REVIEW ARTICLE

The Effect of Physical Activity Interventions on Youth with Autism Spectrum Disorder: A Meta-Analysis

Sean Healy, Adam Nacario, Rock E. Braithwaite, and Chris Hopper

The purpose of this meta-analysis was to examine the effect of physical activity interventions on youth diagnosed with autism spectrum disorder. Standard meta-analytical procedures determining inclusion criteria, literature searches in electronic databases, coding procedures, and statistical methods were used to identify and synthesize articles retained for analysis. Hedge's g (1988) was utilized to interpret effect sizes and quantify research findings. Moderator and outcome variables were assessed using coding procedures. A total of 29 studies with 30 independent samples ($N = 1009$) were utilized in this analysis. Results from meta-analyses indicated an overall moderate effect ($g = 0.62$). Several outcomes indicated moderate-to-large effects ($g \geq 0.5$); specifically, moderate to large positive effects were revealed for participants exposed to interventions targeting the development of manipulative skills, locomotor skills, skill-related fitness, social functioning, and muscular strength and endurance. Moderator analyses were conducted to explain variance between groups; environment was the only subgrouping variable (intervention characteristics) to produce a significant difference ($Q_B = 5.67$, $P < 0.05$) between moderators. While no significant differences were found between other moderators, several trends were apparent within groups in which experimental groups outperformed control groups. ***Autism Res*** *2018, 11: 818–833*. © 2018 International Society for Autism Research, Wiley Periodicals, Inc.

Lay Summary: Results of the meta-analysis—a method for synthesizing research—showed physical activity interventions to have a moderate or large effect on a variety of outcomes, including for the development of manipulative skills, locomotor skills, skill-related fitness, social functioning, and muscular strength and endurance. The authors conclude that physical activity's standing as an evidence-based strategy for youth with ASD is reinforced.

Keywords: Exercise; ASD; evidence-based strategy; sport; youth

Introduction

Individuals with Autism Spectrum Disorder (ASD)—children and adults—are at an even greater risk of having co-occurring medical and psychiatric illnesses (Bauman, 2010; Bradley & Bolton, 2006; Croen, et al., 2015), including obesity and cardiovascular disease (McCoy, Jakicic, & Gibbs, 2016) compared to the general population. For example, Curtin et al. (2010) reported obesity rates of 30.4% among the sample with ASD, in comparison to 23.6% of the group without ASD, a finding reflected in other research (Curtin et al., 2005; Memari et al., 2012; Phillips et al., 2014). Research has also revealed that individuals with ASD have lower physical fitness scores (cardiovascular endurance, upper body and abdominal muscular strength and endurance, and lower body flexibility) when compared to their typically developing (TD) peers (Pan et al., 2016). Physical activity participation is one modifiable risk factor that can affect health outcomes. Physical activity allows the human body to develop and strengthen across the five components of physical fitness; muscular strength, muscular endurance, cardiorespiratory endurance, flexibility, and body composition (Caspersen, Powell, & Christenson, 1985). Working to improve or maintain these factors within everyday life helps prevent life-threatening diseases and conditions, such as cardiovascular disease, diabetes, hypertension, and obesity (CDC, 2016).

Individuals with ASD have been shown to be less active than their TD counterparts (Healy, Haegele, Grenier & Garcia, 2017; McCoy et al., 2016; Cai & Kornspan, 2012). Parents have also indicated that their children with ASD participated in significantly fewer types of physical activities than their TD peers, as well as spent less time annually participating in these physical activities compared to their TD peers (Bandini et al., 2013). Researchers have found age to be a determinant

From the Department of Behavioral Health and Nutrition, University of Delaware, Newark, Delaware (S.H.); Department of Kinesiology and Recreation Administration, Humboldt State University, Arcata, California (A.N., R.E.B., C.H.)
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Address for correspondence and reprints: Sean Healy, Department of Behavioral Health and Nutrition, University of Delaware, 26 North College Avenue, Newark, DE 19716. E-mail: healys@udel.edu
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factor in a child with ASD's activity level, and older children with ASD are significantly more inactive than their younger peers (MacDonald, Esposito, & Ulrich, 2011; Memari et al., 2013). A multitude of barriers preventing increased participation exist (Must, Phillips, Curtin, & Bandini, 2015; Healy et al., 2017; Obrusnikova & Miccinello, 2012; Obrusnikova & Cavalier, 2011; Healy, Msetfi, & Gallagher, 2012): on a child/family level, barriers reported by parents and children include the need for supervision, behavioral problems, and motor skills deficits (Must et al., 2015; Healy, Msefi, & Gallagher, 2012), a preference for sedentary behaviors, particularly screen-based activities (Healy et al., 2017; Obrusnikova & Cavalier, 2011), and parental time constraints (Obrusnikova & Miccinello, 2012). Social barriers also exist such as a lack of experts to include the child (Must et al., 2015), and a lack of peer exercise partners (Obrusnikova & Miccinello, 2012). Finally, community barriers, including a lack of opportunities and high cost may also hinder participation (Must et al., 2015).

Researchers have long sought to understand the effect of exercise on a plethora of outcomes for individuals with ASD, such as motor skills, social skills, stereotypical behaviors, self-stimulating behaviors, and physical fitness—see Young and Furgai (2016) for a review of exercise interventions for individuals with ASD. Previous meta-analysis' (Sam, Chow, & Tong, 2015; Sowa & Meulenbroek, 2012) have sought to quantify the effect of exercise, with the aim of providing recommendations to practitioners. Sam, Chow, and Tong analyzed eight studies examining three outcome measures; physical fitness, exercise mastery, and social competence; moderate to large effects were noted for the latter two outcomes, $d = 0.57$ and $d = 0.58$ respectively. Sowa and Meulenbroek (2012) examined the effects of exercise interventions—categorized as either group or individual–on the areas of motor, social, and communication skills. Pooled results demonstrated an overall improvement of 37.5% and found that both motor skills and social skills individual programs yielded medium effect sizes, outperforming group interventions ($r = -0.31$ and $r = -0.62$ respectively). These meta-analyses have provided a valuable insight into outcomes and moderators of exercise in individuals with ASD. However, these studies have not provided a current (since 2014) synthesis of the literature; five studies have been published since 2014 examining the effect of exercise on individuals with ASD (e.g., Gabriels, 2015; Riggenback, 2015; Putetti, 2016). Furthermore, published meta-analyses on the topic do not provide a comprehensive analysis of outcomes and moderators of exercise interventions; for example, previous meta-analyses did conduct comprehensive moderator analyses on intervention characteristics, participant characteristics, and study characteristics. This restricts our understanding of how a broad range of moderators may account for the differences in the effect being meta-analyzed, thus limiting how the meta-analysis informs practice.

