REVIEW ARTICLE

Active Video Games to Promote Physical Activity in Children and Youth

A Systematic Review

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Objectives: To systematically review levels of metabolic expenditure and changes in activity patterns associated with active video game (AVG) play in children and to provide directions for future research efforts.

Data Sources: A review of the English-language literature (January 1, 1998, to January 1, 2010) via ISI Web of Knowledge, PubMed, and Scholars Portal using the following keywords: *video game, exergame, physical activity, fitness, exercise, energy metabolism, energy expenditure, heart rate, disability, injury, musculoskeletal, enjoyment, adherence,* and *motivation*.

Study Selection: Only studies involving youth (≤21 years) and reporting measures of energy expenditure, activity patterns, physiological risks and benefits, and enjoyment and motivation associated with mainstream AVGs were included. Eighteen studies met the inclusion criteria. Articles were reviewed and data were extracted and synthesized by 2 independent reviewers.

Main Outcome Exposures: Energy expenditure during AVG play compared with rest (12 studies) and activity associated with AVG exposure (6 studies).

Main Outcome Measures: Percentage increase in energy expenditure and heart rate (from rest).

Results: Activity levels during AVG play were highly variable, with mean (SD) percentage increases of 222% (100%) in energy expenditure and 64% (20%) in heart rate. Energy expenditure was significantly lower for games played primarily through upper body movements compared with those that engaged the lower body (difference, −148%; 95% confidence interval, −231% to −66%; $P = .001$).

Conclusions: The AVGs enable light to moderate physical activity. Limited evidence is available to draw conclusions on the long-term efficacy of AVGs for physical activity promotion.

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PHYSICAL INACTIVITY IS A WELL-established risk factor for many chronic conditions, such as diabetes, cardiovascular disease, and cancer,[1] and is estimated to cause 1.9 million premature deaths globally per year.[2] In 2004, the World Health Organization established the "Global Strategy on Diet, Physical Activity, and Health Promotion," recognizing the key role that physical activity plays in disease prevention and promotion of lifelong health.[3] Nearly half of preschool children[4] do not meet recommended levels of physical activity (ie, ≥60 minutes daily) prescribed by the American Academy of Pediatrics.[1] Reported barriers to physical activity include a preference for indoor pastimes, low energy levels, time constraints, unsafe neighborhoods, a lack of motivation, not feeling competent or skilled, a lack of resources, and insufficient social support from parents and peers.[1,5-10]

Many studies have explored strategies to reduce physical inactivity in youth. In a recent systematic review,[11] compulsory aerobic physical activity emerged as the common component of effective programs. However, enforcing participation in physical activity is resource intensive, and the long-term success of these interventions remains unknown.[11] Accessible effective strategies to encourage voluntary participation in daily physical activity are needed.[12] Activity choice is largely dictated by level of enjoyment,[13,14] and the most frequently reported reason for participation in physical activity by children is "fun."[15] This same motivation drives competing interest in sedentary activities, including video game play. A typical child aged 8 to 10 years spends approximately 65 minutes per day in video game play.[16] Eighty-three percent of American youth have access to at least 1 video game console in their bedroom.[13] Evidently, screen time activities are highly valued by children, and attempts to restrict these activities are met with resistance.[17]

Instead of competing against a highly valued activity, an alternative strategy is

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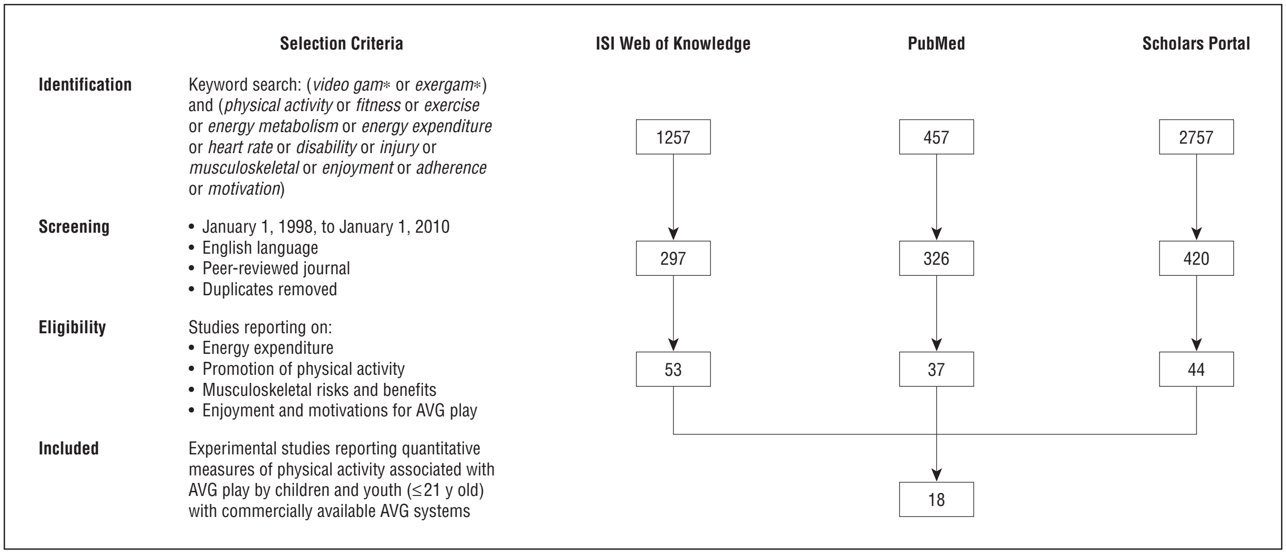

