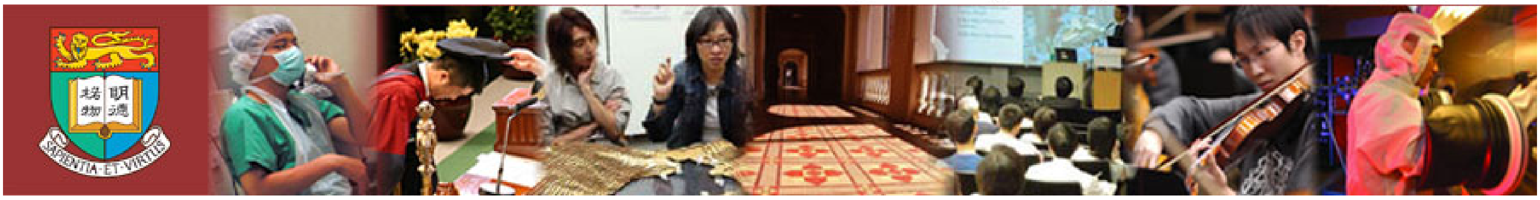

Title	Active video games for youth: A systematic review
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Active Video Games for Youth: A Systematic Review

Anthony Barnett, Ester Cerin, and Tom Baranowski

Background: A population level increase in physical activity (PA) is critical to reduce obesity in youth. Video games are highly popular and active video games (AVGs) have the potential to play a role in promoting youth PA. ***Method:*** Studies on AVG play energy expenditure (EE) and maintenance of play in youth were systematically identified in the published literature and assessed for quality and informational value. ***Results:*** Nine studies measuring AVG play EE were identified. The meta-analytic estimates of average METs across these studies were 3.1 (95% CI: 2.6, 3.6) to 3.2 (95% CI: 2.7, 3.7). No games elicited an average EE above the 6 MET threshold for vigorous EE. Observed differences between studies were likely due to the different types of games used, rather than age or gender. Four studies related to maintenance of play were identified. Most studies reported AVG use declined over time. Studies were of low-to-medium quality. ***Conclusion:*** AVGs are capable of generating EE in youth to attain PA guidelines. Few studies have assessed sustainability of AVG play, which appears to diminish after a short period of time for most players. Better-quality future research must address how AVG play could be maintained over longer periods of time.

Keywords: energy expenditure, physical activity, maintenance, obesity, enjoyment, sedentary

Increasing levels of overweight and obesity are a world public health concern and increased physical activity (PA) is critical to reduce obesity in youth.[1] Video games have shown promise for promoting diet and PA changes.[2] Some video games and associated peripheral control devices [herein after called active video games (AVGs)] directly encourage PA by integrating game play with technology that captures movement of the player [eg, DanceDanceRevolution (DDR), Active Life: Outdoor Challenge, and Wii Fit].

AVGs are of interest in combating the obesity epidemic for at least 4 reasons. First, games involving movement could increase PA levels sufficiently to impact the health and fitness of youth. Current guidelines for youth recommend 60 minutes or more of PA daily, most of which should be aerobic and of moderate and vigorous intensity, but also include muscle and bone-strengthening activities.[3] Any increase in PA, especially when the increase replaces sedentary behavior, had positive health outcomes in adults,[4–6] and perhaps also among youth.[7] Second, video games are very popular. Total hardware and software sales for 2008 in the US were $21.33 billion, a rise of 19% from 2007,[8] suggesting that many people find them highly enjoyable. The ability of a video game to match skill with task difficulty facilitates enjoyment,[9] and enjoyment has been linked to increased PA in girls[10] and children.[11] Though AVGs were developed to stimulate participant enjoyment to sell products, not to remedy national levels of inactivity, the enjoyment they provide may be key to promoting PA. Third, in 2004, 83% of American 8- to 18-year-olds had a video game console at home and 56% had 2 or more,[12] suggesting that this medium reaches large numbers of youth. Fourth, youth living in neighborhoods perceived as unsafe are likely to stay indoors[13–15] when previous generations would have been outside playing (eg, the after-school period). Presence of home exercise equipment was related to PA in girls living in neighborhoods perceived to be unsafe by their parents.[16] AVGs provide a channel for reaching these youth and may reduce sedentary behavior inside the home.

The combination of enjoyment, appropriate exercise intensity, and sustainable involvement may give AVGs the potential to help remedy the inactivity of youth. This paper systematically and critically reviews the published, peer-reviewed literature investigating the level of energy expenditure (EE) attained during participation in AVGs and whether and how participation is sustained at a beneficial frequency and duration. Specifically, it reports findings from studies that examined one or more of the following questions: (1) Does PA during participation in AVGs reach moderate or vigorous intensity levels? (2) Does participation in AVGs increase overall PA? (3) Is participation in AVGs sustained across time? (4) What factors influence sustained participation in AVGs across time? This review also provides methodological and substantive recommendations for future studies examining these issues.

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Method

Manuscript Inclusion and Exclusion Criteria

Peer-reviewed publications were sought for this review using the general search structure, (video game OR dance simulation OR exergame) AND (child OR youth OR adolescent) AND [(maintenance OR sustainability OR intervention OR control) OR (energy expenditure OR indirect calorimetry OR oxygen consumption OR oxygen uptake OR physical activity OR cardiorespiratory fitness)] in PubMed, Scopus, SPORTDiscus, Ovid MEDLINE, PsycInfo, and EMBASE from start of database to March 2009 (266 articles retrieved). Inclusion criteria were studies of youth (18 years or younger) and at least one of EE derived from indirect calorimetry during AVG play, or longitudinal investigation of AVG play. For the purpose of this review, a video game was considered an AVG if the game was controlled by body movements greater than the finger and wrist movement typical of hand controller based games (eg, games in the role playing, maze, fighter, and construction and management genres). Studies of AVGs not designed for the general population (eg, wheelchair based[17]) and all arcade games video games were excluded. Articles were initially included or excluded based on their title or abstract (17 articles included) (Figure 1). The full text of each initially included article was then assessed for relevance [excluded articles: duplicate publication (1), EE estimated by IDEEA (intelligent device for estimating energy expenditure and activity) rather than by indirect calorimetry[18] (IDEEA accurately estimates EE involved in walking and running, but not arm movement,[19] the major activity source in the investigated AVGs (1), inactive video game (2), arcade game (1), lay article/no data collection (1)]. Searches by reference lists, all authors, and citations of all full text articles revealed no further articles meeting inclusion criteria. Two additional studies meeting the inclusion criteria were located during the submission/review process. The final included studies were then divided into those examining EE during video game play (9 articles) and those examining AVG play maintenance over time (4 articles) (see Figure 1).