The primary purpose of this study is to determine the effect of physical activity interventions on young individuals diagnosed with ASD. For the purpose of this study, interventions were included that were conducted in physical activity settings: physical activities were defined as (a) activities resulting in energy expenditure that are planned, structured, and repetitive, and purposely completed to target the development of skills used for exercise, including motor and sport skill development, or social skills, *or* (b) exercise interventions; planned, structured, repetitive, and purposely completed to improve physical fitness (Caspersen, Powell, & Christenson, 1985). The secondary purpose of this study was to analyze the specific characteristics of these interventions (e.g. type of intervention, environment, duration) in order to further understand why an intervention may or may not be effective. In analyzing these practices and methods of physical activity, it is the hope of authors to give a variety of practitioners (e.g., physical educators, coaches, and recreation leaders) tools to utilize in order to aid young individuals with ASD to achieve the benefits of exercise.

Method

Search Strategy

Following PRISMA guidelines (Moher, Liberati, Tetzlaff, Altman, & Prisma Group, 2009), search strategies for this study were developed around several keywords determined by the authors. The main keywords utilized in the article searches included the following: *autism spectrum disorder, autism, ASD, physical education, physical activity, adapted physical education, adapted physical activity, exercise, and evidence-based practices*. Combinations of these keywords identifying the condition (ASD, etc.), setting/context (Physical education, sport, and physical activity), and design (intervention, etc.) were inserted into searches on several academic journal databases that include *SPORTDiscus*, *ERIC, PsychINFO, PubMed/Medline*, *Child Development and Adolescent Studies*, and *PsychARTICLES*. To identify unpublished work—to examine publication bias – thesis and dissertations were searched for using ProQuest. In order to determine whether articles saved from the initial searches were relevant, a three-stage screening process was implemented. In stage 1, two authors conducted the initial searches by dividing search engines and utilizing the list of keywords developed for this analysis. If the title appeared relevant to the context of the study, the author saved the citation of the article to a citation program

(EndNote X7) and after completing the initial screening all duplicates were removed. In stage 2, two authors independently screened the abstracts of articles saved to the citation database and if the abstract did not provide sufficient information related to the inclusion criteria or appeared to be unavailable it was excluded from the study. In stage 3, two authors independently retrieved the remaining articles in full-text form for further screening; if the articles did not meet inclusion criteria, they were excluded from the study. If a study did not provide sufficient data during review of full-texts the lead author was contacted requesting missing information. A follow-up email was sent two weeks later and after one month the study/paper was excluded when no response was received. Disagreements between authors during stage two or three were further discussed with a third author until consensus was reached.

Inclusion and Exclusion Criteria

Several inclusion criteria were implemented to determine which articles the authors would save during the initial screening. The inclusion criteria for this study were as follows: (a) the study took place in a physical education (PE), physical activity (PA), or sport (S) setting; (b) the participants of the study were two to twenty-two (2–22) years of age; (c) the study implemented a method or intervention (d) the study included a quantifiable outcome measure; (e) the population of the study was determined to have ASD; (f) the study was written in the English language; and (g) the study was published after the year 1970.

Definitions of Settings

To define the settings extracted from included studies, a physical education (PE) setting was determined as activity taking place in an educational setting during school hours. Sport (S) settings were described as traditional team or individual, organized, sport-specific gameplay settings that occur outside of educational settings. Physical Activity (PA) settings were defined as activity taking place outside of an educational setting or a sport-specific based setting (e.g., recreational activities such as walking, hiking, playing at a playground, or lab-based activity).

Coding and Data Extraction

Coding and data extraction forms were developed using established protocols (Brown, Upchurch, & Acton, 2003; Wilson & Lipsey, 2001). Study information was separated into three categories: *Intervention*, *Participant*, and *Study* features. *Intervention* information extracted from each article included study design (i.e., experimental or quasi-experimental), duration (<10 weeks, 10–16 weeks, and >16 weeks), setting (i.e., inclusive; including children without ASD, or specialized; including only children with ASD), type of training held by practitioners (adapted physical education, physical education, medical, or other), outcomes measured (i.e., psychomotor, cognitive, or affective), severity of ASD (mild, moderate, severe) support (i.e., whether parental support was reported in study protocol or not), location (i.e., rural vs. urban area), environment (i.e., physical activity, physical education, or sport setting). *Participant* information included age range, gender, country, and sample size. *Study* features included the measurement tool used (i.e., objective or self-report).

Two coders independently reviewed and reported codes for each of the studies meeting inclusion criteria; these codes were then examined by a third coder, who also looked at any discrepancies between the first two coders. Coding results were compared and analyzed using agreement rates and an inter-rater reliability coefficient. Prior to the statistics being calculated, discrepancies between study codes were reviewed and classified as factual or interpretative. Factual errors were considered transcription errors where the correct answer was present in the study and either missed by the coder or inaccurately reported. Interpretative errors were considered to be errors where study information was inferred or not clear and required the coder to make an interpretation on the classification. All factual errors were corrected; interpretative errors were reviewed by a third author and a simple majority decision determined the appropriate code.

Outliers and Publication Bias

Outliers. Outliers are studies determined to be two standard deviations above or below the overall mean effect of the meta-analysis. Studies deemed as outliers had relative residual scores (z-scores) outside the ninety-fifth percentile of the mean effect score (z score $\geq \pm$ 1.96). Outliers were present and a sensitivity analysis ("one study removed") was utilized to examine the impact of retention/removal of outliers (studies) and their influence on the overall effect score (Greenhouse & Ivengar, 1994). Outliers were retained if results remained significant ($P < 0.05$) and within the 95% confidence interval.

Publication bias. In order to assess publication bias, three separate procedures were used to limit the impact of publication bias. A comprehensive search of the literature was conducted to locate published and unpublished research. Literature included in the study is calculated in a funnel plot by the standard error (*y*-axis) and effect size (*x*-axis) to determine if the plot is balanced. Funnel plots are either symmetrical or asymmetrical (Duval & Tweedie, 2000a,b) and if the funnel plot is found to be asymmetrical, a “Trim and Fill” procedure is used to determine and adjust an effect size by the number of studies needed to balance the plot. Finally, a ‘Fail-Safe N’ calculation was used to determine the number of missing studies needed to nullify significant results (Duval & Tweedie, 2000a; Pearson et al., 2014; Rosenthal, 1979).

Effect Size Calculations

Comprehensive Meta-Analysis (CMA) version-2 software was utilized to calculate effect size statistics (Borenstein, Hedges, Higgins, & Rothstein, 2005). Hedges g was the effect size metric selected as the number of studies ($k < 20$) in different analyses (moderator and outcomes) were smaller and used to correct for an overestimate the effect size (Hedges, 1981). Data extracted from included studies uses mean (M), sample size (N), and standard deviation (SD) as the primary methods for effect size calculations. When these data were not available, F-values, t-values, and/or P-values were extracted from each study (Rosenthal, 1994). A random-effects approach was used to model error for the current meta-analysis (Borenstein, Hedges, Higgins, & Rothstein, 2009). A random effects model uses both sampling error and between study variance to estimate the effect size. Also, when several outcomes were extracted, the study was the unit of analysis and used a procedure was used that averaged the outcomes for a single effect size calculation (Borenstein, Hedges, Higgins, & Rothstein, 2009). Cohen’s (1988) criteria for small (> 0.20), moderate (> 0.50), and large (> 0.80) effect sizes was used to aid the interpretation of results.

