Review

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The effect of motor and physical activity intervention on motor outcomes of children with autism spectrum disorder: A systematic review

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Abstract

Difficulty performing age-appropriate motor skills affects up to 83% of children with autism spectrum disorder. This systematic review examined the effect of motor and physical activity intervention on motor outcomes of children with autism spectrum disorder and the effect of motor learning strategies on motor skill acquisition, retention, and transfer. Six databases were searched from 2000 to 2019. Forty-one studies were included: 34 intervention studies and 7 motor learning studies. The overall quality of the evidence was low. Participants included 1173 children with autism spectrum disorder ranging from 3 to 19 years. Results from level II and III intervention studies supported that participation outcomes improved with a physical education intervention; activity outcomes improved with aquatic, motor activity, motor skill, and simulated horse riding interventions; and body structure and function outcomes improved with aquatic, exergaming, motor activity, motor skill, and simulated horse riding interventions. Results from level II and III motor learning studies supported that motor skill acquisition improved with visual, versus verbal, instructions but was not influenced by differences in instructional personnel. More rigorous research on motor intervention is needed with well-controlled study designs, adequate sample sizes, and manualized protocols. In addition, research on motor learning strategies is warranted as it generalizes across motor interventions.

Lay abstract

Up to 83% of children with autism spectrum disorder have difficulty performing age-appropriate motor skills. However, the effectiveness of current interventions to improve motor skills is poorly understood. In this review, we examined 34 research studies that investigated the use of interventions to improve the motor abilities of children with autism spectrum disorder. We also examined seven research studies that investigated strategies used to teach children with autism spectrum disorder age-appropriate motor skills. In total, these studies included 1173 children with autism spectrum disorder ranging from the age of 3 to 19 years. We found that many interventions improved the motor abilities of children with autism spectrum disorder including the following: (1) motor activity interventions (e.g. gymnastics, soccer), (2) motor skill interventions (e.g. throwing, catching), (3) horse riding interventions, (4) swimming interventions, (5) video gaming interventions, and (6) physical education interventions. However, each intervention improved different types of motor abilities. We also found that as a teaching strategy, visual instruction was more effective than verbal instruction for children with autism spectrum disorder. In addition, the children with autism spectrum disorder learned equally well from many different types of instructors (adult, robot, or peer). Further high-quality research on this topic is needed to determine how to best optimize the motor abilities of children with autism spectrum disorder.

Keywords

autism spectrum disorders, children, intervention, motor, quality of life, systematic review

Introduction

Autism spectrum disorder (ASD) is characterized by persistent deficits in social communication and the presence of restrictive, repetitive patterns of behavior or interests (American Psychiatric Association, 2013). Although not

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part of the core diagnostic domains of ASD, up to 79% to 83% of children with ASD have difficulty performing age-appropriate motor skills (Green et al., 2009; Hilton, Zhang, Whilte, Klohr, & Constantino, 2011). These motor limitations are observed throughout childhood and adolescence. Fine and gross motor delays are noted in toddlers with ASD (Landa & Garrett-Mayer, 2006; Provost, Lopez, & Heimerl, 2007), although it is inconclusive if the motor delay in children with ASD can be differentiated from general developmental delay (Provost et al., 2007). Motor limitations are common in children with ASD, regardless of the presence of an intellectual disability (Bhat, Landa, & Galloway, 2011). In a cohort of 101 school-aged children with ASD, 97% of children with ASD and an intellectual disability (intelligence quotient (IQ) < 70) and 70% of children with ASD and near normal or normal intelligence (IQ ⩾ 70) were unable to perform age-appropriate motor skills on a standardized motor test (Green et al., 2009).

Difficulty performing age-appropriate motor skills may limit participation in the activities necessary to support the development of age-appropriate social, communication, behavioral, and cognitive skills (Bhat et al., 2011). In addition, motor impairments may limit participation in the physical activity necessary to promote optimal health and wellness (Srinivasan, Pescatello, & Bhat, 2014). Children and adolescents with ASD exhibit decreased levels of physical activity (McCoy, Jakicic, & Gibbs, 2016) and are more likely than their typically developing peers to be overweight or obese (de Vinck-Baroody et al., 2015; McCoy et al., 2016).

Children with ASD may have difficulty performing age-appropriate motor skills due to specific motor impairments or differences in other domains that affect the way they learn motor skills (Moraes et al., 2017). Children with ASD demonstrate impairments in postural control, motor planning, and motor imitation, which may directly impact their ability to perform age-appropriate motor skills (Downey & Rapport, 2012). In addition, as many as 90% of children with ASD experience sensory processing differences (Tomcheck & Dunn, 2007), including tactile hypersensitivity and other sensory modulation impairments, that may hinder their ability to sustain the engagement in motor activities needed to learn age-appropriate motor skills (Robertson & Baron-Cohen, 2017; Schauder & Bennetto, 2016). Differences in social attention (Chita-Tegmark, 2016), observational learning (Plavnick & Hume, 2014), and executive function (Craig et al., 2016) may result in differences in the way children with ASD learn motor skills. To support learning of new motor skills, children with ASD may benefit from the use of specific strategies to organize practice, provide instruction, and give feedback. In addition, children with ASD may benefit from strategies to support their differences in social communication and patterns of behaviors and interests.

Several systematic reviews have reported improvements in social (Sowa & Meulenbroek, 2012), behavioral (Bremer, Crozier, & Lloyd, 2016; Lang et al., 2010), and cognitive outcomes (Tan & Pooley, 2016) of children with ASD after motor or exercise intervention. The effect of motor or exercise intervention on the motor outcomes of children with ASD has been investigated in three systematic reviews (Dillon, Adams, Goudy, Bittner, & McNamara, 2017; Healy, Nacario, Braithwaite, & Hopper, 2018; Sowa & Meulenbroek, 2012). All reviews reported improvements in motor outcomes; however, a limitation of these reviews is that they combined results from many different types of interventions, such as hippotherapy, aquatic, and physical education, to understand the effect of motor intervention as a whole on motor outcomes. However, it may be more impactful for educators, medical professionals, and researchers to understand the effect of specific types of motor interventions on specific motor outcomes of children with ASD. Another limitation of the previous reviews is that they did not identify strategies used in the studies to augment learning in children with ASD. This systematic review addresses these gaps in literature to provide evidence-based information to inform the selection of appropriate motor interventions to improve specific motor outcomes of children with ASD and to inform the selection of appropriate strategies to augment motor learning in children with ASD.