Figure. Flowchart documenting the article selection process. AVG indicates active video game.

to replace passive screen time with active screen time. Video games that require physical activity beyond that of conventional hand-controlled games are referred to as active video games (AVGs).[18] The state-of-the-art in AVGs is constantly changing and is best accessed through popular media. For an introductory review of commercially available AVG systems, see the studies by Mears and Hansen[18] and Trout and Christie.[19]

Active video gaming is an emerging technology with the potential to overcome many of the current barriers to physical activity in children. A recent review[20] of AVGs raises issues of long-term adherence while remaining cautiously positive about AVG play as a convenient exercise with low to moderate intensity to improve children's health and well-being. The goal of this review was to provide a more comprehensive and quantitative synthesis of the current state of knowledge pertaining to AVG play for physical activity promotion in children. Specifically, the objectives were (1) to systematically evaluate levels of energy expenditure and patterns of activity associated with AVG play in children and youth (≤21 years) and (2) to provide directions for future research and development of AVGs.

METHODS

DATA SOURCES AND STUDY SELECTION

A systematic review of the literature via ISI Web of Knowledge, PubMed, and Scholars Portal was conducted using combinations of the following keywords (and their relevant suffixes): *video game, exergame, physical activity, fitness, exercise, energy metabolism, energy expenditure, heart rate, disability, injury, musculoskeletal, enjoyment, adherence,* and *motivation*. Additional studies were identified by reviewing bibliographies.

The search was limited to English-language communications in peer-reviewed journals published between January 1, 1998, and January 1, 2010, when the popularity of AVGs began to accelerate after the release of Konami's *Dance Dance Revolution* (*DDR*).[21] Articles selected for in-depth qualitative review involved youth 21 years or younger and reported on (1) energy expenditure during AVG play, (2) promotion of physical activity through AVG play, (3) physiological risks and benefits of AVG play, and (4) enjoyment of and motivations for AVG play. Articles that targeted virtual reality rehabilitation, cognitive or behavioral therapies, or health education via computer and video games were excluded. Studies that used conventional video games or television as distracters during exercise activities were also excluded from this review. Only studies that reported on experimental results with mainstream AVGs and systems, such as the Wii, Sony EyeToy, XaviX, *DDR*, and Cateye, were included in the quantitative analyses.

DATA EXTRACTION AND SYNTHESIS

Each article was examined by 2 reviewers (E.B. and J.I.) to authenticate data extraction and interpretation. Data extracted included (1) methodological details (eg, study design, experimental context, sample size, participant age, and outcome measures) and (2) key findings pertaining to energy expenditure (eg, heart rate [HR] and oxygen consumption) and the potential for physical activity promotion (eg, adherence, motivations for play, enjoyment, and reported changes in sedentary behaviors, activity patterns, body mass index, and anthropometric measurements). The quality of randomized controlled trials evaluating AVG interventions were further assessed using the PEDro (Physiotherapy Evidence Database) evaluation scale.[22,23] This well-established checklist is used to quantitatively describe the internal and statistical validity of study designs, particularly with respect to allocation, blinding, and dropout rates.

Data extracted from experimental studies were summarized, tabulated, and compared. Quantitative measures of physical activity (ie, percentage increase from resting HR and energy expenditure) were compiled and statistically described in aggregate and with reference to different game types.

RESULTS

The **Figure** provides a flowchart documenting the results of the study selection process. Eighteen articles were included in the quantitative analyses. Studies targeting adults (>21 years old)[21,24-29] were not included in the quantitative review. Methodological details and data extracted are summarized in **Table 1** and **Table 2** for

Table 1. Summary of Studies That Explored Energy Expenditure During AVG Play[a]