Heterogeneity of Variance

Due to expected differences in sampling error and between study variance in this review, there was an assumption that there would be variability in the true effect sizes between studies. Between-study heterogeneity was quantified using the Q-value, tau-squared (τ^2), and I-squared (I^2) statistics. The Q-value partitions variance and is used to determine if excess variation of between study differences exists, tau-squared provides an estimate of the variation of true effects between studies, and I-squared is an estimate of variance that can be explained by moderators (Shadish & Haddock, 2009). Moderator analyses were conducted to examine associations between physical activity interventions and outcomes (i.e., psychomotor, cognitive, and affective) and the influence of selected demographic and methodological characteristics.

Due to a diversity of outcome measures reported in individual studies and the relatively small number of studies meeting inclusion criteria, the authors chose to combine outcomes into several different constructs based on characteristics of study outcomes. For example, body composition was measured by body mass index (BMI), skinfolds, and waist circumference each provided estimates of body fat. As a result, the authors attempted a thematic organization to reflect variable constructs. These constructs included (a) body composition, (b) muscular strength/endurance, (c) cardiovascular endurance, (d) locomotor skills, (e) manipulative skills, (f) skill-related fitness, and (g) social functioning.

Results

The main purpose of the current study was to determine the overall effectiveness across multiple outcomes and moderators of physical activity interventions on young individuals with ASD. There was a total of 29 studies with 30 independent samples that included 1,009 participants meeting inclusion criteria. Figure 1 provides an overall search strategy and article screening process, while Table 1 displays the coded methodological, participant, and study features for each study as well as each study’s overall treatment effect. Six studies included during the screening process provided insufficient data and when authors failed to respond to requests all papers were excluded. Analysis of the coder agreement determined reliability was acceptable ($\kappa = 0.84$) with 28 total disagreements that included 22 factual errors that were corrected and 6 interpretative errors that were analyzed by a third coder and corrected. When interpreting the treatment effects, Cohen’s (1988) criteria were used for interpretation of standardized mean differences and summarized effect sizes as small (≥ 0.20), medium (≥ 0.50), and large (≥ 0.80). Positive effect sizes were interpreted as treatment groups (intervention groups) showing stronger results than control groups or groups not included in the interventions or programs. Negative treatment effects indicated that the control group or non-intervention group produced larger outcome results than the intervention group.

Random Effects Model, Outlier Analyses, and Publication Bias

The average treatment effect for all exercise intervention studies was moderate ($g = 0.62$; $SE = 0.20$; 95% C.I. = 0.23, 1.01; $P < 0.001$) across all outcomes and represented about six-tenths a standard deviation advantage for treatment groups over control groups. Figure 2 displays the relevant statistical analyses utilized when evaluating the overall effect sizes. Moderator analyses of characteristics coded for studies were conducted in order to further explain the between-study variation based on a significant heterogeneous distribution

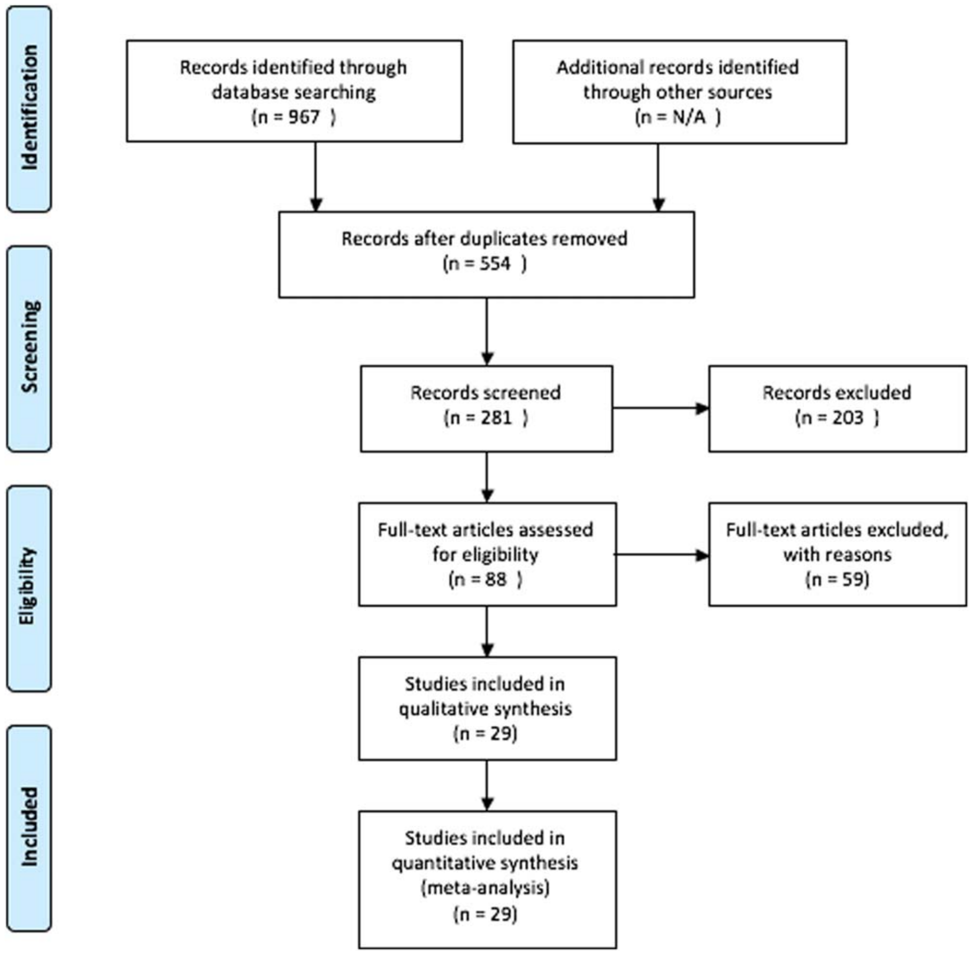

Figure 1. Search Strategy and Article Screening Process.

($Q_T = 249.24$, $P < 0.001$; $I^2 = 88.77$) that was indicative of between study variation.

Outliers and Publication Bias

One independent sample (Favazza et al., 2013) was found to be an outlier ($z = 2.54$), thus an outlier analysis was conducted through evaluation of residual values and a "one-study removed" procedure was performed. The single effect size was retained in the analysis as results indicated a change (−0.21), remaining significant ($P \leq 0.05$) and within the 95% confidence interval. Publication bias was assessed across all constructs of outcomes referenced in Table 2 and reported with the 'Fail Safe N' measurement. Across five outcomes, several studies were deemed necessary to produce non-significant results (Muscular strength/endurance $N = 32$; Locomotor skills $N = 171$; Manipulative skills $N = 162$; Skill-related fitness $N = 271$; Social functioning $N = 26$). However, the two outcomes of body composition and cardiovascular endurance produced a Fail Safe N of 0, suggesting that publication bias may have been violated and no studies were required to yield non-significant ($P > 0.05$) results within these outcomes.

