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Human Kinetics
REVIEW

Effects of Active Video Games on Energy Expenditure in Adults: A Systematic Literature Review

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***Background*:** The objective of this study was to estimate the mean difference in energy expenditure (EE) in healthy adults between playing active video games (AVGs) compared with traditional video games (TVGs) or rest. ***Methods*:** A systematic search was conducted on Ovid MEDLINE, Web of Knowledge, and Academic Search Premier between 1998 and April 2012 for relevant keywords, yielding 15 studies. EE and heart rate (HR) data were extracted, and random effects meta-analysis was performed. ***Results*:** EE during AVG play was 1.81 (95% CI, 1.29–2.34; I^2 = 94.2%) kcal/kg/hr higher, or about 108 kcal higher per hour for a 60-kg person, compared with TVG play. Mean HR was 21 (95% CI, 13.7–28.3; I^2 = 93.4%) beats higher per minute during AVG play compared with TVG play. There was wide variation in the EE and HR estimates across studies because different games were evaluated. Overall metabolic equivalent associated with AVG play was 2.62 (95% CI, 2.25–3.00; I^2 = 99.2%), equivalent to a light activity level. Most studies had low risk of bias due to proper study design and use of indirect calorimetry to measure EE. ***Conclusion*:** AVGs may be used to replace sedentary screen time (eg, television watching or TVG play) with light activity in healthy adults.

***Keywords*:** sedentary time, screen time, meta-analysis, physical activity

Prolonged sedentary screen-based activity has been associated with obesity, diabetes, cardiovascular disease, and premature mortality regardless of participation in physical activity (PA).[1,2] There are many studies that show that breaking down prolonged sedentary time (1.5 metabolic equivalent of task [MET] or below) with light activity (2–3 MET level) is beneficial.[3–5] However, interventions focused solely on the message of reducing sedentary screen time do not seem to be effective, possibly because people value their screen time.[6] According to a 2006 survey, about 45% of American adults play traditional video games (TVGs) with a hand controller.[7] A replacement active behavior is most likely to be successful if it also is screen based, is enjoyable, and can be performed from the comfort and safety of one's home.

Two systematic reviews in children showed that active video games (AVGs), where players physically interact with on-screen images by using various arm/leg/whole-body movements, may be suitable candidates to be a replacement activity (at least in the short term) because they may stimulate energy expenditure (EE) similar to light to moderate PA while still being enjoyable and able to be done in the comfort of one's home.[8,9] AVGs have now become mainstream as all 3 of the major video-game console manufacturers have AVG options for their main consoles (Sony PlayStation 3 Move, Microsoft Xbox 360 Kinect, and Nintendo Wii), and there are many video games (eg, Wii Fit, Wii Sports, and Just Dance) available. However, a more recent systematic review has shown that the story of EE and AVGs is more complex—EE depends on the console, the game, and the difficulty level—and it may not always be a suitable replacement for PA.[10]

Regardless of whether AVGs can substitute as PA, AVGs have the potential to serve as a way to reduce sedentary screen time and increase light activity as a replacement for TVGs. Several studies have examined EE during AVG play. There are several systematic reviews on the EE associated with AVG play in children; however, none have focused on adults. This evidence gap is important to fill because a large number of adults play video games and it is plausible that there are differences in physiological and psychological response to video game play between adults and children. In fact, EE responses to the Wii Fit shows different responses according to age group while playing the same game.[11] This article is the first systematic review of studies reporting objective measure of EE during AVG play in adults. The primary aim of this review is to synthesize the current state of knowledge pertaining to EE during AVG play in healthy adults (18 or older). Specifically, this review aims to estimate the mean difference (MD) in EE between AVG play and TVG play or rest. As a secondary aim, the review also evaluates the MD in heart rate (HR) between AVG and TVG/rest. Lastly, EE during AVG play was compared with EE in brisk walking and jogging to determine whether AVGs can meet moderate-to-vigorous PA (MVPA) guidelines.

Methods

Types of Studies

All experimental studies in peer-reviewed journals, written in English, published between January 1998 and March 2011 were included. The year 1998 was chosen because that was the year Dance Dance Revolution was released, starting the market for popular AVGs.[12] Non peer-reviewed studies such as conference abstracts

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were excluded. The search was repeated in April 2012 to include new studies on EE with AVG play.

Types of Participants

Only studies involving healthy adults (ages 18+) were included, excluding studies on children or adults with any health condition. Previous systematic reviews on this topic in youth have been published.[8,9]

Types of AVG Approach Used

To be included for in-depth review, studies had to report on EE during AVG play or report on injury related to AVG play. Studies using television or TVGs as distracters during exercise activities or reporting on virtual reality rehabilitation, cognitive or behavioral therapies, or health education via computer and video games were excluded.

Types of Outcome Measures

EE during AVG play and the MD in EE between AVG play and TVG/rest were the main outcomes of interest. HR during AVG play was also assessed.