The primary objective of this systematic review is to evaluate the evidence on the effect of motor and physical activity interventions on motor outcomes of children with ASD. To gain a comprehensive understanding, we analyzed motor outcomes from all three levels of the International Classification of Functioning, Disability, and Health for Children and Youth (ICF-CY): societal participation (e.g. physical functioning subtest of a quality of life measure), activity (e.g. norm-referenced motor assessment), and body structure and function (e.g. strength, cardiovascular fitness) (World Health Organization, 2002). We also categorized the motor and physical activity interventions to investigate how specific types of motor interventions affect specific outcome measures at each level of the ICF-CY. The secondary objective of this systematic review is to identify the effects of motor learning strategies on motor skill acquisition, retention, and transfer.

Methods

Search strategy

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher, Liberti, Tetzlaff, Altman, & PRISMA Group, 2009). A comprehensive search of six databases (CINAHL, Clinical Trials, Cochrane, PEDro, PubMed, Web of Knowledge) up to

April 2019 was performed by a clinical services librarian (R.J.). Medical subject headings (MeSH) and non-MeSH search terms were used, including the following: autism spectrum disorder, physical therapy, motor intervention, and exercise. Supplemental Table 1 includes the full search strings by database. No filters were applied for study type or language. Additional studies were identified through a manual search of the references in relevant studies.

Selection criteria

Studies were included based on the following criteria: (1) group study designs included cohort studies and clinical trials; (2) participants included were children with ASD from birth to 21 years, and if other diagnoses were included, the results of participants with ASD were statistically analyzed separately; (3) all types of motor and physical activity interventions; (4) motor outcome of body structure and function, activity, or societal participation was measured using an objective outcome measure and statistically analyzed; (5) published in English; and (6) the study investigated either (a) the effects of a motor intervention on a motor outcome or (b) the effects of a motor learning variable on motor skill acquisition, transfer, and/or retention.

Studies were excluded based on the following criteria: abstracts, conference proceedings, and dissertations. In addition, we did not include studies published before 2000, in order to focus on current research that used contemporary methods to diagnose ASD, such as the Autism Diagnosis Observation Schedule (ADOS), *Diagnostic and Statistical Manual of Mental Disorders-IV* (DSM-IV), or *Diagnostic and Statistical Manual of Mental Disorders-V* (DSM-V).

Study selection

Studies were included based on the title and abstract, using the inclusion and exclusion criteria. If necessary, a full-text review of the studies was completed. Three authors (A.M., A.R., and B.S.) coded the first 10% of studies (n=625) to establish reliability for study selection. Discrepancies were resolved through discussion. Then, using a systematic review production platform, Covidence (Covidence systematic review software), two authors (A.M. and A.R.) independently reviewed the remaining articles (n=5625) and the third author (B.S.) resolved disagreements.

Level of evidence

Studies were assigned a level of design rigor (level I to level V) based on criteria from the American Academy of Cerebral Palsy and Developmental Medicine (AACPDM) Systematic Review Methodology (Darrah, Hickman, O'Donnell, Vogtle, & Wiart, 2008). Level I is the most rigorous study design, and level V is the least rigorous study design.

Study appraisal

Study validity was appraised using the Evaluative Method for Determining Evidence-Based Practice in Autism (Reichow, Volkmar, & Cicchetti, 2008). For group research reports, this tool has an interrater reliability of 94% for primary quality indicators and 85% for secondary indicators (Reichow et al., 2008). Reliability was established by three authors (A.M., A.R., and B.S.) to >90% using six studies. Two authors then independently appraised the remaining articles, scores were compared for agreement, and discrepancies were resolved via discussion among the three authors.

Data extraction

Mutual consensus was used to determine the applicable data to be extracted from each study by three authors (A.M., A.R., and B.S.). Data extracted included study design, tool used to diagnose ASD, age of participants, type of intervention, intervention provider, ratio of instructor to study participants, frequency and duration of intervention, description of control conditions, motor outcome measures, ICF-CY classification of motor outcome measures, timing of measures, results, motor learning variables, and strategies used to support participants with ASD. Reliability of extracted data was established by three authors (AM, AR, and BS) to >90% using six studies. Two authors then independently extracted data from the remaining articles, data were compared for agreement, and discrepancies were resolved via discussion.

Due to the heterogeneity of interventions and outcome measures used in the studies, a meta-analysis was not conducted.

Results

Study selection

Figure 1 includes details of the search strategy and study selection. The search identified 7972 studies. A total of 41 studies are included in the review (Ajzenman, Standeven, & Shurtleff, 2013; Alaniz, Rosenberg, & Beard, 2017; Arzoglou et al., 2013; Borgi et al., 2016; Brand, Jossen, Holsboer-Trachsler, Pühse, & Gerber, 2015; Bremer, Balogh, & Lloyd, 2015; Caputo et al., 2018; Cei, Franceschi, Rosci, Sepio, & Ruscello, 2017; Cheldavi, Shakerian, Shetab Boshehri, & Zarghami, 2014; Chu & Pan, 2012; Dickinson & Place, 2014; Edwards, Jeffrey, May, Rinehartc, & Barnetta, 2017; El Shemy & El-Sayed, 2018; Fragala-Pinkham, Haley, & O'Neil, 2011; Gabriels et al., 2012; Gabriels et al., 2015; Guest, Balogh, Dogra, & Lloyd, 2017; Hayward, Fragala-Pinkham, Johnson, & Torres, 2016; Henderson, Fuller, Noren, Stout, & Williams, 2016; Hilton et al., 2014; Ketcheson, Hauck, & Ulrich, 2017; Kokaridas, Demerouti, Margariti, & Krommidas,