Outcome Analyses

Several outcome analyses that were conducted produced both positive and negative effects, which ranged from $g = -0.18$ to $g = 2.76$. Outcomes that were positive for groups included muscular strength/endurance, locomotor skills, manipulative skills, skill-related fitness, and social functioning. The largest positive effects were found for manipulative skills ($k = 3$, $g = 2.76$, $P < 0.001$), locomotor skills ($k = 6$, $g = 1.60$, $P < 0.001$), skill-related fitness ($k = 12$, $g = 1.07$, $P < 0.001$), muscular strength/endurance ($k = 7$, $g = 0.78$, $P < 0.01$), and social functioning ($k = 6$, $g = 0.57$, $P > 0.05$). A negative effect size was found for body composition ($k = 5$, $g = -0.18$, $P > 0.05$).

Moderator Analyses

Heterogeneity statistics for the random effects model confirmed that there was a heterogeneous ($Q_T = 249.24$, $P < 0.05$) distribution and that a large level ($I^2 = 88.77$)

Table 1. Study Characteristics Meeting Inclusion Criteria

Study	Design	Duration (weeks)	Setting	Training	Outcomes	Level	N	Age (years)	Sex	Environ-ment	Country	School	Support	Loca-tion	Mea-sure	Effect (g)
Anderson-Hanley, 2011	QE	<10	S	NS	C	NR	22	12–14.9	B	PA	US	M	P	NR	O	−0.07
Arzoglou et al., 2013	E	<10	SP	NS	P	NR	5		NR	PE	GER	NR	NR	NR	O	0.41
Bahrami et al., 2012	E	10–16	SP	O	A	C	15		B	PA	IR	COM	NR	NR	O	−0.83
Chan, 2013	E	<10	SP	M	A	C	20		B	PA	C	COM	NR	NR	O	0.24
Borgi, 2016	E	>16	I	O	COM	NR	28	5–14.9	M	PA	I	COM	NR	NR	O	0.87
Chi-Hua, 2012	E	10–16	SP	PE	COM	M	42	5–11.9	B	PE	TAI	E	NP	U	O	1.46
Dickinson, 2014	E	>16	S	PE	P	MOD	100	5–14.9	B	PE	UK	COM	NP	NR	O	0.31
Favazza, 2013	E	<10	SP	O	P	NR	233	5–11.9	B	PE	US	E	P	NR	O	3.11
Fragala-Pinkham, 2008	QE	10–16	S	M	P	M	16	5–11.9	B	PA	US	E	NP	NR	O	0.07
Fragala-Pinkham, 2011	QE	10–16	S	M	P	M	12	5–14.9	B	PA	US	COM	P	NR	O	0.21
Gabriels, 2015	E	10–16	SP	M	COM	NR	116	5–≥15	B	PA	US	COM	NP	NR	O	0.47
Hilton, 2014	QE	10–16	S	M	COM	NR	14	NR	NR	PA	US	COM	NP	NR	O	−0.21
Hinckson, 2013	QE	10–16	SP	O	P	NR	17	12–≥15	B	PE	NZ	COM	P	NR	C	−0.06
Koenig et al., 2012	N	10–16	SP	PE	A	COM	24		B	PE	US	E	NP	NR	O	0.40
Lanning, 2014	E	10–16	SP	O	COM	NR	13	5–14.9	B	PA	US	COM	NP	NR	O	0.65
Lourenco, 2015	E	>16	S	O	P	M	17	5–11.9	B	PA	AUS	E	NP	NR	O	0.21
MacDonald, 2012	E	NR	S	O	P	NR	42	5–≥15	B	PA	US	COM	NP	NR	O	0.69
Movahedi, 2013	E	10–16	SP	O	A	COM	15		B	PA	IR	COM	NP	NR	O	−1.11
Oriel, 2011	E	<10	SP	PE	C	S	9	5–11.9	B	PE	US	E	NP	NR	O	0.67
Pan, 2010	QE	>16	S	PE	COM	M	16	5–11.9	NR	PA	TAI	E	NP	NR	O	0.23
Pan, 2011	QE	>16	S	PE	P	NR	15	5–11.9	B	PA	TAI	E	NP	NR	O	0.06
Pan, 2016	E	10–16	S	PE	COM	NR	22	5–11.9	NR	PA	TAI	E	NP	NR	O	0.33
Pitetti, 2007	E	>16	S	O	P	NR	10	≥15	B	PA	US	H	NP	NR	O	3.44
Ringenbach, 2015	QE	<10	SP	NS	COM	COM	10		B	PA	US	COM	NP	NR	O	0.51
Rosenblat, 2011	QE	<10	SP	M	A	COM	24		B	PA	US	COM	NP	NR	O	0.78
Schleien, 1990	E	NR	I	APE	A	NR	34	5–11.9	B	PE	US	E	NP	NR	O	0.885
Weber, 1989	QE	<10	SP	APE	P	S	28	5–14.9	M	PE	US	COM	NP	NR	O	2.735
Weber, 1992	QE	NR	SP	APE	P	NR	12	5–≥15	M	PE	US	COM	NP	NR	O	2.533
Wuang, 2010	E	>16	S	M	COM	NR	60	5–11.9	B	PA	TAI	E	NP	U	O	0.675

Note. Design: QE, quasi-experimental; E, experimental. Duration (Weeks): NR, not reported. Setting: S, study; I, inclusive; SP, specialized. Training: NS, not specified; PE, physical education; APE, adapted physical education; M, medical; O, other. Outcomes: C, cognitive; P, psychomotor; A, affective; COM, combined. Level: NR, not reported; M, mild; MOD, moderate; S, severe. Gender: NR, not reported; B, both; M, male. Environment: PA, physical activity; PE, physical education. Country: US, United States; I, Italy; TAI, Taiwan; UK, United Kingdom; NZ, New Zealand; AUS, Austria. School: M, Middle; E, Elementary; H, High; COM, Combined. Support: P, Parent Support; NP, No Parent Support; NR, Not Reported. Location: U, Urban; NR, Not Reported. Measure: O, Objective; C, Combined.