Study Quality and Informational Value

Study quality and informational value were assessed using previously-suggested criteria[20–22] and criteria specifically developed for the purpose of this review. Newly developed criteria pertained to (1) sufficient heterogeneity of study samples with respect to age,[23] gender,[24] and weight status[25] necessary to obtain sufficiently generalizable population estimates of EE during AVG play, maintenance of AVG play and associations of AVG play with PA; and (2) reports of point estimates and variability measures of outcome variables (EE or AVG play) in general and by strata (eg, gender and age group). A study was considered to meet the criterion of sufficient age heterogeneity if the participants' age range was 6+ years (eg, primary-school age: from 6–12 yrs; secondary-school age: 12–18 yrs). Gender and weight status heterogeneity were defined as having approximately balanced distributions of males, females, overweight and nonoverweight participants. For studies examining EE during AVG play, sufficient sample size/statistical power was defined as the ability of the study to obtain a 95% confidence interval for PA intensity within 0.25 METs on each side (so that the 95% CI is equal or smaller than 0.5 METs). For each study examining EE during AVG play, a quality score and an informational value score were computed by summing scores (0, 1, or 2) on 3 and 4 relevant items/criteria, respectively (see Table 1; column A). For studies examining maintenance of AVG play and impact of AVG play on PA, quality and informational value scores were computed by summing responses on 4 to 10 criteria (Table 1; columns B-D). Scores ranged from 0 to 1 for all criteria except for 'Appropriateness of statistical analyses' and 'Reports point estimates and variability measures for strata (eg, gender, weight status)' (see Table 1). Analyses classified as statistically inappropriate (inappropriate choice of statistical methods with obvious violations of statistical assumptions) were assigned 0 points; statistically adequate analyses (appropriate choice of statistical methods with no apparent violation of statistical assumptions but relatively low statistical efficiency or power) were assigned 1 point; while optimal analyses (appropriate choice of statistical methods that permits an optimal, efficient analysis of the data) were assigned 2 points. For these studies, sufficient sample size/statistical power was defined as the ability to detect a moderate between- or within-subject effect size with 80% chance, assuming an alpha level of 0.05 and two-tailed significance tests.

Energy Expenditure During AVG Play: Does PA During Participation in AVGs Reach Moderate or Vigorous Intensity Levels?

To examine whether EE during AVG play can meet current recommended intensities for health benefits, it is necessary to use appropriate EE thresholds for moderate and vigorous PA. Recent PA guidelines for youth do not specifically define moderate or vigorous activity levels by energy expenditure.[3] For adults, a standard resting metabolic equivalent (MET) is defined as approximately 4.2 $kJ \cdot kg^{-1} \cdot hr^{-1}$ (3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$),[26] with commonly used arbitrary adult thresholds of 3 METs for moderate and 6 METs for vigorous PA. As youth have higher resting metabolic rates than adults[27] the use of absolute adult METs is not appropriate in youth. However, when METs are based on youth's resting metabolic rates, the relative MET value of most activities is similar to that of adults.[28] Therefore, this review used 3 and 6 (relative) METs as the thresholds for moderate and vigorous PA