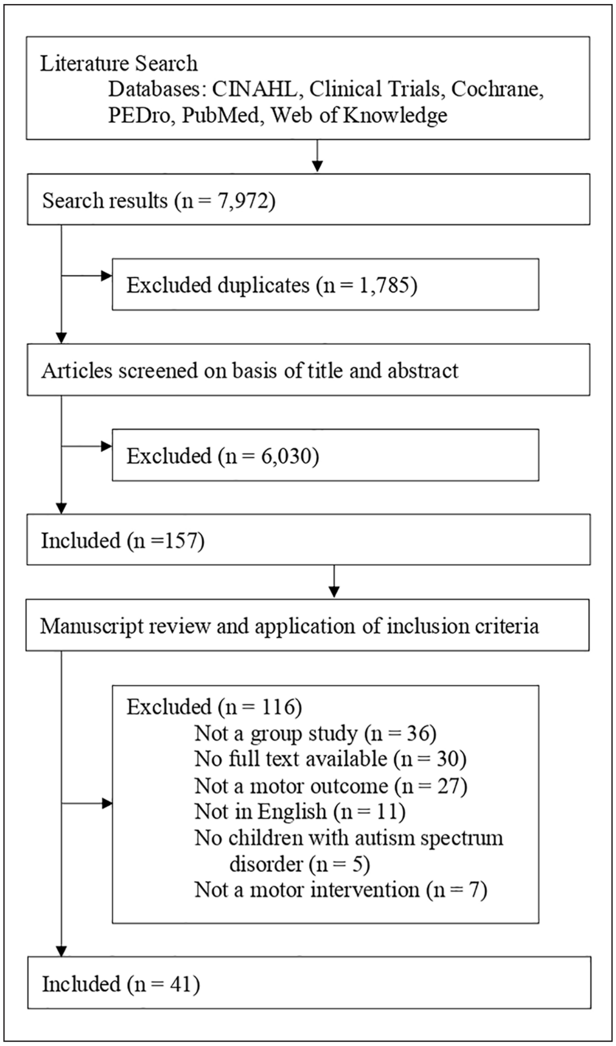

Figure 1. Search strategy and study selection.

2018; Lanning, Baier, Ivey-Hatz, Krenek, & Tubbs, 2014; Lourenco, Esteves, & Seabra, 2015; Najafabadi et al., 2018; Navaee, Abedanzadeh, Salar, & Sharif, 2018; Pan, 2010, 2011; Pan et al., 2017; Rafie, Ghasemi, Zamani Jam, & Jalali, 2017; Samsudin & Low, 2017; Sarabzadeh, Azari, & Helalizadeh, 2019; Sarol & Cimen, 2015; Srinivasan et al., 2015; Taheri-Torbati & Sotoodeh, 2019; Toscano, Carvalho, & Ferreira, 2018; Travers et al., 2018; Tse, 2019; Tse & Masters, 2019; Wuang, Wang, Huang, & Su, 2010; Zamani, Talab, Sheikh, & Torabi, 2017).

Quality assessment

Table 1 includes study design, level of evidence, and strength of the research report for each study. The level of evidence and study design for the 41 studies include 14 level II randomized clinical trials (RCTs), 15 level III non-randomized clinical trials, 11 level IV prospective cohort studies, and 1 level IV retrospective cohort study. The strength of the research report was strong for 1 RCT, adequate for 5 RCTs and 1 non-randomized clinical trial, and weak for the remaining 34 studies. The most common reasons for weak strength of the research report were the lack of a comparison condition and inadequate power or small sample size. Supplemental Table 2 includes the detailed research quality results for each study.

Participants

A total of 1173 children and adolescents with ASD ranging in age from 3 to 19 years participated in the studies. In addition, 82 children and adolescents with typical development (6–13 years) participated in five studies as a control group or as part of the intervention. Table 1 includes the age of the participants for each study. For participants with ASD, 30 studies reported gender with 83% of participants reported as male, 25 studies confirmed the diagnosis of ASD using the DSM-IV criteria (American Psychiatric Association, 2000) or the ADOS (Lord et al., 2000), and 10 studies included IQ data with 7 reporting an IQ of ⩾70 for all participants.

Motor interventions

The characteristics of the interventions are included in Table 1. Thirty-four studies investigated the effects of a motor intervention on a motor outcome, and 7 studies investigated the effects of a motor learning variable on motor skill acquisition, transfer, and/or retention. Types of interventions were categorized into six groups: (1) motor activity interventions (n=9 studies); (2) motor skill interventions (n=7 studies); (3) hippotherapy, equine-assisted, or simulated horse riding interventions (n=6 studies); (4) aquatic interventions (n=5 studies); (5) exergaming interventions (n=4 studies); and (6) physical education interventions (n=3 studies).

Motor outcome measures. The results of motor outcome measures for each study are included in Table 2. The studies used a variety of outcome measures spanning the ICF-CY model. Participation or quality of life was measured in four studies and included the physical functioning subtest of the Pediatric Quality of Life Inventory (pf-PedsQL), Child Activity Card Sort (CACS), and the physical health subtest of the Child Health Questionnaire (ph-CHQ).

Activity was measured in 34 studies and included standardized developmental motor tests, standardized tests of swimming, and individualized outcome measures. Standardized developmental motor tests included the motor subtest of the Vineland Adaptive Behavior Scales, second edition (m-VABS-II); Bruininks-Oseretsky Test of Motor Proficiency, first or second edition (BOT, BOT-2); Movement Assessment Battery for Children, second edition (MABC-2); Peabody Developmental Motor Scales,

Table 1. Study descriptions.