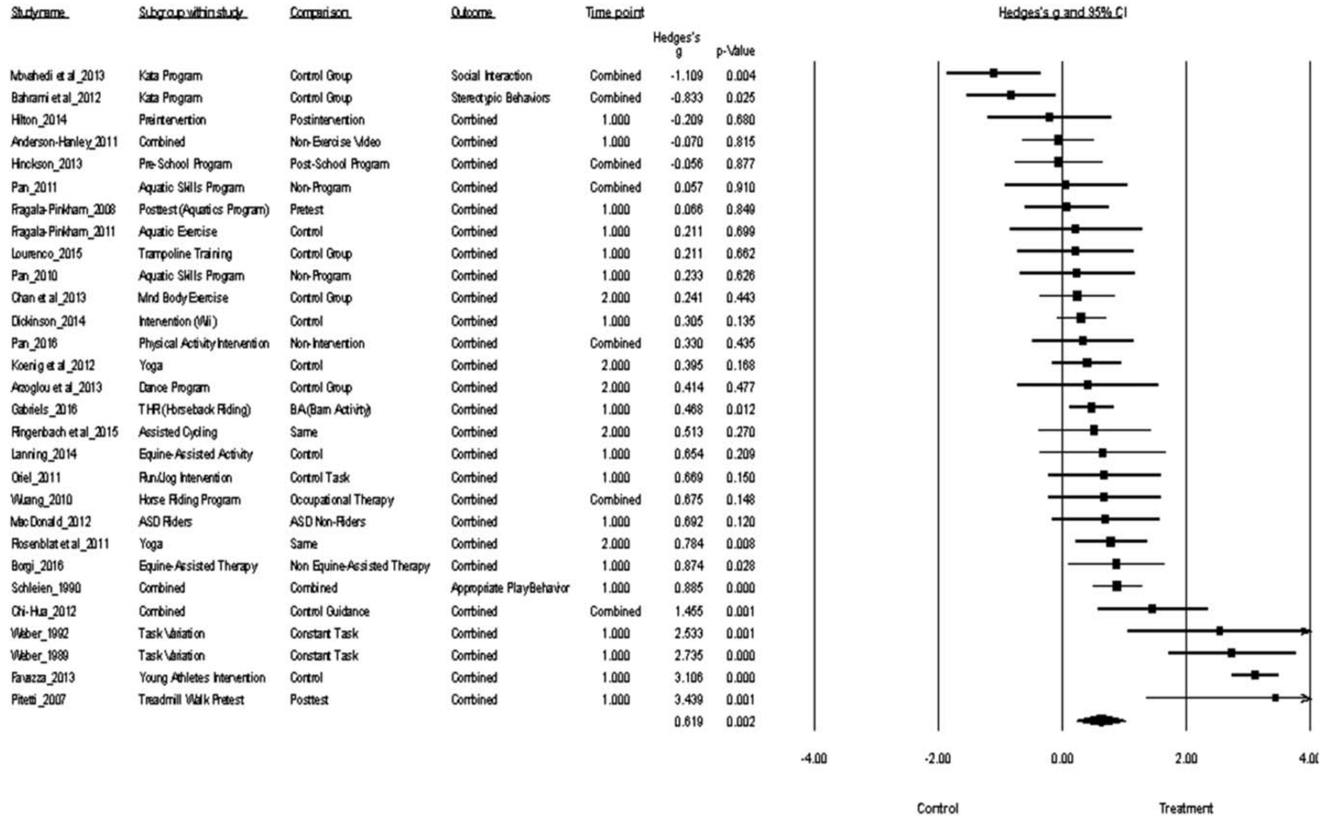

Figure 2. Forest plot for studies meeting inclusion criteria.

of between-study variation existed to justify conducting sub-group analyses for coding characteristics. These results indicate that between study variance was not random and could be explained as a result of the confidence interval overlap. Subgroup results can be imprecise when there are not a critical number of studies ($k \geq 5$) used in the analysis (Borenstein et al., 2009). The authors have selected to report subgroup findings with imprecise estimates of effects for discussion purposes. Table 3 displays all relevant statistical results from moderator analyses on intervention characteristics, participant characteristics, and study characteristics.

Intervention Characteristics

Environment was the only intervention characteristic to produce significant differences between subgroups. Physical education environments ($k = 10$, $g = 1.20$, $Z = 3.92$, $P \leq 0.05$) produced significant large effects for outcomes when compared to physical activity environments ($k = 19$, $g = 0.29$, $Z = 1.31$, $P \geq 0.05$). No other intervention characteristics produced significant differences between subgroups, however, several trends were apparent due to within group comparisons. Studies employing experimental designs ($k = 17$, $g = 0.67$, $Z = 2.67$, $P < 0.05$), employing interventions less than 10 weeks ($k = 8$ $g = 1.06$, $Z = 3.00$, $P < 0.05$), conducted in specialized settings ($k = 12$, $g = 0.7,5$ $Z = 2.38$, $P < 0.05$), facilitated by an instructor with adapted physical education training ($k = 3$, $g = 1.94$, $Z = 2.31$, $P < 0.05$), and interventions that focus on psychomotor outcomes ($k = 12$, $g = 1.21$, $Z = 3.24$, $P < 0.05$) produced significant within group differences between intervention and control groups/conditions. All intervention categories producing significant within group comparisons displayed a high degree of heterogeneity ($Q_T < 0.05$).

Sample Characteristics

There were no subgroup variables for sample characteristics, however, several trends for sample characteristics were discovered within samples that included participants diagnosed with a 'severe' degree of ASD ($k = 2$, $g = 1.68$, $Z = 2.06$, $P \leq 0.05$), samples including both males and females ($k = 16$, $g = 0.74$, $Z = 2.63$, $P \leq 0.05$), samples at elementary grade levels ($k = 11$, $g = 0.77$, $Z = 2.53$, $P \leq 0.05$), and samples from the US ($k = 16$, $g = 0.97$, $Z = 3.49$, $P \leq 0.05$). There was also a large variability within subgroups as indicated by Q and τ^2 values with potential to explain variance between studies ($I^2 > 70$).

Table 2. Outcome Analysis

Variable	Effect size statistics					Null test	Heterogeneity statistics			Publication bias
	k	*g*	*SE*	s^2	95% C.I.	*Z*	*Q*	τ^2	I^2	Fail Safe *N*
Body Composition	5	−0.18	0.15	0.02	(-0.465, 0.103)	−1.25	1.53	0	0	0
Muscular Strength/Endurance	7	0.78	0.29	0.08	(0.223, 1.344)	2.74*	16.98*	0.37	64.66	32
Cardiovascular Endurance	5	0.10	0.30	0.09	(-0.480, 0.686)	0.35	13.42*	0.29	70.20	0
Locomotor Skills	6	1.60	0.56	0.31	(0.516, 2.693)	2.89*	50.04*	1.59	90.01	171
Manipulative Skills	3	2.76	0.85	0.72	(1.099, 4.413)	3.26*	23.09*	1.92	91.34	162
Skill Related Fitness	12	1.07	0.52	0.27	(0.054, 2.082)	2.06*	234.07*	2.98	95.38	271
Social Functioning	6	0.57	0.30	0.09	(-0.023, 1.153)	1.88	26.55*	0.41	81.16	26

Note. K, number of effect sizes; *g*, effect size (Hedges g); *SE*, standard error; s^2, variance. 95% *C.I.*, confidence intervals (lower limit, upper limit); *Z*, test of the null hypothesis; τ^2, between-study variance in random effects model; I^2, total variance explained by moderators. $^*P \leq 0.05$.