Source	Description	Sample	Measures	Key Findings
Leatherdale et al,[30] 2010	Comparison of energy expenditure between active and inactive gaming in young adults	30 M (BMI, 24.3 [3.5]) and 21 F (BMI, 22.5 [2.8]) aged 18.9 (0.9) y	Anthropometry, energy expenditure, HR	Energy expenditure was significantly higher during AVG play (97.4 kcal) vs inactive gaming (64.7 kcal); energy expenditure was significantly higher for M (47.6 kcal) vs F (34.9 kcal) using armband measurements but not HR
Graf et al,[31] 2009	Comparison of energy expenditure between active gaming and treadmill walking in children	14 M (age, 11.9 [1.2] y; BMI, 19.1 [3.1]) and 9 F (age, 11.8 [1.5] y; BMI, 19.9 [2.5])	Anthropometry, energy expenditure, HR, perceived exertion, arterial elasticity	Highest energy expenditure measured during *DDR* (3 times higher than at rest); energy expenditure during AVG play and walking was increased 2- to 3-fold vs at rest; energy expenditure was 19%-33% higher for boys during *DDR* and Wii bowling; large artery elasticity declined immediately after active gaming; change was inversely proportional to increase in energy expenditure above rest
Haddock et al,[32] 2009	Comparison of energy expenditure and perceived exertion between stationary cycling with and without a video game in overweight children (Cateye *Gamebike* with or without Disney's "Cars" [PlayStation 2])	20 Children (13 M with BMI of 29.2 [9.2] and 7 F with BMI of 34 [5.5]) aged 7-14 y	Energy expenditure, HR, VO_2, perceived exertion, anthropometry	Energy expenditure was higher when cycling with the video game (113.2 [31.6] kcal) than without (98.7 [27.2] kcal); no significant difference in average perceived exertion; energy level classified as moderate intensity
Lanningham-Foster et al,[33] 2009	Comparison of energy expenditure during passive video gaming and television viewing and AVG play in children and adults (PlayStation 2 Disney's *Extreme Skate Adventure* and Nintendo Wii *Sports Boxing*)	22 Youths (11 M and 11 F) aged 10-14 y with BMI of 20.2 (3.3) 20 Adults (10 M and 10 F) aged 23-45 y with BMI of 27.7 (5.5)	Anthropometry, accelerometry, energy expenditure, VO_2	Energy expenditure increased significantly during Wii *Boxing* (children: 5.14 [1.71] kcal/h/kg, adults: 2.67 (0.95) kcal/h/kg) vs other activities; movement of the back, trunk, and thighs was significantly greater with Wii *Boxing* vs other activities
Graves et al,[34] 2008	Comparison of energy expenditure during sedentary gaming and AVG play using the Nintendo Wii game system; comparison between games involving upper limb vs total-body movement (eg, bowling, boxing, and tennis)	12 Youths (5 F and 7 M) aged 11-17 y with BMI of 21.8 (3.1)	Energy expenditure, HR, upper and lower body movement	Energy expenditure and HR were highest during Wii *Boxing* at 0.0639 (0.0277) kcal/kg/min[b] and 136.7 (24.5) beats/min, respectively; all AVGs increased levels of physical activity from sedentary games; increased use of both upper and lower limbs may enable higher levels of physical activity to be reached
Mellecker and McManus,[13] 2008	Comparison study of energy expenditure and HR while seated and during AVG play in children using the XaviX gaming system	18 Children (11 M and 7 F) aged 6-12 y	Energy expenditure, HR, anthropometry	Energy expenditure and HR were significantly higher during AVG play vs seated gaming; variance in energy expenditure is high; the highest energy expenditure (5.23 [1.63] kcal/min) and HR (160 [20] beats/min) were reached with the XaviX *J-mat*; this HR is at the cutoff value for vigorous exercise
Graves et al,[35] 2007	Comparison of energy expenditure during sedentary gaming and AVG play using the Nintendo Wii game system; comparison between games involving upper limb vs total-body movement (eg, bowling, boxing, and tennis)	6 M (BMI, 20.7 [2.6]) and 5 F (BMI, 20.7 [2.6]) aged 15-17 y	Energy expenditure, anthropometry	Energy expenditure was $\geq$51% greater during active gaming; highest energy expenditure was achieved with Wii *Tennis* (M: 0.0531 [0.0056] kcal/kg/min, F: 0.0426 [0.0055] kcal/kg/min)[b]; energy expenditure was greater for M vs F
Maddison et al,[36] 2007	Comparison of energy expenditure and physical activity during nonactive gaming and AVG play using the Sony EyeToy gaming system	11 M (age, 12.6 [1.1] y; BMI, 21.2 [4.0]) and 10 F (age, 12.2 [1.0] y; BMI, 19.3 [4.0])	Accelerometry, energy expenditure, VO_2, HR	Significant increases in energy expenditure (129%-400%) and HR (43%-84%) were observed; step counts increased during AVG play (122-1288 steps) from nonactive play (0-23 steps); comparable with light to moderate exercise, such as jogging, walking, and skipping
Straker and Abbott,[37] 2007	Comparison of cardiovascular response and energy expenditure among television watching, sedentary gaming, and AVG play	12 M and 8 F subjects aged 9-12 y	Energy expenditure, HR	HR and energy expenditure were comparable for television watching and conventional video game play; AVG play (EyeToy) increased energy expenditure by 224% and HR by 59% from rest; AVG play (EyeToy) exertion levels were equivalent to activities of moderate intensity (HR, 130 beats/min; energy expenditure, 0.13 kcal/min/kg)
Lanningham-Foster et al,[38] 2006	Comparison of energy expenditure during passive video gaming and television viewing, AVG play (*DDR* and EyeToy), and treadmill walking	25 Children (12 M and 13 F) aged 8-12 y with BMI of 20 (4.0); 10 children had mild obesity and 15 were of typical weight	BMI, energy expenditure	Increases in energy expenditure from rest of 22% (12%) for passive video gaming, 138% (40%) for treadmill walking, 108% (40%) for Sony EyeToy, and 172% (68%) for *DDR* were observed; no difference in energy expenditure during active play between overweight and nonoverweight children
Unnithan et al,[39] 2006	Comparison of energy costs of playing *DDR* between overweight and nonoverweight children	22 Youths (aged 11-17 y); 10 overweight participants with BMI of 27.4 (3.3) and 12 normal-weight participants with BMI of 18.6 (2.9)	Body mass and composition, ventilation, energy cost, respiratory exchange rate, HR, anthropometry	No difference in HR or energy costs associated with *DDR* between overweight and nonoverweight children when adjusted for body weight and stature; HR intensity levels during *DDR* play, but not VO_2 reserve, was sufficient for developing and maintaining cardiorespiratory fitness according to minimum standards
Tan et al,[40] 2002	Energy costs of playing *DDR* after 2 wk of familiarization	40 Youths (21 M and 19 F) aged 17.5 (0.7) y	Oxygen uptake (VO_2), HR, perceived exertion, anthropometry	Exertion levels equivalent to medium-intensity aerobic dance (HR, 137 beats/min; VO_2, 24.6 mL/kg/min) were reached; participants rated game as 11 on Borg scale (fairly light exertion); meets minimum standards for developing and maintaining cardiorespiratory fitness in adults