Author(s) (year)	Study design, level of evidence	Strength of the evidence	Participants (age range and diagnosis)	N	Intervention description	Ratio (instructor:child)	Frequency/duration
Motor activity intervention							
Arzoglou et al. (2013)	Non-randomized clinical trial/III	Weak	16y (mean), ASD	Total $N=10$ IG = 5, CG = 5	Traditional Greek dance	1:1-2	34–45 min, 3×/wk, 8 wks
Cei et al. (2017)	Prospective cohort/IV	Weak	6–13y, ASD	IG = 30	Soccer training program	NR	60 min, 2×/wk, 24 wks
Guest et al. (2017)	Prospective cohort/IV	Weak	8–11y, ASD	IG = 13	Multi-sport camp: locomotor and object control skills, then translational sports	1:3	Full day, 5 days
Hayward et al. (2016)	Retrospective cohort/IV	Weak	5–19y, ASD	IG = 15	Adaptive soccer program	1:1	90 min, 1×/wk, 6 wks
Kokaridas et al. (2018)	Prospective cohort/IV	Weak	9y, ASD and TD	Total $N=6$ ASD = 3, TD = 3	Indoor climbing	1:3	40 min, 2×/wk, 12 wks
Lourenco et al. (2015)	Non-randomized clinical trial/III	Weak	4–11y, ASD	Total $N=17$ IG = 6, CG = 11	Trampoline	1:6	45 min, 1×/wk, 20 wks
Pan et al. (2017)	RCT with crossover/II	Adequate	6–12y, ASD	Total $N=22$ IG1 = 11, IG2 = 11	Table tennis	1:1-2	70 min, 2×/wk, 12 wks
Sarabzadeh et al. (2019)	RCT/II	Weak	6–12y, ASD	Total $N=18$ IG = 9, CG = 9	Tai Chi Chuan training	NR	60 min, 3×/wk, 6 wks
Zamani et al. (2017)	Non-randomized clinical trial/III	Weak	8–12y, ASD	Total $N=30$ IG = 15, CG = 15	Gymnastic exercises	NR	45 min, 3×/wk, 16 wks
Motor skill interventions							
Brand et al. (2015)	Prospective cohort/IV	Weak	7–13y, ASD	IG = 10	Aerobic exercise, balance, ball skills	NR	60 min, 3×/wk, 3 wks
Bremer et al. (2015)	Non-randomized clinical trial/III	Weak	4y (mean), ASD	Total $N=9$ IG = 5, CG = 4	Fundamental motor skills (locomotor, object control)	1:1-2	60 min, 1×/wk, 6 or 12 wks
Cheldavi et al. (2014)	Non-randomized clinical trial/III	Weak	7–10y, ASD	Total $N=20$ IG = 10, CG = 10	Balance training program	NR	45 min, 3×/wk, 6 wks
El Shemy and El-Sayed (2018)	RCT/II	Weak	8–10y, ASD	Total $N=30$ IG = 12, CG = 15	Motor skills and gait training with auditory rhythmic cueing	NR	PT program: 60 min, 3×/wk, 12 wks; RAS program: 30 min, 3×/wk, 12 wks
Ketcheson et al. (2017)	Non-randomized clinical trial/III	Weak	4–6y, ASD	Total $N=20$ IG = 11, CG = 9	Motor skill (locomotor, object control)	1:1	240 min, 5×/wk, 8 wks
Najafabadi et al. (2018)	RCT/II	Weak	5–12y, ASD	Total $N=26$ IG = 12, CG = 14	Sports, play, and active recreation for kids	1:3	40 min, 3×/wk, 12 wks
Rafie et al. (2017)	RCT/II	Adequate	9–12y, ASD	Total $N=20$ IG = 10, CG = 10	Motor skill (body awareness, motor planning, balance, fine motor coordination, visual-motor coordination)	2:10	45 min, 3×/wk, 10 wks
Hippotherapy, equine-assisted, or simulated horse riding interventions							
Ajzenman et al. (2013)	Prospective cohort/IV	Weak	5–12y, ASD	IG = 6	Hippotherapy	NR	45 min, 1×/wk, 12 wks

(Continued)

Table 1. (Continued)

Author(s) (year)	Study design, level of evidence	Strength of the evidence	Participants (age range and diagnosis)	N	Intervention description	Ratio (instructor:child)	Frequency/duration
Borgi et al. (2016)	RCT/II	Weak	6–12 y, ASD	Total N=28 IG = 15, CG = 13	Equine assisted	1:3-4	60–70 min, 1×/wk, 24 wks
Gabriels et al. (2012)	Non-randomized clinical trial/III	Weak	6–16 y, ASD	Total N=42 IG = 26, CG = 16	Hippotherapy	1:3-4	60 min, 1×/wk, 10 wks
Gabriels et al. (2015)	RCT/II	Adequate	6–16 y, ASD	Total N=116 IG = 58, CG = 58	Hippotherapy	1:2-4	60 min, 1×/wk, 10 wks
Lanning et al. (2014)	Non-randomized clinical trial/III	Weak	4–15 y, ASD	Total N=25 IG = 13, CG = 12	Equine assisted	1:1-2	60 min, 1×/wk, 12 wks
Wuang et al. (2010)	Non-randomized clinical trial with crossover/III	Adequate	6–8 y, ASD	Total N=60 IG1 = 30, IG2 = 30	Simulated horse riding	NR	60 min, 2×/wk, 20 wks
Aquatic interventions							
Alaniz et al. (2017)	Prospective cohort/IV	Weak	3–7 y, ASD	IG = 6	Aquatic skills	1:2	60 min, 1×/wk, 8, 16, or 24 wks
Caputo et al. (2018)	Non-randomized clinical trial/III	Weak	6–12 y, ASD	Total N=26 IG = 13, CG = 13	Aquatic skills: emotional adaptation, swimming adaptation, social integration	1:1, then 1:3	45 min, 1–2×/wk, 10 mo
Fragala-Pinkham et al. (2011)	Non-randomized clinical trial/III	Weak	6–12 y, ASD	Total N=12 IG = 7, CG = 5	Aquatic skills, warm up, cool down, stretches	NR	40 min, 2×/wk, 14 wks
Pan (2010)	Non-randomized clinical trial with crossover/III	Weak	5–9 y, ASD	Total N=16 IG1 = 8, IG2 = 8	Aquatic skills, warm up, cool down	1:2	90 min, 2×/wk, 10 wks
Pan (2011)	Non-randomized clinical trial with repeated measure/III	Weak	7–12 y, ASD and TD	Total N=30 ASD = 15, TD = 15	Aquatic skills, warm up, cool down	1:2	60 min, 2×/wk, 14 wks
Exergaming interventions							
Dickinson and Place (2014)	RCT/II	Weak	5–15 y, ASD	Total N=100 IG = 50, CG = 50	Sports video games (Nintendo Wii)	NR	15 min, 3×/wk, "3 academic terms"
Edwards et al. (2017)	Prospective cohort/IV	Weak	6–10 y, ASD and TD	Total N=30 ASD = 11, TD = 19	Sports video games (Xbox Kinect)	NR	45–60 min, 3×/wk, 2 wks
Hilton et al. (2014)	Prospective cohort/IV	Weak	6–13 y, ASD	IG = 7	Speed-based game (Makoto arena)	NR	2 min, 3×/wk, 10 wks
Travers et al. (2017)	Prospective cohort/IV	Weak	7–17 y, ASD	IG = 29	Balance video game (Xbox Kinect, Nintendo Wii)	NR	60 min, 3×/wk, 6 wks
Physical education interventions							
Henderson et al. (2016)	Prospective cohort/IV	Weak	5–12 y, ASD	IG = 37	Locomotor and object control	1:3	40 min, 2×/wk, 20 wks
Sarol and Cimen (2015)	Prospective cohort/IV	Weak	4–18 y, ASD	IG = 59	Balance, locomotor, and object control	NR	120 min, 2×/wk, 8 wks
Toscano et al. (2018)	RCT/II	Weak	6–12 y, ASD	Total N=64 IG = 46, CG = 18	Strength, balance, and coordination	1:3	40 min, 2×/wk, 48 wks