Study Characteristics

No significant differences between subgroups were found for study characteristics. Given the limited number of studies no subgroup comparisons can be made. Smaller subgroups within the study location (urban, $k = 3$), study measures (combined reporting measures, $k = 1$), and publication status (unpublished studies, $k = 0$) prevent precise estimates of effect size.

Discussion

The purpose of this study was to assess the effect of physical activity interventions on youth with ASD. Results indicated an overall moderate-positive effect for participants exposed to physical activity interventions, particularly for interventions targeting the development of manipulative skills, locomotor skills, skill-related fitness, social functioning, and muscular strength/endurance.

Manipulative and Locomotor Skills

Reflecting the positive findings in previous meta-analyses (Sam, Chow, & Tong, 2015; Sowa & Meulenbroek, 2012), in the current study interventions focused on the development of manipulative and locomotor skills were demonstrated to have a large positive effect ($g \geq 0.80$). A variety of intervention types were examined, including the Young Athletes program (YAP) (Favazza et al., 2013), trampoline training (Lourenço, Esteves, Corredeira, & Seabra, 2015), stimulated horse-riding program (Wuang, Wang, Huang, & Su, 2010), and task variation/constant task methods (Weber & Thorpe, 1989, 1992). Improvements in locomotor and manipulative skills for this population are particularly important as poor motor skills have been revealed as a significant barrier to physical activity participation among youth with ASD (Must et al., 2015), and, conversely, a predictor of activity levels among TD children (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2009). Delays of motor milestones and atypical fine and gross motor patterns are consistently reported among this population (Lloyd, Macdonald, & Lord, 2013) and have been suggested as a core feature of ASD (Lee & Bo, 205). To help alleviate these deficits, practitioners must be able to depend on the literature base for clearly-defined, theoretically-sound intervention strategies. Favazza et al. (2013) demonstrates well the structure of the intervention, instructional approaches, and training used to effect motor skill improvements in the preschool aged children in a Young Athletes Program. In addition, Favazza et al. delineated the theoretical foundation—Lerner's and Clark's theories of motor development and Newell's theory of motor acquisition—for the context and instructional approach, and described fidelity measures applied. These details are sparse among research on interventions focused on locomotor and/or manipulative outcomes—interventions were largely atheoretical. Future research should seek to overcome such shortcomings of past research for the refinement of replicable interventions. Research should also consider examining the sustainability of motor gains and the consequence of changes in motor performance on physical activity levels.

Skill-Related Fitness

The category of skill-related fitness, encapsulated a variety of outcomes including balance, body coordination, visual motor control, mobility skills, and response speed; skills that have been previously associated with physical activity participation among TD youth (e.g., speed and agility; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006). This category of outcomes was shown to be greatly affected for experimental groups by the implementation of physical activity interventions ($g \geq 0.80$). Intervention modalities utilized included a computer-based activity program (Dickinson & Place, 2014), exergaming (Hilton et al., 2014), trampolining (Laurenco et al., 2015; Giagazoglou 2013), physical training (Pan, 2016), and a Simulated Developmental Horse-Riding Program (SDHRP) (Wuang et al., 2010).

Table 3. Moderator Analysis

	Effect size statistics					Null test	Heterogeneity statistics		
	k	G	SE	s^2	95% C.I.	Z	Q	τ^2	I^2
Random Effects Model [A]	29	0.62	0.20	0.04	(0.227, 1.010)	3.10*	249.24*	0.96	88.77
Intervention Characteristics [B]									
Design							0.97[B]		
Experimental	17	0.67	0.26	0.07	(0.160, 1.182)	2.57*	203.22*	1.24	92.13
Quasi	12	0.54	0.31	0.10	(−0.070, 1.158)	1.74	36.13*	0.37	69.56
Duration							5.35[B]		
<10 Weeks	8	1.06	0.35	0.13	(0.366, 1.753)	3.00*	131.55*	2.09	94.68
10 to 16	11	0.12	0.30	0.09	(−0.474, 0.711)	0.40	31.62*	0.27	68.38
>16 Weeks	7	0.64	0.30	0.16	(−0.139, 1.415)	1.60	10.75	0.14	44.16
Not Reported	3	1.23	0.59	0.36	(0.061, 2.405)	2.06*	4.74	0.25	57.80
Setting							1.06[B]		
Inclusive	2	1.15	0.75	0.56	(−0.313, 2.612)	1.54	1.31	0.04	23.90
Specialized	12	0.75	0.31	0.10	(0.131, 1.359)	2.38*	203.92*	2.26	94.61
Study Designed	15	0.44	0.28	0.08	(−0.117, 0.996)	1.54	16.35	0.02	14.40
Training							3.82[B]		
APE	3	1.94	0.67	0.45	(0.634, 3.245)	2.91*	13.76*	1.30	85.47
PE	7	0.49	0.48	0.23	(−0.425, 1.446)	1.18	9.76	0.01	24.59
Multiple	2	0.51	0.76	0.58	(−0.978, 2.005)	0.68	1.36	0.05	36.91
Medical	6	0.28	0.48	0.23	(−0.657, 1.214)	0.58	21.08*	0.74	76.28
Not Specified	3	0.27	0.65	0.42	(−1.007, 1.545)	0.41	1.36	0	0
Other	8	0.67	0.39	0.15	(−0.329, 1.314)	1.71*	156.46*	2.17	88.77
Random Effects Model [A]	29	0.62	0.20	0.04	(0.227, 1.010)	3.10*	249.24*	0.96	88.77
Outcomes							3.55 [B]		
Affective	6	0.08	0.42	0.18	(−0.743, 0.911)	0.20	33.49*	0.50	85.07
Cognitive	2	0.28	0.75	0.56	(−1.187, 1.745)	0.37	1.79	0.12	44.16
Psychomotor	12	1.21	0.32	0.10	(0.410, 1.663)	3.24*	165.94*	2.06	93.37
Combined	9	0.56	0.32	0.13	(−0.146, 1.262)	1.33	7.93	0	0
Level							2.65 [B]		
Combined	5	0.22	0.49	0.24	(−0.739, 1.185)	0.45	12.33*	0.23	67.55
Mild	5	0.44	0.51	0.26	(−0.563, 1.433)	0.85	6.76	0.14	40.80
Moderate	1	0.31	1.06	1.12	(−1.772, 2.382)	0.28	1.378	0	0
Severe	2	1.68	0.82	066	(0.079, 3.274)	2.06*	8.60*	1.45	88.37
Not Reported	16	0.71	0.29	0.08	(0.150, 1.268)	2.49*	195.05*	1.89	92.31
Environment							5.67 [B]*		
Physical Activity	19	0.29	0.23	0.05	(-0.147, 0.736)	1.31	42.14*	0.20	57.29
Physical Education	10	1.20	0.31	0.09	(0.599, 1.799)	3.92*	148.65*	1.52	93.95
Sample Characteristics [B]									
Gender							0.79 [B]		
Female & Male	16	0.74	0.27	0.07	(0.208, 1.263)	2.73*	175.44*	1.10	91.45
Male	9	0.59	0.36	0.13	(−0.109, 1.296)	1.66	57.07*	0.88	85.98
Not Reported	4	0.19	0.55	0.31	(−0.892, 1.274)	0.35	0.89	0	0
School							4.82 [B]		
Elementary	11	0.77	0.30	0.09	(0.174, 1.367)	2.53*	133.91*	1.44	92.53
Middle	1	−0.07	0.97	0.95	(−1.979, 1.839)	−0.07	0	0	0
High	1	3.44	1.41	2.02	(0.666, 6.212)	2.43*	0	0	0
Combined	14	0.51	0.27	0.07	(−0.026, 1.041)	1.86	59.74*	0.43	78.24
Not Reported	2	0.09	0.76	0.58	(−1.398, 1.581)	0.12	0.88	0	0
Random Effects Model [A]	22	0.81	0.238	0.057	(0.342, 1.276)	3.40*	200.55*	1.04	89.53
Support							0.42 [B]		
No Parents	24	0.56	0.21	0.04	(0.152, 0.961)	2.70*	78.83*	0.32	70.83
Not Reported	1	0.87	0.99	0.98	(−1.064, 2.812)	0.88	0	0	0
Parents	4	0.87	0.49	0.24	(−0.084, 1.827)	1.79	116.17*	3.79	97.42
Country							6.79[B]		
Austria	1	0.21	1.12	1.25	(−1.978, 2.401)	0.19	0	0	0
China	1	0.24	1.06	1.11	(−1.826, 2.309)	0.23	0	0	0
Greece	1	0.41	1.16	1.35	(−1.865, 2.692)	0.36	0	0	0
Iran	2	−0.97	0.76	0.58	(−2.461, 0.520)	−1.26	0.26	0	0
Italy	1	0.87	1.08	1.17	(−1.248, 2.996)	0.81	0	0	0
New Zealand	1	−0.06	1.07	1.15	(−2.154, 2.041)	−0.05	0	0	0
Taiwan	5	0.55	0.50	0.25	(−0.418, 1.526)	1.12	5.74	0.09	30.33