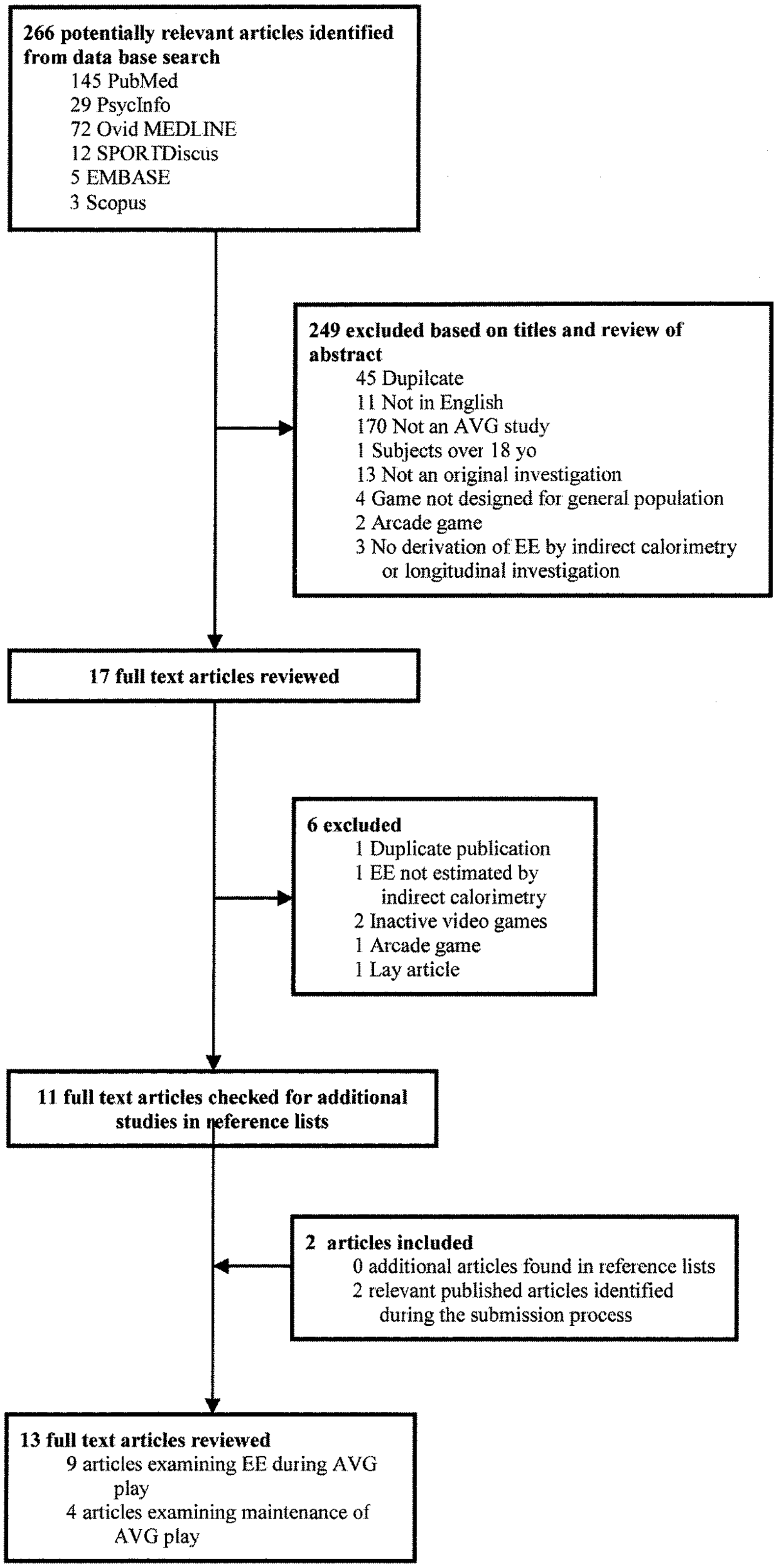

Figure 1 — Flow of studies through the identification and selection process.

Table 1 Criteria of Study Quality (Q) and Informational Value (IV) by Study Questions and Quality and Informational Value Scores by Study

Item / criterion (type of item)	A: Does PA during participation in AVGs reach moderate or vigorous intensity levels? [max Q/IV scores: 3/5] Studies [Q score/IV score]: Lanningham-Foster (2006)[32] [2/3] Unnithan (2006)[25] [2/4] Maddison (2007)[33] [2/1] Straker & Abbott (2007)[34] [2/2] Graves (2008)[36] [1/1] Melleker McManus (2008)[35] [1/2] Haddock (2008)[37] [3/1] Graf (2009)[24] [1/3] Lanningham-Foster (2009)[23] [2/2]	B: Does participation in AVGs increase overall PA? [max Q/IV scores: 10/5] Studies [Q score/IV score]: Maloney (2008)[39] [7/1] Ni Mhurchu (2008)[40] [7/1]	C: Is participation in AVGs sustained across time? [max Q/IV scores: 5/5] Studies [Q score/IV score]: Chin A Paw (2008)[38] [2/0] Madsen (2007)[41] [2/2] Maloney (2008)[39] [3/1] Ni Mhurchu (2008)[40] [2/1	D: What factors influence sustained participation n AVGs across time? [max Q/IV scores: 9/5] Studies [Q score/IV score]: Chin A Paw (2008)[38] [4/0] Madsen (2007)[41] [1/2] Maloney (2008)[39] [1/1]
1. Randomized controlled trial (Q)	Not applicable	39,40	Not applicable	38
2. Objective measure of physical activity / energy expenditure (Q)	All (indirect calorimetry was selection criterion)	39,40	Not applicable	Not applicable
3. Validated measure of AVG play (Q)	All (direct observation was a selection criterion)	None	None	None
4. Eligibility criteria reported (Q)	25,33,34,37,23	39,40	38,39,40,41	38,39,41
5. Reports point estimates and variability measures for each assessment point (Q)	23,24,25,32,33,34,35,36,37	39	39	None
6. Statistical models (inadequate = 0; adequate = 1 pt; optimal = 2 pts) (Q)	Not applicable	39[1],40[2]	38[1],39[1],41[1]	38[2]
7. Adjustment for confounders (Q)	Not applicable	40	Not applicable	None
8. Groups similar at baseline (Q)	Not applicable	39	Not applicable	None
9. Intention-to-treat analyses (Q)	Not applicable	39,40	Not applicable	None
10. Adequate sample size / statistical power (Q)	32,37	None	None	None
11. Sufficient age heterogeneity (IV)	25,35,37	None	41	41
12. Gender heterogeneity (IV)	23,24,25,32,33,34,35,36	39,40	39,40,41	39,41
13. Heterogeneity of weight status (IV)	23,25,32	None	None	None
14. Reports point estimates and variability measures for strata (eg, gender, weight status) (some strata = 1 pt; all strata = 2 pts) (IV)	32[1],25[1],34[1],24[2]	None	None	None

Note. Criteria 2 and 3 are not included in the sum of quality scores for studies addressing research question A because they were used for the selection of such studies. Hence, all the studies addressing question A meet these 2 criteria. Nonbracketed numbers in table are the reference numbers of particular studies (reported for studies meeting specific criteria).

respectively, with 1 MET being the resting metabolic rate reported for a study participant group. Where resting metabolic rate was not measured, the age related values of Harrell et al[27] were used.

For each study and game within a study, we used data on EE from AVG play and on reported or estimated resting EE (in the units reported in the original article) to estimate the corresponding mean MET values and their standard deviations. Since the 2 EE variables represent approximately normally distributed random variables that are likely correlated, the mean and standard deviation of their ratio (representing METs) were computed using appropriate formulas (see footnotes of Table 2).[29] These formulas require knowledge of the correlations between the resting and AVG EE, which were not reported in the examined articles. Hence, the minimum and maximum possible values of means and standard deviations of METs (given the observed means and standard deviations in EE) were derived by fixing the correlations to 0 (to obtain the maximum possible MET values) and 1 (to obtain the minimum MET values). Subsequently, using the derived values for the means and standard deviations of METs and assuming that METs are normally distributed, we estimated the percentage of the sample that achieved at least a moderate level of activity (≥3 METs) or vigorous activity (≥6 METs) while playing a specific game.

To obtain summary (average) estimates of minimum and maximum possible values of PA intensity levels during AVG play (expressed in METs), multilevel meta-analytic procedures, accounting for dependency in the data arising from studies with multiple outcomes, were used as specified by Hox.[30] Estimates of the grand mean (maximum and minimum) METs across studies were obtained. Heterogeneity of study outcomes (mean METs) was assessed by testing the significance of the study-level variance in METs. Finally, the contribution of between-study differences in age and gender distribution to outcome heterogeneity was assessed by entering mean age and percentage of male participants in the sample as predictors of MET values.