(Continued)

Table 1. (Continued)

Author(s) (year)	Study design, level of evidence	Strength of the evidence	Participants (age range and diagnosis)	N	Intervention description	Ratio (instructor:child)	Frequency/duration
Effects of motor learning variables on motor skill acquisition, retention, and transfer							
Chu and Pan (2012)	Non-randomized clinical trial/III	Weak	7–12 y, ASD and TD	Total $N=42$ IG1: ASD = 7, TD = 7; IG2: ASD = 7, TD = 7; IG3: ASD = 7, TD = 7	Aquatic training with trained sibling versus trained peer assisted versus untrained peer	1:2	60 min, 2×/wk, 16 wks
Navaee et al. (2018)	Non-randomized clinical trial/III	Weak	6–10 y, ASD	Total $N=20$ IG = 10, CG = 10	Throwing task with positive normative feedback	1:1	1× with retention the next day
Samsudin and Low (2017)	RCT/II	Weak	7–10 y, ASD	Total $N=10$ IG1 = 5, IG2 = 5	Throwing task with internal versus external attentional focus	NR	10 throws in 6 days over the course of 2 wks
Srinivasan et al. (2015)	RCT/II	Adequate	5–12 y, ASD	Total $N=33$ IG1 = 11, IG2 = 11, CG = 11	Socially embedded movement game with instructor versus robot	1:1	45 min, 4×/wk, 8 wks
Taheri-Torbati and Sotoodeh (2019)	RCT/II	Weak	9–13 y, ASD and TD	Total $N=48$ IG1: ASD = 12, TD = 12; IG2: ASD = 12, TD = 12	Throwing task with video versus live modeling instruction	1:1	17 training blocks in 2 days with retention after 1 wk
Tse (2019)	RCT/II	Strong	9–12 y, ASD	Total $N=65$ IG1 = 22, IG2 = 22, CG = 21	Throwing task with internal versus external attention of focus	NR	1× with retention/transfer the next day
Tse and Masters (2019)	RCT/II	Adequate	9–12 y, ASD	Total $N=48$ IG1 = 12, IG2 = 12, IG3 = 12, IG4 = 12	Basketball-shooting task with visual analogy, verbal analogy, explicit instruction, and control	1:1	6 training blocks of 15 trials in 1 day

N: number; y: years; ASD: autism spectrum disorder; IG: intervention group; CG: control group; min: minutes; wk(s): week(s); NR: not reported; TD: typically developing; RCT: randomized clinical trial; PT: physical therapy; RAS: rhythmic auditory stimulation; mo: months.

Table 2. Summary of results.

Author(s) (year)	ICF level	Outcome	Between-group differences post-intervention	Within-group differences preintervention to post-intervention	Clinical implications
Motor activity interventions					
Arzoglou et al. (2013)	BSF	KTK	NR	↑ IG, NS CG	An 8-wk traditional Greek dance program resulted in improved body coordination/balance and speed and agility of children with ASD.
	BSF	oo-KTK		↑ IG, NS CG	
	BSF	sj-KTK		↑ IG, NS CG	
	BSF	sm-KTK		↑ IG, NS CG	
	BSF	wb-KTK		↑ IG, NS CG	
Cei et al. (2017)	A	Walk between cones	NA	↑IG, ES = −0.48	A 6-month soccer program resulted in improved walking, running, rolling, jumping, catching, and balance skills for children with ASD.
	A	Run between cones		↑IG, ES = −0.59	
	A	Roll on mat		↑IG, ES = −0.43	
	A	Jumping up		↑IG, ES = −0.42	
	A	Catching		↑IG, ES = −0.44	
	A	Balance skill		↑IG, ES = −0.46	
	A	Throw ball		NS	
	A	Run straight		NS	
	A	Run with ball		NS	
	A	Jump forward		NS	
Guest et al. (2017)	A	L-TGMD-2	NA	↑ IG, ES = 0.51	A 5-day multisport camp resulted in improved locomotor and object control skills of girls with ASD.
	A	OC-TGMD-2		↑ IG, ES = 0.53	
	A	GMQ-TGMD-2		↑ IG, ES = 0.63	
	A	Physical activity (pedometer)		NS	
Hayward et al. (2016)	A	Kicking accuracy	NA	↑	A 6-wk community-based soccer group resulted in improved kicking accuracy and speed and agility of children with ASD.
	BSF	15-yd agility run		↑	
	BSF	30-yd run		NS	
Kokaridas et al. (2018)	A	Traverse speed	↑ IG2 (TD)	NS	A 12-wk indoor climbing program resulted in no difference in hand grip strength and an increase in traverse speed of typically developing children versus children with ASD.
	BSF	Hand grip strength	NS	NS	
Lourenco et al. (2015)	A	BOT-2	↑	NR	A 20-wk trampoline training program resulted in improved motor skills, body coordination/balance, speed and agility, and strength of children with ASD, compared to a control group.
	A	fmi-BOT-2	NS		
	A	fmp-BOT-2	NS		
	A	md-BOT-2	NS		
	A	ulc-BOT-2	↑		
	BSF	b-BOT-2	↑		
	BSF	bc-BOT-2	↑		
	BSF	s-BOT-2	↑		
	BSF	sa-BOT-2	↑		
Pan et al. (2017)	A	BOT-2	↑, $\eta^2 = 0.30$	↑ IG1, $\eta^2 = 0.25$; IG2, ES = 1.59	A 12-wk table tennis intervention resulted in improved motor skills of children with ASD, compared to a control group. These improvements were maintained for 3 months.
	A	FMC-BOT-2	NS	NS IG1; NS IG2	
	A	MC-BOT-2	NS	↑ IG1, $\eta^2 = 0.49$; IG2, ES = 0.52	
	BSF	BC-BOT-2	NS	↑ IG1, $\eta^2 = 0.21$; IG2, ES = 0.80	
	BSF	SA-BOT-2	NS	↑ IG1, $\eta^2 = 0.43$; IG2, ES = 1.02	
Sarabzadeh et al. (2019)	A	MABC-2	↑	↑ IG, ↓CG	A 6-wk Tai Chi training resulted in improved balance and ball skills of children with ASD, compared to a control group.
	A	bs-MABC-2	↑	↑ IG, NS CG	
	A	md-MABC-2	NS	NS	
	BSF	b-MABC-2	↑	↑ IG, NS CG	