Data Sources

A systematic search was conducted on 3 different databases: Ovid MEDLINE, Web of Knowledge (ISI), and Academic Search Premier. The following keywords were used as search terms: ("video game" or "exergame") and ("physical activity" or "fitness" or "exercise" or "energy metabolism" or "energy expenditure" or "heart rate" or "enjoyment" or "adherence" or "motivation"). Additional studies were identified by reviewing the reference list of included studies. The first author performed the searches. The second author double checked search results from Ovid MEDLINE as a quality control step; no major disagreement was found.

Data Extraction

Each article was examined, and data were extracted on methodological details (eg, study design, experimental context, sample size, type of AVG, type of comparator, etc), participant characteristics (age, body mass index, fitness level, etc), and key findings pertaining to EE (mean and standard deviation of EE and HR) during AVG play. Data extraction was done primarily by the first author. The second author performed data extraction on a subset of articles as a quality control step. Minor disagreements were resolved via discussion; no significant disagreement was found that required arbitration.

Assessment of Risk of Bias

Included studies were assessed for appropriate study design, validity of EE estimation method, and drop-out rate. The first author performed quality assessment. The second author performed quality assessment on a subset of included studies as a quality control step; no major disagreement was found.

Data Analysis

MD was calculated if sample size, mean, and standard deviation were reported. Random effects meta-analysis was performed using EE and HR estimates (mean and standard deviation) and number of participants. MET values were calculated as an indicator of overall EE with AVG and TVG. MD in EE between AVG and brisk walking (indicator of moderate physical activity; MPA) and jogging (indicator of vigorous PA) was calculated to determine whether AVGs can meet MVPA guidelines. If studies included multiple age groups or multiple games, data were extracted for each age group or each game separately and then entered into the meta-analysis separately as if they were separate studies.

EE was reported in various units in the studies. Efforts were made to convert EE units to kcal/kg/hr whenever possible so that highest number of studies could be combined for the meta-analysis; however, that was not always possible as some studies only provided EE in kcal/min or in METs. Therefore, 3 different meta-analyses had to be conducted for the 3 units of EE (ie, kcal/kg/hr, kcal/min, and MET). HR was reported as beats per minute (bpm). An alpha level of .05 was considered significant for calculation for confidence intervals around the mean. I^2 score was used as a measure of heterogeneity, and an alpha value of .05 was again used as a measure of significant heterogeneity. Stata Statistical Software: Release 10 (2007), Meta-Analyst (2009), and Microsoft Excel (2007) were used to perform data extraction and analysis.

Results

Study Selection

Figure 1 displays a flowchart of the study selection process; 366, 434, and 174 studies were identified after screening title using 3 search engines; the number of studies identified for full-text review after screening abstracts was 7, 7, and 6 from the 3 search engines. Additional studies were found from the reference list of included studies and from a search update in April 2012, yielding a total of 15 studies for this systematic review. Heart rate was estimated from the EE studies; no separate search was performed to find studies that reported HR but did not report EE since EE was the primary outcome.

Assessment of Risk of Bias

Given that the majority of the studies used a crossover design (13 out of 15; 1 used parallel design and 1 used pre–post design), the following criteria were assessed for risk of bias according to the *Cochrane Handbook for Systematic Reviews of Interventions*: suitability of crossover design, preventing carryover effect, whether only first-period data were available, whether correct analysis was performed, and comparability of results with those from a parallel design.[13] Crossover designs are suitable for this type of study because the durations of the AVG play used in the studies were short and the effect of the AVGs (in terms of EE and HR) returned to baseline quickly. Carryover effect can be prevented by allowing adequate resting time in between AVGs/control so participants can return to baseline before the next round of the experiment. All studies used "washout" periods in between experimental phases to minimize carryover effect. All studies reported data from both periods. There was only one included study that employed a parallel design (Bonetti et al), and the effect measure was in the same direction (EE with AVG higher than TVG) and of a similar magnitude (MD = 1.58 kcal/min) as in the crossover designs. Therefore, the included studies appear to have a low risk of bias.