Abbreviations: AVG, active video game; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); *DDR*, *Dance Dance Revolution*; F, female; HR, heart rate; M, male; VO_2, oxygen consumption.

[a] All values are given as mean (SD).

[b] To convert energy expenditure to joules per kilogram per minute (as originally reported), multiply by 4184.

Table 2. Summary of Heart Rates and Energy Expenditures During AVG Play

Movement and Game	Source	Increase in HR From Resting Values, %	Increase in Energy Expenditure From Resting Values, %	Child-Specific Metabolic Equivalent[a]
Primarily upper body, eg, swinging and reaching				
XaviX *Bowling*	Mellecker and McManus,[13] 2008	26	100	2.0
Wii *Bowling*	Graf et al,[31] 2009	49	101	NA
Wii *Bowling*	Graves et al,[34] 2008	47	117	2.2
EyeToy *Nicktoons Movin'*	Lanningham-Foster et al,[38] 2006	NA	110	2.1
EyeToy *Groove*	Maddison et al,[36] 2007	42	129	2.3
Wii *Tennis*	Graves et al,[34] 2008	53	139	2.4
Primarily lower body, eg, stepping and running				
DDR	Lanningham-Foster et al,[38] 2006	NA	167	2.7
DDR, low level	Graf et al,[31] 2009	63	171	NA
DDR, high level	Graf et al,[31] 2009	83	228	NA
DDR	Unnithan et al,[39] 2006	NA	173	2.7
DDR	Tan et al,[40] 2002	51	246	3.5
DDR	Maddison et al,[36] 2007	63	286	3.9
Cateye *GameBike*	Haddock et al,[32] 2009	59	367	4.7
XaviX *J-Mat*	Mellecker and McManus,[13] 2008	98	400	5.0
Upper body + lower body, eg, for ducking, swaying, and running				
EyeToy *Antigrav*	Maddison et al,[36] 2007	41	186	2.9
Wii *Boxing*	Graf et al,[31] 2009	97	205	NA
Wii *Boxing*	Graves et al,[34] 2008	95	218	3.2
Wii *Boxing*	Lanningham-Foster et al,[33] 2009	NA	321	4.2
EyeToy *Cascade*	Straker and Abbott,[37] 2007	59	229	3.3
EyeToy *Homerun*	Maddison et al,[36] 2007	77	369	4.7
EyeToy *Knockout*	Maddison et al,[36] 2007	82	400	5.0

Abbreviations: AVG, active video game; *DDR*, *Dance Dance Revolution*; HR, heart rate; NA, not available.

[a] Energy expended during AVG play divided by resting energy expenditure.[29]

energy expenditure and in **Table 3** for patterns of activity and use of AVGs. The results presented herein are based on the data compiled in these tables.