Studies on Maintenance of AVG Play and Impact of AVG Play on PA

Information on sample characteristics, study design, research questions, outcome, and AVG play measures, and findings were extracted from studies assessing maintenance of play over time (see Table 3). Finally, the statistical power to detect moderate effect sizes (defined as Cohen's $d = 0.50$ or $f^2 = 0.15$[31]) assuming a probability level of 0.05 and two-tailed significance tests was computed for each study and each type of statistical analysis within studies (eg, between-group and within-group comparisons of the mean).

Results

Energy Expenditure During AVG Play

Nine peer-reviewed journal articles using indirect calorimetry to investigate EE of youth playing AVGs were identified (Tables 1 and 2).[23–25,32–37] Most of these studies were of moderate quality and informational value (Table 1). All studies reported overall point estimates and variability measures of EE, but less than half provided this information by gender, age groups or weight-status categories. In general, samples were balanced by gender but not weight status. In addition, most study samples had a very narrow age range (Table 1). Five out of nine studies clearly reported eligibility criteria for subject recruitment. Only 2 studies had a sufficient sample size to achieve PA intensity-level estimates within 0.5 METs accuracy.

On average, games examined in these studies elicited EE at or above 3 METs, the moderate intensity PA threshold. The grand (meta-analytic) estimate of minimum and maximum possible METs across the examined studies was 3.1 (95% CI: 2.6, 3.6) and 3.2 (95% CI: 2.7, 3.7), respectively. Significant heterogeneity of outcomes (minimum and maximum METs) across studies was observed, with between-study variances of 0.6 [$\chi^2(1) = 4.39$; $P = .036$) and 0.5 [$\chi^2(1) = 3.98$; $P = .045$], corresponding to between-study standard deviations of 0.8 and 0.7 METs, respectively. Between-study differences in gender distribution and mean age did not explain variations in study outcomes. Hence, differences between studies were likely due to the different types of games used. Games achieving the recommended minimum intensity of PA for health in over 50% of the sample were DDR;[24,25] Wii Sports boxing;[24,36] the Playstation2 games EyeToy: Play 2 Knockout (boxing), EyeToy: Play 2 Homerun (baseball), EyeToy: Groove (dance),[33] EyeToy: Kinetic Cascade ("hitting" virtual on-screen targets);[34] XaviX J-mat Jackie's Action Run (multiple activities);[35] and XaviX J-mat Jackie Chan Studio Fitness (multiple activities).[37] Some of these games elicited moderate-intensity levels of activity in over 80% of the sample. No games elicited an average EE above the 6 MET threshold for vigorous EE. However, a sizeable percentage of participants playing Play 2 Knockout (boxing),[33] Homerun (baseball),[33] EyeToy: Cascade,[34] XavX J-mat Jackie's Action Run,[35] and Wii Sports boxing[23] might have achieved vigorous-intensity activity. The estimated percentage is dependent on the assumed correlation between the AVG and resting EE (0 or 1).

Studies on Maintenance of AVG Play

Only 4 studies examined AVG play over time in youth, 3 of which were randomized controlled trials and evaluated the effects of diverse implementation of AVG interventions[38,39] and/or those of AVG play vs. control conditions

Table 2 Energy Expenditure During Active Video Game Play

Authors	Participants: Age	N	Sex	Game classification: Platform	Game	Type of activity	Energy expenditure: Video game EE[a]	Resting EE[a]	METs[b]	% ≥ 3 METs	% ≥ 6 METs
Lanningham-Foster et al (2006)	9.7 ± 1.6	25	12b 13g	PS2 Eyetoy	Nicktoons Movin'	catch objects interactively	13.61 ± 4.20 $kJ \cdot kg^{-1} \cdot hr^{-1}$	6.47 ± 1.18 $kJ \cdot kg^{-1} \cdot hr^{-1}$	Min: 2.1 ± 0.3	0.1	<0.1
									Max: 2.2 ± 0.8	13.7	<0.1
				Xbox	DDR Ultramix 2	dance	17.26 ± 4.28 $kJ \cdot kg^{-1} \cdot hr^{-1}$	6.47 ± 1.18 $kJ \cdot kg^{-1} \cdot hr^{-1}$	Min: 2.6 ± 0.2	1.8	<0.1
									Max: 2.8 ± 0.8	38.3	<0.1
Unnithan et al (2006)	13.5 ± 3.3	22	16b 6g	PS2	DDR	dance	12.9 ± 3.2 $ml \cdot kg^{-1} \cdot min^{-1}$	4.6[c] $ml \cdot kg^{-1} \cdot min^{-1}$	Min: 2.8 ± 0.7	38.9	<0.1
									Max: 2.8 ± 0.7	30.9	<0.1
Maddison et al (2007)	12.4 ± 1.1	21	11b 10g	PS2 Eyetoy	Knockout	boxing	24.5 ± 4.9 $ml \cdot kg^{-1} \cdot min^{-1}$	4.9 ± 0.9 $ml \cdot kg^{-1} \cdot min^{-1}$	Min: 4.9 ± 0.1	100.0	0.0
									Max: 5.2 ± 1.4	94.5	27.0
					Homerun	baseball	23.0 ± 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$	4.9 ± 0.9 $ml \cdot kg^{-1} \cdot min^{-1}$	Min: 4.7 ± 0.1	100.0	0.0
									Max: 4.9 ± 1.2	94.1	16.7
					Groove	dance	18.9 ± 3.6 $ml \cdot kg^{-1} \cdot min^{-1}$	4.9 ± 0.9 $ml \cdot kg^{-1} \cdot min^{-1}$	Min: 3.9 ± 0.03	100.0	0.0
									Max: 4.0 ± 1.0	83.3	2.4
					AntiGrav	hoverboard	11.2 ± 2.2 $ml \cdot kg^{-1} \cdot min^{-1}$	4.9 ± 0.9 $ml \cdot kg^{-1} \cdot min^{-1}$	Min: 2.3 ± 0.03	0.0	0.0
									Max: 2.4 ± 0.6	16.0	<0.1
				PS2 dance mat	Dance UK	dance	14 ± 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$	4.9 ± 0.9 $ml \cdot kg^{-1} \cdot min^{-1}$	Min: 2.8 ± 0.3	22.6	0.0
									Max: 3.0 ± 0.9	48.0	<0.1
Straker & Abbott (2007)	9–12	20	12b 8g	EyeToy PS2	Cascade	moving hands and feet to touch virtual on-screen targets	0.127 ± 0.041 $kcal \cdot kg^{-1} \cdot min^{-1}$	0.029[c] $kcal \cdot kg^{-1} \cdot min^{-1}$	Min: 4.4 ± 1.4	83.5	12.6
									Max: 4.4 ± 1.4	83.5	12.6
Graves et al (2008)	15.1 ± 1.4	13	7b 6g	Nintendo Wii	Wii Sports	bowling	182.1 ± 41.3 $J \cdot kg^{-1} \cdot min^{-1}$	84.0 ± 14.6 $J \cdot kg^{-1} \cdot min^{-1}$	Min: 2.1 ± 0.1	<0.1	0.0
									Max: 2.2 ± 0.6	10.8	<0.1
						tennis	200.5 ± 54.0 $J \cdot kg^{-1} \cdot min^{-1}$	84.0 ± 14.6 $J \cdot kg^{-1} \cdot min^{-1}$	Min: 2.3 ± 0.2	0.2	0.0
									Max: 2.5 ± 0.8	24.0	<0.1
						boxing	267.2 ± 115.8 $J \cdot kg^{-1} \cdot min^{-1}$	84.0 ± 14.6 $J \cdot kg^{-1} \cdot min^{-1}$	Min: 3.0 ± 0.8	51.8	<0.1
									Max: 3.3 ± 1.5	57.4	3.3
Melleker &McManus (2008)	6–12	18	11b 7g	XaviX	XaviX bowling	bowling	0.06 ± 0.01 $kcal \cdot kg^{-1} \cdot min^{-1}$	0.03 ± 0.01 $kcal \cdot kg^{-1} \cdot min^{-1}$	Min: 2.1 ± 0.3	0.4	0.0
									Max: 2.2 ± 0.7	14.8	<0.1
					XaviX J-mat Jackie's Action Run	walking or running with side-stepping, squatting, jumping and stamping	0.15 ± 0.03 $kcal \cdot kg^{-1} \cdot min^{-2}$	0.03 ± 0.01 $kcal \cdot kg^{-1} \cdot min^{-1}$	Min: 5.2 ± 0.7	99.9	12.2
									Max: 5.6 ± 1.9	90.6	41.0