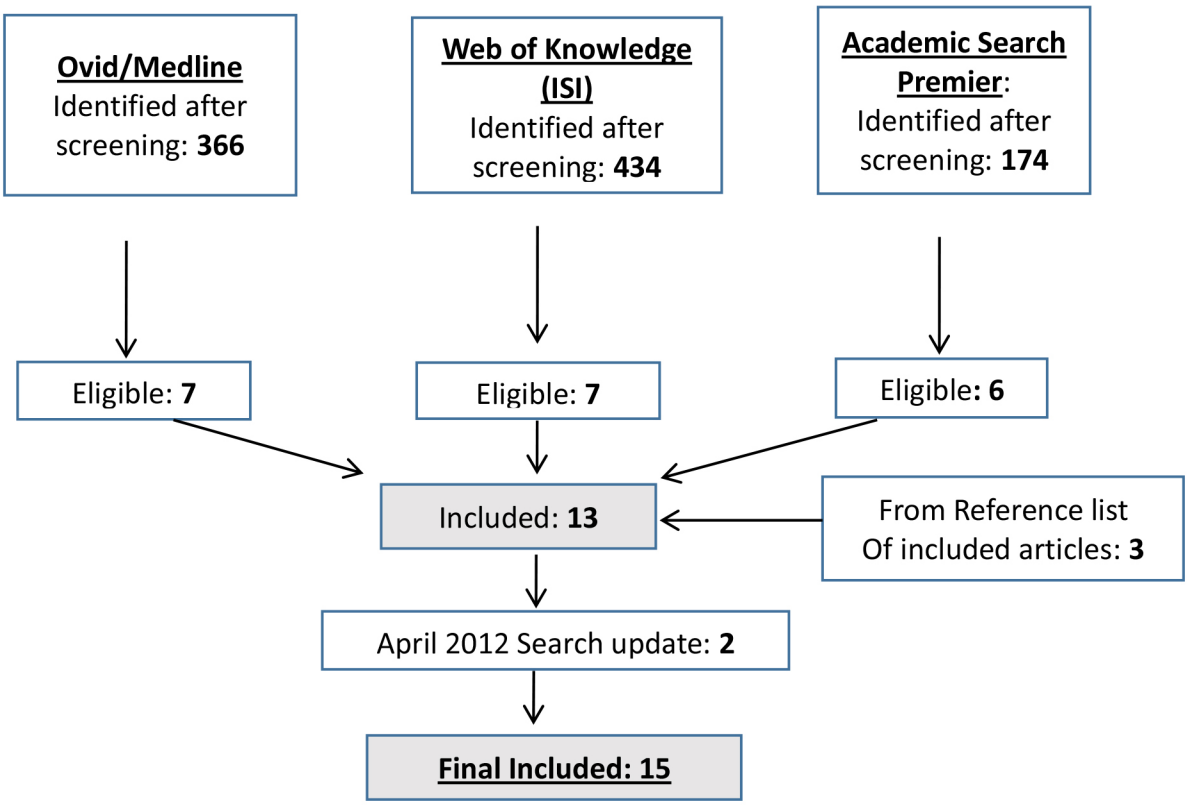

Figure 1 — Flowchart of study selection.

Three more criteria were evaluated for a more thorough quality assessment as deemed appropriate by the authors: whether order of AVGs/control was randomized in the crossover design, whether a valid EE estimation method was employed, and whether there was a low drop-out rate (shown in Table 1). Six out of the 13 studies that employed a crossover design did not randomize the order, which increases risk of bias. Two out of the 15 studies estimated EE from HR, which is not as accurate, but all others used indirect calorimetry or better methods of estimating EE. Two out of the 15 studies had a higher than 10% drop-out rate. Taken as whole, the included studies had a low risk of bias.

Study Summary

Table 2 provides a summary of the 15 studies. Studies were done recently, since 2008, and were conducted in the United States (10 of 15), the United Kingdom (3 of 15), Canada, and Japan. Sample sizes for the studies were generally small, but there were a few studies with a large sample size (sample sizes ranged from N = 8 to N = 100). Most studies used participants of both sexes; most used young adults, but some used middle-aged and elderly adults; and most used individuals of average fitness level, but some used highly fit individuals. Most studies used a crossover design. Wii Sports by Nintendo Wii was the AVG of choice for most of the studies (10 of 15 studies), with Dance Dance Revolution being the second most popular AVG. Most studies had EE during AVG play and TVG play or rest as primary outcomes; some compared AVG play with MVPA. The length of exposure (play time) was about 10 minutes in most studies. Every study found that EE during AVG play was higher than EE during rest or TVG play; however, EE with AVG play was usually less than that of MVPA.

Energy Expenditure

The MD and 95% confidence interval (95% CI) in EE and HR between AVG and TVG and rest were calculated in 10 of the 15 studies (where the mean and the standard deviation for EE for AVG and TVG or rest were provided) and are shown in Online Appendix Table 1. Five out of the 15 studies could not be used in the quantitative analysis because of lack of EE measurement during TVG/rest (since an MD was sought) or because of lack of reported data (eg, no standard deviation, which prevents calculation of the confidence interval). The EE data were expressed as kilocalories burned per kilogram of body weight per hour (kcal/kg/hr) where possible; otherwise they were expressed as kilocalories burned per minute (kcal/min) or MET. HR data were shown in beats per minute. In every instance, EE (0.92 to 4.3 kcal/kg/hr higher for AVG) and HR (9.8 to 61 bpm higher for AVG) were higher for AVG compared with TVG. In every instance EE (1.01 to 3.56 kcal/kg/hr higher) and HR (15.8 to 84.2 bpm higher) were also higher for AVG compared with rest. However, there was wide variability depending on type of video game and the difficulty level at which the game was played (eg, beginner, intermediate, or expert). Two of the included studies (Sell et al[14] and Worley et al[15]) specifically addressed the issue of effect of difficulty level at which the game is played on EE; both found that EE was higher when the game is played at a more difficult level.