ENERGY EXPENDITURE

Several studies[13,30-40] have demonstrated the potential of AVG play to increase energy expenditure from levels observed during sedentary or passive video game activities in children and adolescents (Table 1). Energy expenditure, when adjusted for body composition, seems to be comparable for overweight and nonoverweight participants[38,39] but may be higher for boys than for girls.[30,31,35]

Sustained vigorous activity (eg, >6 metabolic equivalents of task) was generally not elicited during AVG play. Rather, AVG play was found to increase energy expenditure to light or moderate levels[24,26-29,37] (ie, intensities similar to brisk walking, skipping, jogging, and stair climbing). Child-specific metabolic equivalents of task (as defined by Maddison et al[36]) ranged from 2.0[13] to 5.0[36], with a mean (SD) of 3.3 (1) (n=17). Table 2 tabulates these child-specific metabolic equivalents together with the percentage increases in HR and energy expenditure for a variety of AVGs. Energy expenditure during AVG play is highly variable, with percentage increases (from rest) ranging from 100%[13] to 400%,[13,36] with a mean (SD) of 222% (100%) (n=21). Percentage increases in HR varied from 26%[13] to 98%,[13] with a mean (SD) increase of 64% (20%) (n=17). For games that rely primarily on movements of the upper body (eg, bowling and tennis), the mean (SD) percentage increase in energy expenditure was 116% (15%) (n=6) and in HR was 43% (10%) (n=5). For *DDR*, which involves mainly lower body movement, the mean (SD) percentage increase in energy expenditure was 212% (49%) (n=6) and in HR was 65% (13%) (n=4). For games that require both upper and lower body movement (eg, boxing), mean (SD) percentage increases of 275% (86%) (n=7) for energy expenditure and 75% (22%) (n=6) for HR were observed. Percentage increases in HR (difference, −29%; 95% confidence interval, −47 to −11; *P*=.03) and energy expenditure (difference, −148%; −231% to −66%; *P*=.001) were significantly lower for games that require primarily upper body movements compared with those that engage the lower body as well. Evidently, energy expenditure largely depends on the game played, with more intense physical activity sustained during games that promote both upper and, especially, lower body movement.[31,33-35,38]

PATTERNS OF ACTIVITY

Table 3 summarizes the results of several studies[41-46] that evaluated the potential of AVG systems for physical activity promotion in the home. Preliminary evidence suggests that home play of AVGs may provide some moderate increase in physical activity or decrease in sedentary screen time.[42-45] However, a variety of confounding factors and methodological limitations associated with these studies impede the strength of evidence presently available (Table 3). After 12 weeks, dropout rates ranged from 0%[44] to 41%.[42] Other quantitative measures (eg, duration

Table 3. Summary of Studies That Explored the Potential of AVGs for Physical Activity Promotion in the Home