(continued)

Table 2 *(continued)*

	Participants			Game classification			Energy expenditure				
Authors	Age	N	Sex	Platform	Game	Type of activity	Video game EE[a]	Resting EE[a]	METs[b]	% ≥ 3 METs	% ≥ 6 METs
Haddock et al (2008)	10.13 ± 2.20	23	18b 5g	XaviX	Jackie Chan Studio Fitness	walking or running with side-stepping, squatting, jumping and stamping; stepping; running on spot; jumping	14.03 ± 3.54 ml·kg⁻¹·min⁻¹	4.06 ± 0.86 ml·kg⁻¹·min⁻¹	Min: 3.4 ± 0.1	99.9	0.0
									Max: 3.6 ± 1.1	70.4	1.8
Graf et al (2009)	11.9 ± 1.2	23	14b 9g	Sony Playstation	DDR (beginner)	dance	12.3 ± 1.9 ml·kg⁻¹·min⁻¹	4.5 ± 1.0 ml·kg⁻¹·min⁻¹	Min: 2.8 ± 0.2	14.9	0.0
									Max: 2.9 ± 0.8	43.7	<0.0
					DDR (basic)	dance	14.8 ± 3.0 ml·kg⁻¹·min⁻¹	4.5 ± 1.0 ml·kg⁻¹·min⁻¹	Min: 3.3 ± 0.1	99.9	0.0
									Max: 3.5 ± 1.0	67.7	0.1
				Nintendo Wii	Wii Sports	bowling	9.1 ± 2.3 ml·kg⁻¹·min⁻¹	4.5 ± 1.0 ml·kg⁻¹·min⁻¹	Min: 2.0 ± 0.04	0.0	0.0
									Max: 2.1 ± 0.7	10.5	<0.1
						boxing	13.7 ± 4.2 ml·kg⁻¹·min⁻¹	4.5 ± 1.0 ml·kg⁻¹·min⁻¹	Min: 3.0 ± 0.2	48.5	0.0
									Max: 3.2 ± 1.2	57.0	0.1
Lanningham-Foster et al (2009)	12.1 ± 1.7	22	11b 11g	Nintendo Wii	Wii Sports	boxing	5.14 ± 1.71 kcal·hr⁻¹·kg⁻¹	1.22 ± 0.31 kcal·hr⁻¹·kg⁻¹	Min: 4.2 ± 0.1	100.0	0.0
									Max: 4.5 ± 1.4	84.9	14.6

[a] As conversion to equivalent units involves assumptions, energy expenditure is reported in units used by each investigation.

[b] METs = ratio of 2 normally distributed random variables: active video game EE (X)/resting EE (Y). Approximate values of the mean of the ratio of X and Y are Mean(X/Y) = Mean(X)/Mean(Y)—$r_{XY}\sigma_X\sigma_Y$/Mean(Y)² + Mean(X)(σ_Y)²/Mean(Y)³ where r_{XY} is the correlation between X and Y and σ_X and σ_Y are observed standard deviations of X and Y, respectively. Approximate values of the standard deviation of X/Y are given by $\sigma_{X/Y}$ = Mean(X)/Mean(Y) · √[(σ_X)²/Mean(X)² + (σ_Y)²/Mean(Y)²—2$r_{XY}\sigma_X\sigma_Y$/Mean(X)Mean(Y)]. Given that values of r_{XY} were unknown, values of 0 (minimal correlation) and 1 (maximal correlation) were used in the computations of the mean and standard deviation of METs, giving the maximum (when r_{XY} = 0) and minimum (when r_{XY} = 1) possible values for the means and standard deviations of METs for given means and standard deviations of active video game EE (variable X) and resting EE (variable Y). For studies where data on resting EE was not available a standard deviation of 0 for resting EE (ie, same value of resting EE for the entire sample) was assumed.

[c] Resting EE not available, age related values of Harrell et al (2005) used.