Meta-Analysis

Table 3 displays the results of random-effects meta-analysis of the EE and HR from the 10 out of the 15 studies where mean and SD

Table 1 Assessment of Risk of Bias

Author and year	Randomization of order for crossover design	Valid energy expenditure estimation method (indirect calorimetry or better)	Low drop-out rate (<10%)
Graves et al, 2010[11]	No	Yes	Yes
Leatherdale et al, 2010[30]	No	No (armband and HR monitor)	Yes
Lanningham-Foster et al, 2009[31]	No	Yes	Yes
Siegel et al, 2009[32]	Yes	Yes	Yes
Bonetti et al, 2010[19]	Parallel design; randomized	Yes	Yes
Miyachi et al,[33]	Yes	Yes	Yes
Willems et al, 2009[17]	No	Yes	Yes
Stroud et al, 2010[34]	Yes	Yes	Yes
Sell et al, 2008[14]	No	Yes	Yes
Worley et al, 2011[15]	No	Yes	Yes
Trout et al, 2008[21]	Randomization not applicable; pre–post design	No (HR monitor)	Yes
Barkley and Penko, 2009[20]	Yes	Yes	Yes
Bausch et al, 2008[23]	Yes	Yes	No (>10%)
Lyons, 2011[22]	Yes	Yes	No (33%)
Jordan, 2010[24]	Yes	Yes	Yes

Abbreviation: HR, heart rate.

for EE for AVG and TVG/rest were provided. The random effects meta-analysis demonstrated that EE during AVG play expends approximately 1.81 additional kcal/kg/hr (95% CI, 1.29–2.34; I^2 = 94.2%), or close to 108 additional kilocalories for a 60-kg person per hour. Compared with rest, the additional EE was 1.72 kcal/kg/hr (95% CI, 1.24–2.21; I^2 = 93.6%). AVGs had an average MET of 2.62 (95% CI, 2.25–3.00) while TVG had an average MET of 1.12 (95% CI, 1.08–1.16; I^2 = 99.2%). There was considerable heterogeneity in EE depending on the type of AVG used in the different studies, as shown by the high I^2 = values. For the 2 studies where kcal/kg/hr (the preferred units) was not possible to estimate, AVG was compared with TVG in kcal/min, and the results were in the same direction as the main findings—1.45 kcal/min higher for AVG compared with TVG.

Many of the studies used multiple video games, which allowed us to consider them as separate data points in the meta-analysis, providing higher available samples sizes (n = 67 to n = 635) and increased statistical power. Meta-analysis showed that HR was 21 bpm higher (95% CI, 13.7–28.3; I^2 = 93.4%) during AVG play compared with TVG, and approximately 38 bpm higher (95% CI, 26.7–49.2; I^2 = 96.8%) compared with rest, as shown in Table 3. Again, there was considerable heterogeneity across studies depending on the type of AVG shown.

Moderate-to-Vigorous Physical Activity Guideline

Although it is clear that EE and HR during AVG play is higher than TVG play or rest, most of the included studies also examined how AVG play compared with the recommended dose of MVPA. As can be seen in Table 4, almost all of the studies found at least one AVG that met MPA guidelines. Popular AVGs that do meet MPA are Wii Fit Aerobics, some other Wii Fit games played at intermediate or higher level of difficulty, Wii Sports Boxing, and Dance Dance Revolution. Wii Sports Tennis was found to meet moderate intensity exercise level by Leatherdale et al, but not by Willems et al or Bausch et al; this could be due to the fact that Leatherdale et al used armband and HR monitors, instead of the more accurate indirect calorimetry, to estimate EE.

Although AVGs burn more calories than TVGs or rest, overall AVGs burn fewer calories than brisk walking (MD [95% CI] = –2.31 [–3.05 to –1.58] kcal/kg/hr; I^2 = 89.7%, P < .01) or jogging (MD [95% CI] = –7.61 [–8.66 to –6.57] kcal/kg/hr; I^2 = 88.1%, P < .01); meta-analysis was done from the study by Graves et al[11,25] combining the 4 types of AVG play and both age groups where brisk walking was chosen as a form of moderate exercise and jogging was chosen as a form of vigorous exercise. The overall MET value of approximately 2.62 during AVG play puts AVG play at a low intensity activity, not sufficient to qualify as MVPA by the ACSM guidelines.[16]

Discussion

Overall, all 15 studies showed that AVG increases EE and HR compared with TVG and rest. However, the magnitude of the MD in EE and HR varies quite a bit (eg, MD in EE between AVG and TVG varied from 0.92 kcal/kg/hr for Wii Fit Yoga to 4.3 kcal/kg/hr for Wii Sports Boxing). This is to be expected because different AVGs require different motions and thus different physiological responses. Furthermore difficulty level, fitness level of participants, amount of effort put into the game, familiarity with the game, instructions provided by investigators, and verbal encouragements can influence the outcome.[17]

Overall EE values suggest that the intensity level of AVG play is in the light activity spectrum. The most robust finding from this review is that overall AVGs have a MET value of 2.62. The EE findings of this study are in line with findings from systematic review of AVGs in children.[9] The wide variation in EE estimates, shown

Table 2 Summary of Studies Included for Energy Expenditure During Active Video Game Play