Source	Description	Sample[a]	Measures	Key Findings	Study Limitations	PEDro Score[b]
Madsen et al,[41] 2007	Noncomparative design wherein obese children with a video game console were provided with *DDR* and were motivated through biweekly semistructured telephone interviews; 24 wk	30 Obese children (18 F and 12 M) aged 13 [2.6] y (range, 9-18 y) with BMI of 38.3 [9.0]	Self-reported use, BMI, anthropometry, estimate of energy expenditure	Regular use of *DDR* and changes in BMI were not observed; use of the game decreased with time; at wk 12, only 2 children used *DDR* twice a wk or more; children reported that group play, competitions, and greater variety would motivate use of the system	Methods used to determine estimate of energy expenditure were not detailed; technical difficulties with AVG systems and data collection instruments were encountered; AVG use data were collected for only 40% of participants and were not clearly reported; 30% dropout rate	ND
Chin A Paw et al,[42] 2008	Randomized controlled trial; children were provided with home access to *DDR*; half of the children attended weekly multiplayer classes and the others did not; 12 wk	16 Children (14 F and 2 M) of low fitness aged 10.6 [0.8] y (range, 9-12 y)	Aerobic fitness test, anthropometric measurements, body composition, self-reported playing time, physical and sedentary activity recall, perceived competence in sport, focus group	In total, multiplayer group logged 901 min of play vs 376 min by the nonmultiplayer group (nonsignficant); dropout rate was significantly lower for multiplayer group (15%) vs nonmultiplayer group (64%); multiplayer group's playing time increased during the study, whereas nonmultiplayer group's playing time decreased (nonsignificant)	Intervention group was leaner, which may confound study results; 41% dropout rate	4
McDougall and Duncan,[43] 2008	Mixed-methods, noncomparative design wherein children participated in lunchtime AVG play; 1 wk	12 Children (7 F and 5 M) aged 8-11 y	Pedometry, heart rate monitoring, focus groups	Average play duration of 24 min/d; game play resulted in 10% of recommended steps daily and 11 min of sustained moderate to vigorous physical activity; children liked AVG as an alternative to traditional forms of physical activity	Short study duration and limited sample	ND
Ni Mhurchu et al,[44] 2008	Randomized controlled trial of home-based AVG play (Sony EyeToy and dance mat); 12 wk with before and after measurements	20 Children (8 F and 12 M) aged 12 [1.5] y with BMI of 19.7 [3.6]	Accelerometry, self-reported activity log, estimate of energy based on an established activity compendium, Physical Activity Questionnaire for Children, anthropometric measurements (waist circumference), body composition	Children with access to AVGs had increased activity counts and played game on average 41 min/d; body weight decreased by 0.13 kg in 12 wk; waist circumference decreased by 1.4 cm in 12 wk[c]	Small sample size led to a variety of differences in demographic (intervention group was younger) and activity (intervention group played fewer video games) profiles of control and intervention groups that may confound results	6
Maloney et al,[45] 2008	Randomized wait-list (10-wk delay); controlled group comparison of experimental (home-based *DDR* intervention) and control groups; total study duration of 28 wk; focus on physical activity and enjoyment	Control: 11 F and 9 M (age, 7.6 [0.5] y; BMI, 18.0 [3.3]) Experimental: 19 F and 21 M (age, 7.5 [0.5] y; BMI, 17.2 [2.4])	Self-reported sedentary screen time, self-reported *DDR* use, physical activity measured via accelerometry and pedometry, body composition, anthropometry, seated blood pressure and pulse, satisfaction survey, focus groups	Mean (SD) play duration was 89 (82) min/d; use of *DDR* was highest in wk 1 and decreased to half the prescribed level by end of study; significant changes in physical activity were not observed; however, a significant reduction in sedentary screen time was evident in *DDR* group; children and parents liked game (93%-95%) and would recommend it to others (54%)	Some technical difficulties with data collection tools (eg, accelerometers and data cards); sample was predominantly white with above-average socioeconomic status and below-average BMI and sedentary screen time; pedometer was provided as a data collection tool but may have confounded study results by providing real-time feedback to participants regarding activity counts; seasonal variations may have played a role in study outcomes	6
Paez et al,[46] 2009	As in Maloney et al[45]; focus on assessment of parental and intervention-specific environmental supports in *DDR* participation during first 10 wk of study	As in Maloney et al[45]	Self-report logs, parental support questionnaire, home assessment	At wk 1, absence of other video games and parent participation was associated with child *DDR* participation; general parental support (eg, encouragement and watching child play) was not associated with child participation; at wk 10, sibling and friend participation was associated with child *DDR* participation	Sample was predominantly white with above-average socioeconomic status and below-average BMI and sedentary screen time; validity and reliability of questionnaire used was not established; seasonal variations may have played role in study outcomes	6

Abbreviations: AVG, active video game; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); *DDR*, *Dance Dance Revolution*; ND, not determined; PEDro, Physiotherapy Evidence Database.

[a] Values are given as mean (SD) unless otherwise noted.

[b] The PEDro rating scale assesses internal and statistical validity, and a maximum score of 10 is attainable. For this research, however, a maximum score of 8 was possible because blinding study participants and therapists (where appropriate) to the intervention (ie, AVG play) is not practically feasible.

[c] Differences in demographic and activity profiles between the control and intervention groups may confound these results.

of play) were difficult to compare between studies owing to variations in methods and documentation. These are reported for each study in Table 3. In general, changes in physiological measures, such as body mass index, were not observed at a statistically significant level as a result of AVG play.[44,45] To date, home-based studies have been relatively short (ie, 10[46] to 28 weeks[45]). As such, long-term use and efficacy remain unknown, although several studies[41,42,45] noted a decrease in AVG play during the study for reasons ranging from technical difficulties to illness or changes in living arrangements. Nevertheless, participants generally reported enthusiasm for and enjoyment of the AVG intervention.[43,45,46] Group or competitive play with peers seemed to improve interest and participation in AVGs[41,42,46] and is an important direction for future research.

COMMENT

KEY FINDINGS

Baquet et al[47] suggest that, to improve aerobic fitness in young people, exercise intensity must exceed 80% of the maximum HR (HR_{peak}). Only 2 studies[39,40] (both with older youths) measured HR_{peak}. In each of these studies, average HR surpassed 60% of HR_{peak} during AVG play but did not exceed the 80% target. For rough estimations, an HR_{peak} of 200 beats/min[48] is often assigned for children with the understanding that HR_{peak} has a large degree of interindividual variability. With this limitation in mind, AVG play generally raises HRs to a mean (SD) of 61% (8%) of HR_{peak}, with a range of 50% to 80% based on the data presented in this review. In light of the current evidence base, participation in AVG play should not be regarded as a replacement for vigorous physical activity but can increase energy expenditure from sedentary or passive video gaming levels to that associated with light to moderate physical activity. These results agree with those of several studies[32-35,37] in adults that also establish AVG play as a light- to moderate-intensity activity. In children and adults, activity intensity varies greatly among participants and games and is significantly greater for games that involve the lower body.