Abbreviations: Min, minimum possible values; Max, maximum possible values; % ³ 3 or 6 METs, percentage of the sample achieving an EE equivalent or higher than 3 or 6 METs, respectively; b, boys; g, girls.

Table 3 Studies on Maintenance of Active Video Game (AVG) Play: Characteristics and Findings

	Study			
	Chin A Paw et al (2008)	**Madsen et al (2007)**	**Maloney et al (2008)**	**Ni Mhurchu et al (2008)**
Sample	• N = 27 (initial); 16 (final) • Age: 9–12 yrs • Least fit children in 4 Dutch primary schools	• N = 30 (initial); 21 (final) • Age: 9–18 yrs (13.0 ± 2.6) • Overweight children • Owned video-game console	• N = 60 (initial); 51 (final) • Age: 7–8 yrs (7.5 ± 0.5)	• N = 20 (initial and final) • Age: 10–14 yrs (12.0 ± 1.5) • Owned video-game console
Study design	• Randomized controlled trial • Duration: 12 weeks • Active video game: interactive dance simulation • Control group: home-based intervention (self-determined use of AVG) • Intervention group: home-based + 60-min/wk multiplayer class	• Prospective observational with intervention • Duration: 6 months • Active video game: interactive dance simulation • Intervention: exercise prescription to use AVG 30 min/d, 5 d/wk	• Randomized controlled trial • Duration: 6 months • Active video game: interactive dance simulation • Control group: wait-list for 10 weeks • Intervention group: exercise prescription to use AVG 120 min/wk preferably over 4 sessions; 2 mats provided to encourage social/competitive play; 50% of group received 30 min coaching 5 times per week for 10 weeks	• Randomized controlled trial • Duration: 12 weeks • Active video game: EyeToy and dance simulation • Control group: wait-list for 12 weeks • Intervention group: instructed to substitute usual non-AVG play with AVG
Assessments	Baseline, 6 wks, 12 wks	Biweekly for 2 months then monthly; baseline, 3 months, 6 months (BMI)	Baseline, 10 wks, 28 wks	Baseline, 6 wks, 12, wks
Research questions	• effect of multiplayer class on motivation to play	• motivation of AVG use over time • association between AVG use and changes in BMI • reasons for use and nonuse of AVG	• temporal course of AVG play • associations of use of AVG in age group with physical activity and sedentary screen time • association of AVG use with changes in BMI, blood pressure, and pulse • effect of coaching, playing with others and parental involvement on AVG use	• frequency and duration of AVG play over 12 weeks • relationships of AVG play with physical activity
Measures of AVG play (reliability)	• self-reported minutes of play per day (unknown)	• self-reported minutes of play per day (unknown) • video memory card (unknown)	• self-reported minutes of play per day verified and cosigned by parents (unknown) • video memory card (unknown)	• self-reported minutes of play per day (unknown)

(continued)

Table 3 *(continued)*

	Study			
	Chin A Paw et al (2008)	**Madsen et al (2007)**	**Maloney et al (2008)**	**Ni Mhurchu et al (2008)**
Measures of PA	None	None	Accelerometry 7-day: 0.8158	Accelerometry 4-day: 0.73;58 Self-report PAQ-C: ~0.7859
Other outcome measures (reliability)	Motivation and barriers to play—focus group (N/A)	Body Mass Index (BMI; >0.9960)	BMI (>0.9960); pulse (unknown, assumed high); blood pressure (unknown, assumed high61); sedentary screen time (joint self and parent report; unknown)	Waist circumference (0.9862); BMI (>0.9960)
Study findings	• % dropout lower in multiplayer group (SS) • median total minutes of play higher in multiplayer group (NSS) • median play duration lower in wks 6–12 than wks 0–6 in home group (228 min vs 0 min; NSS) • median play duration higher in wks 6–12 (475 min vs 601 min) than wks 0–6 in multiplayer group (NSS)	• <50% children used the AVG twice a week in the initial 3-month period; <10% children used AVG twice a week from 3 to 6 months • use of AVG was not associated with changes in BMI	• peak use occurred in wk1 (147 min/wk) and gradually decreased to 60 min/wk in wk 10 • at wk 10, no significant between-group difference in physical activity but significant difference in sedentary screen time (lower in intervention group) • from wks 0–10, increase in vigorous and decrease in light physical activity and sedentary screen time in intervention group • no relationships of AVG use with changes in pulse, BMI, and blood pressure • no effect of coaching on AVG use	• intervention group spent less time on non-AVG play than control group • physical activity as measured by accelerometry counts was higher in intervention group at 6 wks (SS) but not at 12 wks (NSS) • no significant between-group differences in moderate-to-vigorous physical activity and body weight • smaller waist circumference in intervention than control group at wk 12 (SS)
Statistical power to detect a moderate effect size (Cohen's d = 0.50 or $f^2 = 0.15$; $P = .05$; 2-tailed test)	• 0.14 (between-group analyses) • 0.14 (within-group analyses for smallest group)	• 0.47 (analyses at 3 months) • 0.39 (analyses at 6 months)	• 0.42 (between-group analyses) • 0.56 (within-group at wk 10 for smallest group) • 0.41 (within-group at wk 28 for smallest group)	• 0.37 (between-group analyses)
Facilitators of maintenance of AVG play (self-reported)	N/A	• playing with friends • competitions • greater variety of music • peer or family support	• playing with others	N/A
Barriers to maintenance of AVG play (self-reported)	• technical problems • boredom	• technical problems • family stressors • boredom	N/A	N/A

Abbreviations: SS, statistically significant; NSS, not statistically significant; *P*, probability level; PAQ-C, Physical Activity Questionnaire for Older Children; N/A, not applicable.

on PA and anthropometric measures (Tables 1 and 3).[39,40] A prospective observational study examined maintenance of AVG play over time and associations between AVG use and change in BMI.[41] All studies chose an interactive dance simulation as their AVG intervention, while 1 study also included EyeToy. Study duration ranged from 12 to 28 weeks. Three studies targeted specific subgroups of children (eg, owners of video-game consoles, overweight, or unfit). Specific exercise prescriptions on frequency and duration of AVG play were given in 2 studies.[39,41]

Three out of 4 studies looked at factors influencing sustained participation in AVG, while 2 studies examined whether AVG play was associated with increases in PA (Table 1). Both studies used objective measures of PA. However, they relied on daily self-report diaries or logs of play with unknown reliability and validity. The same problem was observed in the other 2 studies examining maintenance of AVG play. Only 1 study[39] had the logs verified and cosigned by parents due to the younger age of the sample. Two studies attempted to complement self-report AVG play measures with objective data from video memory cards. However, technical problems compromised the usability of these measures. Anthropometric pulse and blood pressure were assessed objectively and had acceptable levels of reliability (>0.70), while sedentary screen time was assessed using child-parent joint self-reports of unknown reliability.