Author, year, and country	Description	Sample size	Mean age (SD), sex, mean BMI (SD)	Design and sampling method	AVG	Comparison	EE results
Graves et al, 2010, UK[11]	Compared cardiorespiratory and enjoyment measures during rest, TVG, AVG, and treadmill walking and jogging.	N = 15 for YA, N = 13 for OA	Age: 28.2 (4.6) YA; 57.6 (6.7) OA. Sex: 8 F, 7 M, YA; 3 F, 10 M, OA. BMI: 22.6 (1.3) YA; 28.4 (4.4) OA.	Crossover design (not randomized); convenience sampling	Wii Fit: Yoga, Muscle, Balance, Aerobics	Rest, TVG, treadmill walking (6.1 [0.6] kph YA; 4.8 [1.0] kph OA), treadmill jogging (9.7 [0.8] kph for YA)	EE of AVG was higher than TVG.
Leatherdale et al, 2010, Canada[30]	EE during AVG and TVG.	51	Age: 18.9 (0.9). Sex: 30 M; 21 F. BMI: 24.3 (3.5) M; 22.5 (2.8) F.	Crossover design (not randomized); convenience sampling	Only Wii Sports Tennis	TVG	EE for AVG was higher than TVG. EE was significantly higher in males estimated by the armband but not by the HR monitor.
Lanningham-Foster et al, 2009, USA[31]	Measured EE and physical activity during rest, standing, watching TV seated, sitting, TVG, and AVG.	20	Age: 33.5 (10.7). Sex: 10 M; 10 F. BMI: 27.7 (5.5).	Crossover design (not randomized); advertisement	Only Wii Sports Boxing	Rest, sit and watch TV, stand and watch TV, and TVG	EE during AVG was double that of TVG.
Siegel et al, 2009, USA[32]	EE and HR during AVG.	13	Age: 28.2 (6.6) M; 24.4 (4.6) F. Sex: 6 M; 7 F. BMI: 28.3 (3.7) M; 24.8 (5.3) F.	Crossover design (randomized); sampling method unclear	Three different Arcade Games: 3-kick, Power Boxing, Car Race	Rest	EE was higher than rest.
Bonetti et al, 2010, USA[19]	Exercise responses to full-body isometric muscle resistance AVG in solo play and against human opponent.	N = 32, 16 in each group	Age: 18–30. Sex: 32 M. BMI: NR, <20% body fat.	Parallel design (randomized); advertisement	Full-body isometric muscle resistance AVG: against human opponent and solo	TVG: against human opponent and solo	EE was higher for AVG in both modes compared with TVG without increase in RPE. No difference in solo vs. human opponent.
Miyachi et al, 2010, Japan[33]	EE during Wii Fit Plus and Wii Sports activities.	12	Age: 34 (6). Sex: 7 M; 5 F. BMI: NR, percentage of body fat = 22.3 (3.9).	Crossover design (randomized); sampling method unclear	Wii Fit and Wii Sports; 68 different measurements	Rest	Mean MET ranged from 1.3 to 5.6. Out of 68 activities, 67% were "light intensity" (<3 MET) and 33% were moderate intensity (>6 MET).
Willems et al, 2009, UK[17]	Compared Wii Sports Tennis, Baseball, and Boxing to self-paced brisk treadmill walking.	10	Age: 21(1). Sex: 7 M; 3 F. BMI: 23.7 (3.3).	Crossover design (not randomized); convenience sampling	Wii Sports: Tennis, Baseball, Boxing	Self-paced brisk walking: 6.1 (0.6) km/hr, or 3.8 (0.4) miles/hr)	EE during Wii Boxing was similar to brisk walking but was lower during Wii Tennis and Baseball ($P < .05$).
Stroud et al, 2010, USA[34]	Quantified metabolic responses and EE while playing upper-body accelerometer-controlled and AVG and TVG.	19	Age: 30.2 (6.4) M; 29.1 (7.8) F. Sex: 12 M; 7 F. BMI: 27.8 (4) M; 22.6 (1.8) F.	Crossover design (randomized); sampling method unclear	Wii Sports Bowling (low intensity) and Mario and Sonic at the Olympic Games (high intensity)	TVG	EE during AVG was higher than TVG, or rest. EE during high intensity AVG was higher than low intensity AVG.

(continued)