(Continued)

Table 2. (Continued)

Author(s) (year)	ICF level	Outcome	Between-group differences post-intervention	Within-group differences preintervention to post-intervention	Clinical implications
Zamani et al. (2017)	A BSF BSF BSF BSF BSF BSF	BOT b-BOT bc-BOT rs-BOT s-BOT sa-BOT ulsmd-BOT	↑ IG ↑ IG ↑ IG NS NS NS ↑ IG	NR NR NR NR NR NR NR	A 16-wk gymnastic program resulted in improved bilateral coordination, balance, and upper limb speed and agility in children with ASD compared to controls.
Motor skill interventions					
Brand et al. (2015)	A BSF	Ball skills Balancing	NA	↑ ↑	A 3-wk stationary biking and coordination program resulted in improved ball handling and balance skills of children with ASD.
Bremer et al. (2015)	A A A A A A A A A	PDMS-2 FMQ-PDMS-2 GMQ-PDMS-2 g-PDMS-2 l-PDMS-2 om-PDMS-2 s-PDMS-2 vmi-PDMS-2 m-VABS-II	↑, ES = 0.65 NS, ES = 0.67 NS, ES = 0.57 NS, ES = 0.61 NS, ES = 0.58 ↑, ES = 0.70 NS, ES = 0.42 NS, ES = 0.28 NS	NR	A 12-hr fundamental motor skills program resulted in improved motor skills of children with ASD, compared to a control group. These improvements were maintained for 6 wks.
Cheldavi et al. (2014)	BSF	Postural stability (7 parameters and conditions)	↑, 7 parameters and conditions	NR	A 6-wk balance training program resulted in improved body coordination/ balance of children with ASD, compared to a control group.
El Shemy and El-Sayed (2018)	A A BSF BSF BSF BSF	BC-BOT-2 SA-BOT-2 b-BOT-2 bc-BOT-2 s-BOT-2 sa-BOT-2	↑ IG ↑ IG ↑ IG ↑ IG ↑ IG ↑ IG	↑ IG, CG ↑ IG, CG ↑ IG, CG ↑ IG, CG ↑ IG, CG ↑ IG, CG	A 12-wk motor skills and gait training intervention with rhythmic auditory stimulation resulted in improved motor skills of children with ASD as compared to a control group with motor skill training alone.
Ketcheson et al. (2017)	A A A A	GQ-TGMD-2 L-TGMD-2 OC-TGMD-2 Physical activity (accelerometer)	↑, partial $\eta^2 = 0.53$ ↑, partial $\eta^2 = 0.42$ ↑, partial $\eta^2 = 0.48$ NS	NR NR NR NR	An 8-wk motor skills intervention resulted in improved motor skills of children with ASD, compared to a control group. These improvements were maintained for 1 month.
Najafabadi et al. (2018)	BSF BSF BSF	sb-BOT db-BOT bc-BOT	↑ IG ↑ IG NR	NR NR NR	A 12-wk motor skills program resulted in improved balance in children with ASD, as compared to controls.
Rafie et al. (2017)	A BSF BSF BSF BSF BSF BSF BSF	vmc-BOT b-BOT bc-BOT rs-BOT s-BOT sa-BOT ulc-BOT ulsmd-BOT	↑, ES = 1.24 ↑, ES = 1.69 NS, ES = 1.21 NS, ES = 0.69 ↑, ES = 1.16 NS, ES = 1.28 ↑, ES = 1.33 ↑, ES = 0.23	NR	A 10-wk motor skill program resulted in improved visual-motor control, balance, strength, and manual coordination of children with ASD, compared to a control group.

(Continued)

Table 2. (Continued)

Author(s) (year)	ICF level	Outcome	Between-group differences post-intervention	Within-group differences preintervention to post-intervention	Clinical implications
Hippotherapy, equine-assisted, or simulated horse riding interventions					
Ajzenman et al. (2013)	P	cm-CACS	NA	NS	A 12-wk hippotherapy program resulted in improved low-demand leisure activities and postural control of children with ASD but did not improve motor skills.
	P	hdl-CACS		NS	
	P	ldl-CACS		↑, ES = 0.89	
	A	m-VABS-II		NS	
	BSF	Postural stability (12 COM and COP variables)		↑ 9 COM/COP variables, ES = 0.19–1.91 NS 3 COM/COP variables	
Borgi et al. (2016)	A	m-VABS-II	NS	NR	A 6-month equine-assisted therapy program did not result in improved motor skills of children with ASD, compared to a control group.
Gabriels et al. (2012)	A	sf-BOT-2	NS	↑	A 10-wk hippotherapy program did not result in improved motor skills or praxis of children with ASD, compared to a control group.
	BSF	pp-SIPT	NS	↑	
	BSF	pvc-SIPT	NS	↑	
Gabriels et al. (2015)	A	BOT-2	NS, ES = 0.24	NR	A 10-wk hippotherapy program did not result in improved motor skills or praxis of children with ASD, compared to a control group.
	BSF	pp-SIPT	NS, ES = 0.35		
	BSF	pvc-SIPT	NS, ES = 0.04		
Lanning et al. (2014)	P	PS-PedsQL	NS	NS IG, NR CG	A 12-wk equine-assisted program did not result in improved physical functionality of children with ASD, compared to a control group.
	P	pf-PedsQL	NS	NS IG, NR CG	
	P	pf-CHQ	NS	NS IG, NR CG	
Wuang et al. (2010)	A	BOT	NR	↑ IG1, ES = 10.85; IG2, ES = 13.31	A 20-wk simulated horse riding program resulted in improved, visual-motor control, body coordination/balance, reaction speed, strength, speed and agility, and manual coordination of children with ASD, compared to a control group. These improvements were maintained over 24 wks.
	A	GMC-BOT	NR	↑ IG1, ES = 7.27; IG2, ES = 7.87	
	A	FMC-BOT	NR	↑ IG1, ES = 10.16; IG2, ES = 4.89	
	A	vmc-BOT	↑, partial $\eta^2 = 0.94$	↑ IG1, ES = 7.61; IG2, ES = 9.86	
	BSF	b-BOT	↑, partial $\eta^2 = 0.74$	↑ IG1, ES = 5.29; IG2, ES = 8.16	
	BSF	bc-BOT	↑, partial $\eta^2 = 0.86$	↑ IG1, ES = 6.75; IG2, ES = 6.83	
	BSF	rs-BOT	↑, partial $\eta^2 = 0.92$	↑ IG1, ES = 5.68; IG2, ES = 6.67	
	BSF	s-BOT	↑, partial $\eta^2 = 0.87$	↑ IG1, ES = 6.17; IG2, ES = 6.16	
	BSF	sa-BOT	↑, partial $\eta^2 = 0.84$	↑ IG1, ES = 4.85; IG2, ES = 5.27	
	BSF	ulc-BOT	↑, partial $\eta^2 = 0.83$	↑ IG1, ES = 4.50; IG2, ES = 8.00	
	BSF	ulsmd-BOT	↑, partial $\eta^2 = 0.93$	↑ IG1, ES = 4.62; IG2, ES = 4.60	
Aquatic interventions					
Alaniz et al. (2017)	A	ASC	NA	↑	An 8- to 24-wk swim program resulted in improved swim skills of children with ASD.
	A	bc-ASC		↑	
	A	bf-ASC		NS	
	A	cp-ASC		↑	
	A	ep-ASC		NS	
	A	n-ASC		NS	
	A	p-ASC		↑	
	A	bc-GAS		↑	
	A	bf-GAS		↑	
	A	p-GAS		↑	