All studies had insufficient power to detect moderately-sized intervention effects and time changes (Table 1 and 3). In general, the study samples were not balanced by weight status and had too narrow age ranges. While all studies used adequate methods of statistical analyses, often these were not optimal. Specifically, although all of the studies could have applied generalized linear mixed models to examine temporal patterns of AVG use (see Discussion for details), none of them did so. In addition, only one study appeared to have used generalized linear models to assess between-group differences in outcomes and associations between AVG play and anthropometric and PA outcomes.[40] With the exception of Maloney et al[39] overall point estimates and variability measures of AVG play (and, where applicable, PA) across time were not reported. Other study deficiencies were failure to perform intention-to-treat analyses, adjust for confounders, and report stratum-specific point estimates across time (Table 1).

Most studies reported AVG use declined over time. Two studies reported peak use in the first week of the study.[39,41] The only group of participants that showed an increase in play across time were those exposed to a multiplayer condition, although this change was not statistically significant.[38] With the exception of 1 study which observed a decrease in waist circumference,[40] no associations were found between AVG use and changes in anthropometric and vital signs measures. Some short-term beneficial effects of AVG play on PA and sedentary screen time were reported.[39,40] Boredom and technical problems were identified as barriers to maintenance of AVG play,[38,41] while peer and family support, competition, and a greater variety of music were listed as facilitators of AVG play.[41]

Discussion

Energy Expenditure During Active Video Game Play

The average intensity level of PA during AVG play across various games and studies was approximately 3.2 METs (95% CI: 2.7, 3.7) (ie, just over the moderate-intensity threshold). However, AVGs can be played at a range of intensities, which makes it possible for individuals to exercise below or above minimal cut points for recommended intensities of PA. For example, we estimated that the standard deviations of METs associated with playing some of the reviewed games were sometimes greater than 1.4 (see Table 3). The variability might have been even larger if studies included more heterogeneous samples in age and weight status. Achieving current PA intensity guidelines during AVG play at home will depend on the ability of the game to provide sufficiently intense exercise and for the players to choose this intensity. While the first of these conditions appears achievable in most of the examined games, the intensity chosen when playing these games at home still needs to be investigated.

Prior experience of participants with the games used in EE studies varied. Most studies involved participants who had no previous experience with the games examined, and were given none[34] or short familiarization sessions of 3 to 45–60 minutes.[25,32,33,35] No details of game-specific experience were given for 1 study[36] and all participants in another study had previous experience playing the games investigated.[37] Both these studies also provided familiarization before testing. In a comparison of experienced and inexperienced college-age males (19.7 ± 2.1 y) during DDR game play, experienced game players could play at higher intensities and had significantly higher EE.[42] The intensity of EE during AVG play may be dependent on skill level related to the game. Experienced players may be able to reach the intensity assumed to be beneficial, but novice players may notNot all AVGs elicited EE above the 3 MET threshold for moderate PA in the majority of players (>50%). While moderate and vigorous PA are recommended, the evidence for particular thresholds of PA to attain desirable health outcomes in youth is not strong.[43] PA is positively related to health benefits in youth, but dose-response relationships are unclear.[44] Light activity and breaks in sedentary time had positive health effects in adults[5,6] and while information on the effect of sedentary time on youth is limited it has been found to be significantly associated with metabolic risk factors.[7] If AVG play is substituted for inactive video game play or other sedentary activities, even when played at lower than moderate intensity, beneficial health outcomes may occur.

Some AVGs include activities that may contribute to fulfilling child PA guidelines for muscle and bone strengthening activities. For example, there are bone-strengthening activities in the minigames Jackie's Action Run for the XaviXPORT (running on-the-spot, jumping, and stamping), and Log Jumping and Jump Rope in Active Life: Outdoor Challenge (Namco Bandai) for the Wii console (jumping). Similarly, Wii Fit (Nintendo) includes a strength training component with bodyweight activities such as pushups and lunges. No studies to date have examined the effect of AVG play on muscle or bone strength.

It is not surprising that video games involving PA increase EE and that this is sometimes above the threshold for moderate intensity PA.[45] The important consideration is whether AVGs will be played by youth at these intensities so to significantly contribute to the daily accumulation of 60 or more minutes of moderate-to-vigorous PA, as recommended in the current PA guidelines for youth.[3]

Studies of Maintenance of AVG Game Play

There is not yet strong support for AVGs enabling engagement in play over periods of time necessary to make a contribution to the health of participants. Due to the newness of this type of video game play, only a few of the rapidly increasing number of games in this area have been investigated. High-quality randomized control studies of prescribed AVG play with appropriate sample sizes, validated measures of AVG play and PA, and appropriate analytical approaches are needed to determine if sustained AVG play can contribute to youth meeting PA guidelines and has health benefits. Some interventions have given instructions regarding desired play duration, provided ongoing support, and have not provided a choice of AVGs to participants. Since prescription is contrary to a perceived strength of AVGs (ie, spontaneous adoption because they are motivating to play), it is also important to examine the intensity and duration of in-home usage of AVGs by the users of these games, where purchase and use is not motivated by study participation.

Many AVGs are appearing on the market [eg, Wii Fit (Nintendo), We Ski (Namco Bandia), Active Life: Outdoor Challenge (Namco Bandia), Sega Superstars Tennis (Sega)]. Investigation into the EE levels when playing these games and their ability to maintain interest in participants over time is warranted. Future evaluation of a game's ability to change PA behaviors should include an analysis of mediating and moderating variables.[40,41] For example, gender, age, and other sociodemographic characteristics may be moderators of a game's effectiveness in changing PA behavior. The identification of such moderators can assist the planning and delivery of more effective, individually-tailored AVG-based PA interventions. An analysis of mediating variables is important for the identification of mechanisms through which AVG play changes PA behavior. This knowledge can help refine current theories of behavior change and enhance understanding of the reasons for success or failure of AVG-based interventions.[46] In addition, a process evaluation can help clarify what happens during game play and why it continues or stops.