Nonprogrammed and lifestyle-related physical activities seem to be extremely important for sustaining weight loss and fitness.[1,10] Provision of nonstructured opportunities for physical activity is in line with the American Academy of Pediatrics recommendations, which advocate the increase in structured and nonstructured physical activity of mixed forms (ie, team, individual, competitive, and noncompetitive).[1] With indoor time increasingly dedicated to inactive pastimes,[49] expansion of home-based opportunities for physical activity is essential. The AVGs are not constrained by typical barriers to participation, such as unsafe neighborhoods, lack of transportation, and seasonal conditions.[50] Although AVGs eliminate many of these environmental barriers, spatial (eg, arrangement of furniture and television in multipurpose living areas) and auditory (eg, jumping or stepping may be disruptive in multilevel or shared living spaces such as apartment buildings) barriers to daily use have been reported.[21,41,42] At this stage, the potential of AVG play for significantly decreasing childhood physical inactivity is inconclusive, although preliminary results of short-term interventions indicate some promise, particularly when opportunities for group play are provided.[42-45] Further research is greatly needed to strengthen the evidence base surrounding this emerging technology, which is, at present, relatively weak. Further study in this area must explore the long-term use and efficacy of AVGs and the changes to sedentary and physical activity patterns that they generate.

DIRECTIONS FOR FUTURE RESEARCH AND DEVELOPMENT

The second objective of this article was to provide directions for future research based on the findings of this review. The following subsections present a variety of areas in need of focused research efforts.

Unknown Physiological Risks

Unlike traditional sports, AVG play is not limited by physical strength, endurance, and training, which provide protection against upper extremity overuse syndrome, delayed-onset muscle soreness, and acute muscular and myotendinous strain.[51] Minimal data are available on injury rates and quality of movement during AVG play. Several case studies[51-53] have reported Wii-related injuries due to prolonged or overly aggressive play. Tan et al[40] reported no injuries during 201 hours of *DDR* play, which compares favorably with injury rates of 2.44 per 100 hours for runners. With the growing popularity of AVGs, research is needed that quantifies injury rates and the forces and eccentric loads exerted by muscle groups during play. This understanding would be beneficial for the development of prescriptive guidelines for physical activity, physical therapy, and general public health.

Energy Expenditure Associated With AVG Play in the Home Setting

It is unknown how well estimates of energy expenditure conducted in a laboratory setting translate to the home environment, where AVG play is often episodic and unsupervised. In the future, games may be designed to minimize interruptions and to promote higher levels of activity with healthy rest periods. Success in the game may be linked to energy expenditure measured using lightweight wearable sensors.[54] The AVGs that encourage higher levels of stable physical activity while limiting the use of low-energy strategies (eg, a wrist flick in lieu of a swing in Wii *Tennis*) should be the focus of further developments. Systems such as the Sony EyeToy and new concepts for the Xbox 360 that translate body motions directly to on-screen play may achieve this goal. Advanced methods that enable game designers to simulate the physiological responses of players in the development and testing stages may also facilitate the creation of optimized systems to maximize the health benefits of the AVGs of the future.[55]

Outcome Measures

Significant changes in physiological outcomes were generally not observed in the studies reviewed. A focus solely on weight loss or body mass index may, however, miss other important benefits rendered by physical activity,[1] including measures of fitness (eg, cardiovascular endurance, muscular endurance, muscular strength, balance, body composition, and flexibility) and changes in sedentary behaviors. Independent of increasing exercise time, reducing sitting time is vital to metabolic health.[56] As emphasized by Pate,[57] research targeting the behavioral aspects of AVG play is absolutely essential to the design and evaluation of AVGs, particularly with respect to the possible displacement of alternative activities that are either more sedentary (positive outcome) or more active (negative outcome). As such, it is important to understand how the introduction of AVGs affects the entire activity profile.