(Continued)

Table 2. (Continued)

Author(s) (year)	ICF level	Outcome	Between-group differences post-intervention	Within-group differences preintervention to post-intervention	Clinical implications
Caputo et al. (2018)	A	m-VABS	NS	↑ IG, CG	A 10-mo aquatic program resulted in improved both swim and motor skills in children with ASD.
	A	HAAR stage 1	NR	↑ IG	
	A	HAAR stage 2	NR	↑ IG	
	A	HAAR stage 3	NR	↑ IG	
	A	HAAR stage 4	NR	↑ IG	
	A	HAAR stage 5	NR	↑ IG	
Fragala-Pinkham et al. (2011)	A	m-PEDI	NS, ES = 0.18	NS	An 18-wk aquatic exercise program did not result in improved swim skills, cardiovascular fitness, or strength in children with ASD, compared to a control group.
	A	SCS	NS, ES = 0.66	↑, ES = 0.27	
	A	YMCA Water Skills Checklist	NS	↑, ES = 1.51	
	BSF	½ mile walk/run	NS	NS	
	BSF	Isometric push-up	NS	NS	
	BSF	Modified curl-ups	NS	NS	
Pan (2010)	A	HAAR	↑, partial $\eta^2 = 0.94$	↑ IG1, IG2	A 10-wk aquatic program resulted in improved swim skills of children with ASD, compared to a control group. These skills were maintained over 10 wks.
	A	HAAR stage 1	NS, partial $\eta^2 = 0.14$	NS IG1, IG2	
	A	HAAR stage 2	↑, partial $\eta^2 = 0.93$	↑ IG1, IG2	
	A	HAAR stage 3	↑, partial $\eta^2 = 0.50$	↑ IG1; NS IG2	
	A	HAAR stage 4	↑, partial $\eta^2 = 0.83$	↑ IG1, IG2	
	A	HAAR stage 5	↑, partial $\eta^2 = 0.87$	↑ IG1, IG2	
Pan (2011)	A	HAAR stage 1	NS	↑ IG1, ES = 0.59, IG2	A 14-wk aquatic intervention resulted in improved swim skills and strength of children with ASD, compared to a control group. These improvements were maintained for 14 wks.
	A	HAAR stage 2	↑	↑ IG1, ES = 1.03, IG2, ES = 0.35	
	A	HAAR stage 3	NS	↑ IG1, ES = 0.64, IG2, ES = 1.98	
	A	HAAR stage 4	↑, ES = 1.24	↑ IG1, ES = 1.15, IG2, ES = 1.02	
	A	HAAR stage 5	↑, ES = 1.32	↑ IG1, ES = 1.00, IG2, ES = 0.33	
	BSF	Curl-ups 30 s	↑, ES = 1.18	↑ IG1, ES = 1.20, IG2, ES = 0.84	
	BSF	Curl-ups 60 s	↑	↑ IG1, ES = 0.82, IG2, ES = 1.13	
	BSF	PACER	NS	↑ IG1, ES = 0.23, IG2, ES = 0.57	
	BSF	Sit and reach	NS	↑ IG1, ES = 0.64, IG2, ES = 0.43	
Exergaming interventions					
Dickinson and Place (2014)	BSF	Multistage progressive shuttle run test	↑	↑ IG	A computer-based activity game for 3 academic terms resulted in improved cardiovascular fitness, strength, and speed and agility of children with ASD, compared to a control group.
	BSF	Partial curl-up	↑	↑ IG	
	BSF	Sit and reach	NS	↑ IG, CG	
	BSF	Shuttle test	↑	↑ IG, CG	
	BSF	Standing long jump	↑	↑ IG	
Edwards et al. (2017)	A	Golf skills	NS	NS	A 2-wk active video game program did not result in improved golf or motor skills of children with ASD, compared to a control group.
	A	TGMD-3	NS	NS	
	A	Overall object control (TGMD-3 + golf skills)	NS	NS	
Hilton et al. (2014)	A	BOT-2	NA	NS, ES = 0.08	A 30-session exergaming program resulted in improved speed and agility, strength, and speed within the exergame of children with ASD.
	A	FMC-BOT-2		NS, ES = −0.12	
	A	MC-BOT-2		NS, ES = 0.31	
	BSF	BC-BOT-2		NS, ES = 0	
	BSF	SA-BOT-2		↑, ES = 0.46	
	BSF	Reaction speed (within exergame)		↑, ES = 1.18	

(Continued)

Table 2. (Continued)