With respect to factors influencing maintenance of AVG play, comments by AVG participants suggest that interaction with other players may be important.[38,41] New generation video game consoles support multiplayer interaction with other players in the same room or, via the internet, anywhere in the world. Studies on non-AVG forms of PA in youth have shown that participation in community-based sports clubs[42] and the presence of friends, peers, and family members can affect motivation to be physically active[43] and intensity of PA.[44] These findings may have important implications for the design of AVGs providing opportunities for desirable levels of PA. Yet, a series of good-quality randomized controlled trials is needed to ascertain the effects of social interaction on maintenance of AVG play.

If PA benefits are to be achieved, consideration of the motivations that attract players to video games and sustain their involvement should be an important part of future AVG design. Self-determination theory purports that innate needs for autonomy, competence, and relatedness drive intrinsic motivation,[47] likely one of the strongest drives to play video games. For inactive video games, perceived in-game competence and autonomy were related to game enjoyment, game preferences, and pre- to postgame changes in well being.[48] In addition, relatedness predicted enjoyment and future game play in players of multiplayer video games. This suggests that an AVG designed to satisfy these 3 needs would be expected to attract players and sustain their involvement. Population participation levels in PA are low, indicating that PA has not proven to be an intrinsically motivating activity for the majority of the population. AVGs, designed to be enjoyable, but their hedonic value not relying on the activity component, may contribute to increasing PA levels in youth.

There are no prevalence data on what percentage of video game play involves AVGs and age, gender, weight status or ethnic differences in time spent playing these games. Research in this area should examine the types of AVGs most likely to be played by different categories of youth, why they liked it, who tried it but gave it up (and why they gave it up), and who hasn't tried it. Qualitative research is needed on groups who may be most likely to benefit from AVG participation to see what they would like to do (eg, inner city kids who may have limited play opportunities outside the house).

The PA recommendation for youth is 60 minutes or more of daily PA involving a variety of activities.[3] Reported daily video game play time in 8- to 18-year-olds is 49 minutes[12] and likely increasing. While it is unlikely and not desirable for AVG play to comprise the total recommended PA for this age group, it could theoretically comprise an important part of that requirement. Given a choice between highly likeable sedentary and vigorous activities obese youth chose the sedentary activities.[49] This suggests that, to induce sustainable play in obese youth, an AVG would need to have a higher level of enjoyment than available sedentary video games. Thus, for AVG designers there is a challenge to design highly enjoyable games with mechanics that do not allow PA to be substituted by sedentary behavior. Due to likely easier accessibility,[50] AVG play may also substitute for other physical activities that may make greater contributions to PA guidelines. When assessing maintenance of AVG play over time, the effect on total PA and sedentary time should be considered.

When playing DDR, nonoverweight youth were more active than overweight youth,[25,51] and maintenance of DDR play over 6 months in overweight school-age youth was found to be very low.[41] Overweight youth engaged in higher intensity PA, and at a higher intensity than lean youth, in the presence of peers and friends.[52] If AVGs are promoted as a mode of EE for health benefits in this population, more research is needed to ascertain the attractiveness of various AVGs to overweight youth and the advantages of multiplayer experiences.

Future studies on maintenance of AVG play and its effects on PA and health outcomes need to overcome the methodological limitations of the current literature. Apart from the need to be sufficiently powered to detect intervention effects and changes in play across time, studies need to employ validated and reliable measures of AVG play and outcomes (ie, PA, sedentary behavior, and adiposity). While relatively valid and reliable measures of AVG-play outcomes exist, AVG play has been in the main assessed using self-reports with unknown reliability and validity. Objective and metrically sound measures of AVG play are yet to be developed. This is clearly an important issue that future studies need to address. It is also particularly important for studies of AVG play to ascertain whether AVG play results in increased volumes of PA. This calls for the adoption of good-quality measures of PA (eg, heart rate monitoring and accelerometry) or EE (eg, doubly labeled water). To date, no studies have mathematically quantified trajectories of AVG play, individual differences in these trajectories, and variables accounting for such individual differences. Appropriate quantification of temporal trajectories of AVG play would require the use of generalized linear mixed models[53] with power polynomials[54] or restricted cubic splines.[55] Only 1 of the reviewed studies appears to have used optimal statistical methods for the analysis of associations between AVG play and changes in PA and health outcomes across time.[40] Future studies on the health effects of AVG play should use generalized linear mixed models.[53] First, they are highly efficient because they allow the use of all available data, even from subjects with missing information. Second, they can model outcome variables that are not normally distributed (eg, PA). Third, they allow formal quantification of interindividual differences in associations between AVG play and outcomes of interest. Fourth, they permit the identification of personal or situational variables that may be responsible for interindividual differences in associations.[56]

Limitations and Strengths

This review is limited by the number and quality of research articles in the area of AVGs. In addition, due to the rate of introduction of new AVGs in this rapidly evolving area and the lag time until research on current games can be completed, any review of this area will suffer some out-datedness. However, it is timely to highlight possible future research directions that will lead to a better understanding of the likelihood that AVGs can make a contribution to population PA levels in youth or end up in the "virtual" garage beside the exercise bike. Other limitations of this review include potential publication bias due to studies reporting positive results having a better chance of being published; selection bias due to the inability to identify relevant studies not included in the selected search engines; and bias in the assessment of study quality. The latter type of bias arises when information necessary to evaluate the quality of a study is inadequately reported.[57]

Conclusions

While AVGs, like many activities, can elicit PA of recommended intensity, sustainable play has yet to be demonstrated. The popularity of video game play is seen as an indicator that maintenance of play is possible, but some studies highlight barriers to this occurring. There is a need for high-quality investigations of maintenance of AVG play, and the effect of this play on total PA and enhancement of bone and muscle strength. The effect of social interaction on the maintenance of play also warrants investigation.

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