Table 3. Continued

	Effect size statistics					Null test	Heterogeneity statistics		
	k	*G*	*SE*	s^2	95% C.I.	*Z*	*Q*	τ^2	I^2
United Kingdom	1	0.31	1.03	1.06	(−1.709, 2.319)	0.30	0	0	0
United States	16	0.97	0.28	0.08	(0.423, 1.506)	3.49*	176.58*	1.20	91.51
Study Characteristics B									
Location							0.12 B		
Not Reported	26	0.60	0.22	0.05	(0.173, 1.018)	2.76*	245.32*	1.06	89.81
Urban	3	0.83	0.63	0.39	(−0.505, 2.639)	1.32	3.92	0.09	30.78
Measure							0.43 B		
Combination	1	−0.06	1.06	1.11	(−2.124, 2.011)	−0.05	0	0	0
Objective	28	0.65	0.20	0.04	(0.243, 1.047)	3.14*	244.72*	0.96	88.77

Note. *K*, number of effect sizes; *g*, effect size (Hedges g); *SE*, standard error; s^2, variance; 95% *C.I.*, confidence intervals (lower limit, upper limit); *Z*, test of the null hypothesis; τ^2, between study variance in random effects model; I^2, total variance explained by moderators; A, total *Q*-value used to determine heterogeneity; B, between study *Q*-value used to determine significance ($\alpha = 0.05$). *$P < 0.05$.

Deficits in skill-related fitness—for example, related to postural stability (Molloy, Dietrick, & Bhattacharya, 2003), body coordination, and agility (Pan, 2012)—are prevalent among youth with ASD. To prevent skill-related fitness levels from impeding physical activity participation, and thus, the attainment of the related health and social benefits, early intervention is crucial. Future research should continue to refine the structure, and dose, of early interventions focused on developing skill-related fitness, and seek to examine the impact on physical activity participation. Curriculum-based instruction and assessment should be considered when appropriate to ensure delivery of interventions that are goal-orientated, structured, and progressive (Pan, 2011).

Social Functioning

Due to the social deficits at the core of ASD, researchers, including in the field of adapted physical activity, have long tried to positively impact development in this domain. In the current meta-analysis multiple studies were included that measured outcomes in the social functioning category (which encompassed outcomes related to factors such as social communication, adaptive functioning, and appropriate play behaviors). Strategies utilized included horseback riding (Borgi et al., 2016; Gabriels et al., 2016; Lanning, Baier, Ivey-Hatz, Krenek, & Tubbs, 2014), various types of group play (Schleien, Rynders, Mustonen, & Fox, 1990), running/jogging programs (Oriel, George, Peckus, & Semon, 2011), and exergaming interventions (Anderson-Hanley, Tureck, & Schneiderman, 2011). The outcome analysis indicated that social functioning in young individuals with ASD was moderately influenced by the implementation of physical activity interventions ($g = 0.57$); similar to previous meta-analyses (Sowa & Meulenbroek, 2012). Various factors are postulated as contributing to the social development that occurs in physical activity settings, including the nature of physical activity to encourage appropriate play behavior (Schlein et al., 1990) and promote interactions with peers, siblings and instructors (Chia-Hua, 2012); and, specifically related to equine interventions, the formation of relationships with instructors and horses, and the ability of the animals to positively engage people thus counteracting social withdrawal (Borgi, 2016; Lanning, 2014). Future research should continue to identify the 'active ingredient' (O'Haire, 2013) of physical activity interventions that aim to develop the social domain of youth with ASD. Fidelity measures should also be collected. Randomized control trials, with a comparable control group, will be key to disentangling the factors contributing to positive outcomes. Intervention characteristics that showed a trend for producing differences between subgroups in this meta-analysis, that may be worthy of examination in future exercise interventions to impact the social domain, include the training of the intervention facilitator; a trained facilitator, skilled in fostering an environment that promotes social interaction, may be key for success for development of social skills.