Table 2 *(continued)*

Author, year, and country	Description	Sample size	Mean age (SD), sex, mean BMI (SD)	Design and sampling method	AVG	Comparison	EE results
Sell et al, 2008, USA[14]	Physiological response to AVG in experienced (exp) versus inexperienced (inexp) players.	N = 12 exp; N = 7 inexp	Age: 19.7 (2.1) exp; 25.6 (1.6) inexp. Sex: all male. BMI: 26.5 (6.1) exp; 22.8 (6.7) inexp.	Crossover design (not randomized); convenience sampling	Dance Dance Revolution with experienced participants (playing at the highest level, 4)	Dance Dance Revolution with inexperienced participants (playing at level 1 or 2)	Experienced participants had higher EE compared with inexperienced ones.
Worley et al, 2011, USA[15]	Determined %VO_2 max and EE from 2 levels of Wii Fit Hula and Step games.	8	Age: 21.9 (2.20). Sex: all female. BMI: NR.	Crossover design (not randomized); sampling method unclear	Wii Fit Hula and Step games at Intermediate level	Wii Fit Hula and Step games at beginner level	EE was higher in the intermediate level than beginner level. EE was higher for Wii Hula compared with Step.
Trout et al, 2008, USA[21]	Examined change in body fat percentage, time in target heart zone, estimate EE, prior physical activity, and enjoyment levels as a result of AVG 3 times/wk for 20 min for 8 wk.	26	Age: 22 (3) F; 21 (3) M. Sex: 14 F; 12 M. BMI: 26 (6) F; 24 (3) M.	Pre–post design (randomization not applicable); advertisement	Dance Dance Revolution 3 times/wk for 20 min for 8 wk	Baseline	On average, Male EE was 276 calories (more than jogging) and female EE was 176 calories (more than weight lifting) during each dance session.
Barkley and Penko, 2009, USA[20]	Examined whether VO_2, HR, RPE, and liking of playing AVG was greater than TVG and treadmill walking.	12	Age: 35.7 (13.9) M; 27.3 (10.3) F. Sex: 6 F; 6 M. BMI: 28 (5.7) M; 26.8 (6) F.	Crossover design (randomized); convenience sampling	Wii Boxing	TVG and treadmill walk (2.5 mph)	MET for Wii Boxing for all 12 subjects was 4.4 (1.3), higher than walk or TVG.
Bausch et al, 2008, USA[23]	Examined VO_2R, HRR, EE, and METs during AVG and compared that to common daily activities.	12	Age: 22.1 (2.3) F; 22.0 (1.4) M. Sex: 8 F; 4 M. BMI: NR.	Crossover design (randomized); sampling method unclear	Wii Boxing and Tennis	Rest	EE was higher for Wii Boxing compared with Wii Tennis. Both higher than rest.
Lyons et al, 2011, USA[22]	Examined EE of 4 different types of games.	100	Age: 24.0 (4.25) M; 23.6 (3.69) F. Sex: 50 F; 50 M. BMI: 27.5 (5.88) M; 26.8 (7.15) F.	Crossover design (randomized); advertisement	Four categories of AVGs: shooter, band, dance, and fitness	Rest	Shooter games did not have significantly higher EE compared with rest. Band simulation (73%), dance (298%), and fitness (322%) games had higher EE than rest.
Jordan et al, 2010, UK[24]	Examined EE and postexercise blood lactate.	15	Age: 29 (4). Sex: all male. BMI: 25.9 (3.8).	Crossover design (randomized); sampling method unclear	Wii Boxing	TVG, walk (3.5 mph), bicycle (120 W), run (6 mph), and lower-limb adapted video game	Wii Boxing had higher EE, HR, and VO_2 max than TVG or brisk walking but lower than bicycling, running, or lower-limb adapted video game.

Abbreviations: BMI, body mass index; AVG, active video game; EE, energy expenditure; TVG, traditional video game; YA, young adult; OA, older adult; HR, heart rate; NR, not reported; RPE, rated perceived exertion; MET, metabolic equivalent of task; VO_2R, VO_2 reserve; HRR, heart rate reserve.

Table 3 Random Effects Meta-Analysis of Energy Expenditure and Heart Rate

	EE: AVG vs. TVG (kcal/kg/hr)	EE: AVG vs. TVG (kcal/min)	EE: AVG vs. rest (kcal/kg/hr)	MET of AVG play (mean and CI)[a]	HR: AVG vs. TVG (bpm)	HR: AVG vs. rest (bpm)
MD, CI	1.81 (1.29 to 2.34)	1.45 (1.02 to 1.87)	1.72 (1.24 to 2.21)	2.62 (2.25 to 3.00)	21.0 (13.7–28.3)	37.94 (26.7–49.2)
I^2, P	94.2%, <.01	53.6%, .14	93.6%, <.01	99.2%, <.01	93.4%, <.01	96.8%, <.01
Studies	Graves[11,25] (Wii Fit Yoga, condition, balance, and aerobics in 2 age groups)	Bonetti[19] (full-body muscle resistance)	Graves[11] (Wii Fit Yoga, condition, balance, and aerobics in 2 age groups)	Graves[11] (Wii Fit Yoga, condition, balance, and aerobics in 2 age groups)	Graves[11] (Wii Fit Yoga, condition, balance, and aerobics in 2 age groups)	Graves[11] (Wii Fit Yoga, condition, balance, and aerobics in 2 age groups)
	Lannigham- Foster[31] (Wii Sports Boxing)			Miyachi[33] (Wii Fit aerobics, balance, resistance, yoga, Wii Sports); Barkley[20] (Wii Sports boxing)	Bonetti[19] (full-body muscle resistance—solo and opponent)	Siegel[32] (3-Kick game, Power Boxing, Disney Car race)
	Jordan[24] (Wii Sports Boxing)	Leatherdale[30] (Wii Sports Tennis)	Lannigham- Foster[31] (Wii Sports Boxing)	Leatherdale[30] (Wii Sports Tenis), Lyons[22] (Shooter, Band, Dance Dance Revolution, Wii Fitness)	Stroud[34] (Wii Sports Bowling, Mario and Sonic)	Stroud[34] (Wii Sports Bowling, Mario and Sonic)
					Barkley (Wii Sports Boxing) Jordan[24] (Wii Sports Boxing)	Barkley[20] (Wii Sports Boxing)
Sample size	N = 15 × 4 = 60	N = 16	N = 15 × 4 = 60	N = 15 × 4 = 60	N = 15 × 4 = 60	N = 15 × 4 = 60
				N = 13 × 4 = 52	N = 13 × 4 = 52	
				N = 12 × 5 = 60	N = 16 × 2 = 32	N = 13 × 4 = 52
	N = 13 × 4 = 52			N = 12	N = 19 × 2 = 38	N = 13 × 3 = 39
	N = 20		N = 13 × 4 = 52	N = 51	N = 12	N = 19 × 2 = 38
	N = 15	N = 51	N = 20	N = 100 × 4 = 400	N = 15	N = 12
	Total = 147	Total = 67	Total = 132	Total = 635	Total = 209	Total = 201

