to achieve (4,51).

We should note several important limitations to our results. We used a convenience sample that might not be representative of the population. Our study assessed children's activities in a laboratory setting (eg, device attachments, presence of investigators) that might interfere with their free-living performance, but assuming that overweight/obese children are not more sensitive to performing while being watched, any such interference would have been equally present in both groups. Although the study protocol for measuring resting metabolic rate (average 6.5 mL/kg/min) did not use a strictly controlled environment (21), our resting metabolic rate was close to that (about 6 mL/kg/min) reported under very controlled conditions (eg, a longer time of assessment, supine position) (26,36). This study is also limited by the absence of fat-free mass measurement as an estimate of metabolic body size (57) using advanced techniques (eg, dual-energy X-ray absorptiometry) as a criterion measure for body composition, although body mass is commonly used to estimate energy expenditure (28). In addition, we used a self-reported 7-day recall questionnaire for children; however, this instrument has been validated against an objective assessment of accelerometer-based measures of moderate to vigorous physical activity among children aged 8–13 years (56). Finally, individual differences including motivation, perceived competence, or motor skill competence can affect a participant's performance during gameplay; thus, they should be assessed in future research.

Conclusion

We examined energy expenditure and bodily movement elicited during gameplay in different modes and levels among 8- to 12-year-old children with different weight status. Although normal-weight children compared with overweight/obese children put greater effort into playing a more intense exergame, the chosen exergames in the present study were able to elicit moderate- to vigorous-intensity physical activity for all children, potentially contributing to the recommended physical activity levels for improving children's health and fitness (46). While children should still be encouraged to play naturally, our findings suggest that exergaming can count toward meeting current physical activity guidelines for all children.

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