Designing for Long-term Adherence

Self-initiation and choice are important factors that motivate engagement in physical activity for children.[58] The self-determination theory posits that initiation and continued performance of behaviors is driven and predicted by factors such as enjoyment, mastery, and achievement.[12] The development of games that spark these intrinsic motivators in individuals of all ages and levels of physical ability is needed. The following strategies, based on the principles of behavioral economics,[59] should be considered in the design of future AVG systems and interventions: (1) AVGs must provide positive reinforcement and be an accessible (ie, low-cost and easy-to-use) alternative to sedentary activity; (2) early exposure to active in lieu of passive games may increase their acceptance, suggesting the need for games that appeal to a wide range of ages and interests; (3) use of AVGs may be more prolonged and acceptable when perceived as a personal choice as opposed to a treatment or therapy; and (4) immediate reinforcement (eg, enjoyment and points) in addition to continued or long-term reinforcement (eg, progress toward goals and skills development) is important. Future research should address the individual's ability to set and attain goals, to initiate activity, and to achieve recommended intensities and durations of physical activity for a prolonged period.[12] To date, home-based studies have been relatively short (ie, ≤28 weeks[45]). Long-term adherence and efficacy remain unknown. Strategies (eg, diversifying games provided, incorporating a story or plot development into games, and providing opportunities for group play) to maintain interest and enthusiasm in active play with AVGs require further exploration.

Remote Sports and Social Interaction

Mueller et al[60] proposed the value of "sports over a distance" that enable individuals to motivate, participate, and compete against friends regardless of location. The AVGs offer opportunities for group play nonlocally (ie, over the Internet) or in a local setting. For example, in 2006, West Virginia introduced multiple *DDR* consoles into its schools' physical education programs.[61] The current evidence base supports the hypothesis that group play encourages participation in AVG play.[42,46] There are many opportunities for research in this area, including the exploration of virtual and nonvirtual AVG clubs to encourage group and competitive play to maximize acceptance and enjoyment of AVGs for physical activity and health.

Applicability to Disability Groups

For individuals with physical and cognitive disabilities, the physical, social, and environmental barriers to physical activity can be even greater.[10] Providing expanded opportunities and promoting physical activity for children and adolescents with disabilities is a key priority in government health policy.[62] Active video games may be particularly suited to children with disabilities who spend more time alone and engaged in sedentary activities than do their able-bodied peers.[49] A few studies have used AVGs to elevate enjoyment of physical therapies in individuals with cerebral palsy,[63,64] stroke,[65] burns,[66] spinal cord injury,[67] and spina bifida.[68] To our knowledge, no studies have evaluated energy expenditure elicited by AVG play in children with disabilities or have explored the potential of this pastime for increasing physical activity, independent of rehabilitation. Only 1 study[69] has explored the potential use of an AVG adapted for virtual rehabilitation in the home. In this study, 5 children with hemiplegic cerebral palsy were provided with a system based on the Sony EyeToy for 10 days. The children enjoyed having the AVG system at home and used it for a mean (SD) of 29 (32) minutes per day.[69] A final study[70] exploring the potential of AVGs as a leisure activity in adults with intellectual and physical disabilities also observed high levels of enjoyment of this activity. More research is needed to develop prescriptive guidelines for the safe use of AVGs for individuals with disabilities[71] and to determine appropriate measures to evaluate fitness outcomes; body mass index, for example, has been shown to have limited applicability to children with physical disabilities.[62]

MERITS AND LIMITATIONS

This study provides a systematic overview of the current state of knowledge and identifies a variety of opportunities for future research. The timing of this study is opportune given the growing prevalence of and interest in AVGs as an avenue for recreation, health promotion, and rehabilitation. This review provides important guidelines for future research and development in this area to ensure that the health and safety of children is protected while optimizing the health value of AVG play.

Limitations of this study are as follows. Regarding energy expenditure measurements, nonstandardized protocols may have contributed to some of the variations observed among studies. The current evidence base does not allow for strong conclusions to be drawn regarding daily use of AVGs in the home or their efficacy to promote physical activity or reduce sedentary behaviors.

Quantitative interstudy comparisons of activity patterns were not feasible owing to variations in study methods (eg, study duration and outcome measures) and reporting (eg, units of measurement and variations in descriptive statistics reported). The randomized controlled trials included in this review were associated with a median score of 6 on a 10-point scale as assessed using the PEDro evaluation tool. The most common risks for bias included unconcealed allocation, lack of blinding (where possible), and selectively reported outcomes. Dissimilarities between control and intervention groups at baseline were often problematic given the small sample sizes. To strengthen the current evidence base, it is important to address these limitations in the design and dissemination of future studies evaluating the efficacy of AVG play for physical activity promotion.

CONCLUSIONS

Physical inactivity in children and youth remains a significant health issue that will likely be solved only through a multifaceted approach that includes education and structured interventions combined with the provision of enticing opportunities for voluntary daily physical activity. New-generation AVGs are an emerging technology that have recently entered the health care arena with promise to address the latter. Preliminary evidence seems to support AVG play as an enjoyable medium for self-directed physical activity of light to moderate intensity. It remains to be seen whether AVGs can be used effectively in the long term to help motivate increased daily physical activity and decreased sedentary pastimes. The AVGs designed to engage both the upper and lower body while providing opportunities for multiplayer participation may improve the quality and enjoyment of this activity. Providing accessible and appealing options for physical activity in the home will overcome many reported barriers to physical activity, particularly for high-risk disability groups.

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