Abbreviations: EE, energy expenditure; AVG, active video game; TVG, traditional video game; MET: metabolic equivalent of task, 1 MET, 3.5 mLO_2/min/kg, 1 kcal/kg/hr; CI, 95% confidence interval; HR, heart rate; bpm, beats per minute; MD, mean difference; I^2, the percentage of variation across studies that is due to heterogeneity.

[a] MET for TVG was 1.12 (1.08–1.16) MET as found by random effects meta-analysis of Graves et al and Leatherdale et al (I^2 = 72%, P = .000; total N = 163).

Table 4 Active Video Games Meeting Moderate Physical Activity Guideline

Study	AVGs that did not meet ACSM guideline for MPA	AVGs that met ACSM guideline for MPA
Graves et al[11]	Wii Fit: Yoga, Muscle, Balance	Wii Fit: Aerobics
Leatherdale et al[30]		Wii Sports Tennis
Lanningham-Foster et al[31]		Wii Sports Boxing
Siegel et al[32]		Three different Arcade Games: 3-kick, Power Boxing, Car Race
Bonetti et al[19]		Full-body isometric muscle resistance AVG: against human opponent and solo
Miyachi et al[33]	Two-thirds of the AVG in Wii Fit and Wii Sports do not count as moderate intensity.	One-third of the AVG in Wii Fit and Wii Sports count as moderate intensity
Willems et al[17]	Wii Sports: Tennis, Baseball	Wii Sports Boxing
Stroud et al[34]	Wii Sports Bowling	Sonic at the Olympic Games
Sell et al[14]	Dance Dance Revolution with inexperienced participants (playing at lowest level)	Dance Dance Revolution with experienced participants (playing at the highest level)
Worley et al[15]	Wii Fit Hula and Step games at beginner level	Wii Fit Hula and Step games at intermediate level
Trout et al[21]		Dance Dance Revolution
Barkley and Penko[20]		Wii Sports: Boxing
Bausch et al[23]	Wii Sports: Tennis	Wii Sports: Boxing
Lyons et al[22]	Shooter Games (Medal of Honor, Resident Evil) and Band Games (Guitar Hero, Rock Band)	Dance Dance Revolution, Wii Fit
Jordan et al[24]		Wii Boxing

Abbreviations: AVG, active video game; ACSM, American College of Sports Medicine; MPA, moderate physical activity.

by large I^2 values, is also in agreement with systematic reviews in children.[8,9] Replacing sedentary screen time with AVG can yield an additional 108 kcal/hr of EE for a 60-kg adult. Therefore, AVGs could be thought of as a tool to replace sedentary time with light activity. Video games are not just for children and teenagers; close to half of American adults play video games, and a recent survey showed that as many as 20% do so on a daily basis.[18]

AVGs hold promise for replacing sedentary screen time because they increase EE without changing perceived exertion, compared with TVG.[19] In 2 studies, participants found AVG to be significantly more enjoyable than TVG.[11,20] In a longitudinal study, participants underwent 8 weeks of treatment with AVG (20 min/d, 3 d/wk) without any change in enjoyment level.[21] Another study comparing different types of AVGs showed that people had the highest level of enjoyment with band simulation games, which did not meet the MPA guideline, compared with dance simulation and fitness simulation AVGs, which do meet the exercise guidelines, further suggesting AVG may be better suited to reducing sedentary time than meeting MVPA guidelines, especially in the long run.[22]

Given that all 15 studies included in this review found at least one AVG that met the ACSM guideline for MPA, along with being a replacement of sedentary behavior, some AVGs (eg, Wii Boxing or Dance Dance Revolution) may contribute to the recommended PA guidelines if played at an appropriate intensity.[14–17] AVGs may be specifically useful for persons with disability or others struggling to meet PA limits, especially as a stepping-stone to something more physically intense.[23] Whole-body movement seems to be necessary for making AVGs meet the MPA guidelines, especially movement of both upper limbs (eg, boxing) or lower limbs (eg, dance).[24,25]