Muscular Strength and Endurance

Youth with ASD are demonstrated to have lower muscular strength and endurance that their TD counterparts (Pan, 2014; Tyler, MacDonald, & Menear, 2014). It was significant, therefore, that within the outcome of muscular strength and endurance, experimental groups outperformed control groups to a large effect ($g = 0.818$). Studies measuring these outcomes utilized a number of intervention modalities, such as Nintendo Wii exergaming (Dickinson & Place, 2014), aquatic exercise programs (Fragala-Pinkham, Haley, & O'Neil, 2008; Fragala-Pinkham, Haley, & O'Neil, 2011; Pan, 2011), and horse riding programs (Wuang et al., 2010). The research in this area highlights some challenges, and areas in need for future study; for example, Fragala-

Pinkham et al. (2011) discuss that the 14-week program may not have been of sufficient duration to show changes; perhaps the longer duration of other interventions that showed to positively affect muscular strength and/or endurance contribute to their success (e.g., 20-week intervention: Wuang et al, 2010; one-year intervention: Dickinson, 2014). Future research should seek to identify the dosage required for significant, sustained improvement in muscular strength and endurance. Furthermore, Fragala-Pinkham et al. (2008) makes reference to the challenges of motivating the participants to increase resistance. Future research should clearly define instructional and motivation methods use for the benefit of practitioners and other researchers.

Moderator Effects

Moderator analyses were conducted on intervention characteristics, participant characteristics, and study characteristics overcoming limitations of previous meta-analyses on this topic (Sam, Chow, & Tong, 2015; Sowa & Meulenbroek, 2012). The moderator analysis indicated that specialized classes (i.e., classes consisting of students with ASD only) had a significant influence on the performance of the experimental groups. Specialized classes are designed to help practitioners modify the environment to suit the specific needs of individual students, and this ability to modify has been shown to be an influential component to the success of students with ASD within a physical education context (Hamilton, 2006). The moderator analysis also indicated a significant influence of the intervention facilitator having training in APE on the overall effect of the intervention (reported in three studies). It has been suggested (Jones et al., 2017) that due to complexities of ASD and the prevalence of ASD comorbidities that may affect physical activity participation, specialized facilitators are most suited to implementing interventions. In addition, the moderator analysis indicated that studies not utilizing parental support within the study protocols had the greatest influence on the performance of experimental groups. This is an interesting finding, as the literature suggests that involving parents as support personnel in physical activity for young individuals with ASD is a vital component to their child's success; including parents allows them to be advocates for their children, increases collaborative efforts, and can decrease teaching challenges for practitioners (Obrusnikova & Dillon, 2011; An, 2011). It is possible that the significant findings within this moderator were due to the fact that only four of the 29 total studies reported any parental involvement; perhaps many authors may have overlooked reporting the fact that they specifically chose to not include parents in the study protocols. Future research should seek to include, and provide detail on the role of parents, in physical activity interventions for youth with ASD. Parents may also have a role to increase sustainability and scalability of physical activity interventions for youth with ASD.

Finally, the moderator analysis indicated that a duration of up to 16 weeks had a significant influence on the performance of experimental groups (versus interventions of more than 16 weeks). Further exploration is required to fully understand why a shorter duration may influence the effect of physical activity interventions among youth with ASD. Perhaps shorter interventions encourage a higher degree of engagement in the intervention, higher fidelity of the intervention implementation, or, perhaps, the tendency for shorter interventions to be more frequent and intense? Identifying an optimum duration for physical activity interventions for provided youth with ASD with sustainable results is necessary. In doing so, researchers must be cognizant that factors including the anticipated outcome (e.g., the development of social skills may take longer than the development of motor skills), the nature of the intervention (for example exercise intensity), and severity levels of the participants will be influential. Furthermore, the examination of the effect of interventions of varying durations should include sustained results.

Future research. This meta-analysis provides a comprehensive synthesis of the literature base on physical activity interventions involving individuals with ASD. The potential for physical activity interventions to effect change in a variety of domains has been reinforced. To continue the trajectory of increasingly impactful experimental investigation of interventions for youth with ASD, it is worthy to reflection on opportunities for improving the rigor of evidence underling physical activity as an intervention modality. Here, we will outline four suggestions for future research; (a) Interventions were largely theoretical in nature; the dearth of theory masks the causal factors underlying behavior change. Future intervention research should strive to clearly delineate how the intervention's components are underpinned by sound theory, to allow for reproducibility of research, and ultimately achieve real-world impact and exportability of the findings. (b) Fidelity of the intervention implementation should be assessed; to influence future research and practice, researcher need to demonstrate that the intervention was implemented as planning; the intervention mechanism was delivered as intended. Only then can one infer, in confidence, the process-outcome linkage presented in the research. (c) Randomized control trials, with a comparable control group will be key to disentangling the factors contributing to positive outcomes in interventions. A true experimental design allows researchers to make a clear and sensible interpretation of whichever variables they are attempting to detect within their research, whereas quasi-experimental designs are subject to internal validity as participants may not be comparable at baseline (Quinn & Keough, 2002). For future researchers to make clearer interpretations about the effects of physical activity interventions on young individuals with ASD, it is recommended that true experimental designs be employed in order to ensure participants are at comparable levels prior to the implementation of an intervention. Furthermore, a comparable control group, consisted of individuals with ASD of similar severity should be used. (d) The moderator analysis was to attempt to account for differences in the size of the effect that was meta-analyzed. Due to the limitations of the current meta-analysis (e.g., the heterogeneity of studies in the analysis) the moderator analysis should be interpreted with caution. Nevertheless, several interventions factors emerged as significant; factors that should be detailed, and when possible isolated in future research, to understand their true moderating influence. These factors included the use of specialized settings, a trained intervention facilitator, the inclusion of parent support, and a duration of less than sixteen weeks.

Limitations. Synthesizing studies into one large, comprehensive and critical statistical analysis, the current findings can help to clarify the current state of the literature. However, relatively little research has been conducted on the effects of physical activity interventions on individuals with ASD and much of what has been published lacks scientific rigor. The current meta-analysis did not complete a methodical quality assessment of studies included; this is recommended for future reviews of the literature. Furthermore, it is recommended that future researchers use Medical Subject Headings (MeSH) search terms. Problematic to the current analysis was the selection of control groups as many studies chose to use TD populations for comparison. Furthermore, the frequency and variability of outcomes (and measurement of outcomes) reported are both inconsistent and inconclusive. Physical activity interventions have been found to improve physical, cognitive, emotional, and social outcomes and in the current investigation limited information was reported for cognitive, emotional, and social outcomes. As research continues to improve and more sophisticated methods and measures are developed results of a future meta-analysis regarding the effects of physical activity on individuals with ASD may result in different findings. Another limitation of this study is the small number of studies with sufficient data to be included in a meta-analysis. While this problem is not unique to the current study it further highlights the importance of the need for additional high-quality research and publishing sufficient data to allow for such analyses.

Conclusion

The physical activity interventions examined in this study have been shown to have an overall moderate effect ($g = 0.62$). Specifically, moderate to large positive effects were revealed for participants exposed to interventions targeting the development of manipulative skills, locomotor skills, skill-related fitness, social functioning, and muscular strength and endurance. For future replication of studies, and refinement and implementation of effective physical activity interventions for youth with ASD, several recommendations for future research can be made; increased attention should be paid to utilizing true experimental designs, application and delineation of a sound theoretical foundation, and rich details of intervention structure. Future research should also examine sustainability of intervention effects.

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