Taken together, there are 2 key findings in this review. First, the overall EE with various types of AVGs is in the light activity zone but still higher than rest (by definition, 1 MET) and TVG (1.12 MET). An adult can expect to expend close to 100 more kilocalories from playing an hour of AVGs compared with a sedentary screen-based behavior. Therefore, the best use of AVG may be to replace sedentary screen time with light activity. Second, EE with AVGs can vary tremendously depending on the game being played and the difficulty level at which it is being played. Some AVGs that have whole-body movement, such as boxing or dancing, may be able to induce a physiological response similar to that of MPA if played at a proper intensity level.

One way to help consumers make informed decisions about purchasing AVGs may be to include with each game a rating of the physiological response likely to be elicited by that game. Similar to the rating for maturity level, which helps consumers buy video games that are of appropriate content level, a rating of PA intensity level (light, moderate, or vigorous) will help consumers choose an AVG appropriate for their desired PA level. External validity of the ratings may be achieved by having 3 age groups (children, young adults, and elderly populations) of both sexes. This will add to the manufacturing cost of AVGs, but perhaps after a certain number of these studies manufacturers can create computer simulations so that studies do not need to be replicated for similar games in the future.

Most of the studies included in this review had a low risk of bias according to Cochrane criteria, used proper methods for estimating EE, and had low drop-out rates. One concern in this field of research seems to be the lack of randomization of order in crossover design; 6 out of 13 studies did not randomize the order. One reason for the lack of randomization of the order of games may be the different intensity levels associated with different games; investigators may have designed the study so that participants played lower intensity games first before moving on to higher intensity games. It is likely

this approach was used to reduce the potential impact of higher intensity games on lower intensity games' EE. While the studies had good internal validity, external validity may be low because of nonrandom/convenience sampling, sample characteristics that were nonrepresentative of the wider adult population (in terms of age, fitness, and sex), and assessments conducted in the laboratory as opposed to the natural environment. Moreover, many of the studies did not provide volunteers with unlimited time to familiarize themselves with the AVG. Therefore, the EE and HR reported may be different than those of a free-living user who is playing in the comfort of his or her home and has familiarity with the game.

Future research should include longitudinal studies and randomized controlled trials with large samples of diverse population (in terms of age, sex, fitness, and functional capacities) identified from the general population. Future studies should determine long-term effects of AVGs on replacing sedentary screen time, improving fitness, and changing PA behavior, weight, body fat, and overall health. Future studies should also examine the impact of AVGs in different settings such as the home and other social settings, as well as whether the games are played alone or with companions.

Enjoyment is a key factor if AVGs are going to be successful at replacing TVGs. One study found that people felt less in control with AVGs—possibly because of a lesser sense of illusion that one is actually engaging in the activity and because of a learning curve in using an AVG controller as opposed to TVG controllers.[26] Also, a 3-month study in a small sample of participants assigned to use Dance Dance Revolution, which is one of the AVGs that can elicit a physiological response similar to that of MVPA, showed a decline in use of 82% from the first 6 weeks to the second 6 weeks.[27] Therefore, more studies need to be done to make AVGs more enjoyable and sustainable so that people play them often and play them at an adequate intensity level for the AVG-play time to count as a replacement of sedentary time, and perhaps even as a tool to meet some of the weekly MVPA goals.

One hindrance to conducting more research on video game play and physiological response is the lack of a standardized unit for reporting EE. EE was reported in 8 different ways in the 15 studies included in this review. This prevented subgroup analysis based on age or gender because of small-sample-size issues. MET is a useful unit; however, it should only be reported if resting EE is estimated on the individual level because using 3.5 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ as the resting metabolic rate may be not be accurate for some individuals.[28] Heart rate during AVG play was mostly reported as beats per minute; however, HR reported as a percentage of HR maximum may be a better indicator of the quality of cardiovascular exercise one can achieve.[29]

A limitation of the study is that the literature search, study selection, data extraction, and data analysis were done primarily by the first author. However, the second author performed quality control on a subset of articles, and no major disagreement was found.

Conclusions

In this review, meta-analysis of recent studies on the impact of AVGs in terms on EE and HR have been reported. AVGs result in higher EE and HR compared with TVG/rest.

The following conclusions and recommendations can be made from the key findings in this review:

- Overall, AVGs may be a good tool to replace sedentary screen-based behavior with light activity
- Certain AVGs may be able to elicit physiological responses similar to MPA
- Video game manufacturers should apply physiological response rating (eg, Light/Moderate/Vigorous PA) with AVGs to help consumers make informed decision about AVG purchases
- Researchers should report EE in kcal/kg/hr for internal and external validity.

Video games are very popular, and AVGs are becoming increasingly popular. Therefore, it is necessary to understand the health impacts of AVGs and how they can be used to promote healthy living.

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