Author(s) (year)	ICF level	Outcome	Between-group differences post-intervention	Within-group differences preintervention to post-intervention	Clinical implications
Travers et al. (2018)	A	Wii Fit performance	NA	↑	A 6-wk biofeedback-based video game balance training program resulted in improved balance of children with ASD.
	BSF	1-foot balance time		↑	
	BSF	2-feet balance time		↑	
Physical education interventions					
Henderson et al. (2016)	A	b-TGMD-2	NA	↑	A 20-wk PE program resulted in improved motor skills of children with ASD.
	A	c-TGMD-2		↑	
	A	g-TGMD-2		NS	
	A	h-TGMD-2		↑	
	A	j-TGMD-2		↑	
	A	k-TGMD-2		↑	
	A	l-TGMD-2		NS	
	A	r-TGMD-2		↑	
	A	s-TGMD-2		↑	
	A	st-TGMD-2		↑	
	A	t-TGMD-2		↑	
	A	ur-TGMD-2		↑	
Sarol and Cimen (2015)	P	pf-PedsQL	NA	↑	An 8-wk adapted recreational physical activity program resulted in improved reported physical functionality of children with ASD.
Toscano et al. (2018)	P	PH-CHQ	↑, ES = 1.05	NR	A 48-wk exercise program resulted in improved reported physical functioning of children with ASD, compared to a control group.
Effects of motor learning variable on motor skill acquisition, retention, and transfer					
Chu and Pan (2012)	A	HAAR	NS	↑ IG1, IG2, IG3	A 16-wk aquatic program, with 3 different instructional conditions, did not result in improved swim skills of children with ASD among groups.
Navaee et al. (2018)	A	Throwing accuracy, acquisition	NS	NR	A throwing task with positive normative feedback resulted in no difference in throwing accuracy at acquisition or retention as compared to controls in children with ASD.
	A	Throwing accuracy, retention	NS	NR	
Samsudin and Low (2017)	A	Throwing accuracy	↑ IG1	NR	A throwing task with an external, versus internal, attentional focus resulted in improved acquisition of children with ASD in the external focus group.
Srinivasan et al. (2015)	A	FMC-BOT-2	↑ CG > IG1, IG2	NS IG1, IG2; ↑ CG, ES = 0.33	An 8-wk rhythm or robot-led motor intervention did not result in improved manual coordination, body coordination, or praxis of children with ASD.
	BSF	BC-BOT-2	NS	↑ IG1, ES = 0.60; IG2, ES = 0.48; NS CG	
	BSF	Praxis test	NS	↑ IG1, ES = −0.65; IG2, ES = −0.23; CG, ES = −0.70	

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Table 2. (Continued)

Author(s) (year)	ICF level	Outcome	Between-group differences post-intervention	Within-group differences preintervention to post-intervention	Clinical implications
Taheri-Torbati and Sotoodeh (2019)	BSF	NoRMD, acquisition	NS	↑ IG1-ASD, IG1-TD, IG2-ASD, IG2-TD	A 2-day throwing task with video versus live modeling resulted in similar acquisition and retention of an arm coordination pattern in children with ASD and children with typical development.
	BSF	NoRMS, acquisition	NS	↑ IG1-ASD, IG1-TD, IG2-ASD, IG2-TD	
	BSF	NoRMD, retention	NS	↑ IG1-ASD, IG1-TD, IG2-ASD, IG2-TD	
	BSF	NoRMS, retention	NS	↑ IG1-ASD, IG1-TD, IG2-ASD, IG2-TD	
Tse (2019)	A	Throwing accuracy, acquisition	NS, partial $\eta^2 = 0.78$	↑ throwing accuracy all groups, partial $\eta^2 = 0.44$	A throwing task with an internal attentional focus versus an external focus and no focus resulted in similar skill acquisition across all groups but improved retention and transfer of children with ASD in the internal focus group compared to the other groups.
	A	Throwing accuracy, retention	↑ IG1 (IF) > IG2 (EF), CG	NR	
	A	Throwing accuracy, transfer	↑ IG1 (IF) > IG2 (EF), CG	NR	
Tse and Masters (2019)	A	Shooting scores-acquisition	↑ IG1, IG2, IG3	↑ IG1, IG2, IG3; NS CG	A modified basketball shooting task with 4 different types of instruction resulted in improved retention and transfer with instruction using visual analogy for children with ASD.
	A	Shooting scores-retention	↑ IG1	NR	
	A	Shooting scores-transfer	↑ IG1	NR	

ICF: International Classification of Functioning, Disability, and Health; BSF: body, structure, and function; KTK: Korperkoorinationstest fur Kinder, total score; oo-KTK: overcoming obstacles with one leg; sj-KTK: sideways jump; sm-KTK: sideways movement and repositioning; wb-KTK: balance when walking backwards; NR: not reported; ↑: increased/improved; IG: intervention group; NS: not significant; CG: control group; ASD: autism spectrum disorder; wk(s): week; A: activity; NA: not applicable; ES: effect size (Cohen's *d*); TGMD-2: Test of Gross Motor Development, second edition; L-TGMD-2: locomotor; OC-TGMD-2: object control; GMQ-TGMD-2: gross motor quotient; yd: yard; TD: typically developing; BOT-2: Bruininks-Oseretsky Test of Motor Proficiency, second edition, total motor composite; fmi-BOT-2: fine motor integration; fmp-BOT-2: fine motor precision; md-BOT-2: manual dexterity; ulc-BOT-2: upper limb coordination; b-BOT-2: balance; bc-BOT-2: bilateral coordination; s-BOT-2: strength; sa-BOT-2: running speed and agility; FMC-BOT-2: fine motor control subsection; MC-BOT-2: manual coordination subsection; BC-BOT-2: body coordination subsection; SA-BOT-2: strength and agility subsection; $\eta 2$: effect size (ANOVA: analysis of variance/ANCOVA: analysis of covariance); MABC-2: Movement Assessment Battery for Children, second addition; bs-MABC-2: ball skills subsection; md-MABC-2: manual dexterity subsection; b-MACB-2: balance subsection; BOT: Bruininks-Oseretsky Test of Motor Proficiency, total score; b-BOT: balance; bc-BOT: bilateral coordination; rs-BOT: response speed; s-BOT: strength; sa-BOT: running speed and agility; ulsmd-BOT: upper limb speed-manual dexterity; PDMS-2: Peabody Developmental Motor Scale, second edition, total score; FMQ-PDMS-2: fine motor quotient; GMQ-PDMS-2: gross motor quotient; g-PDMS-2: grasping; l-PDMS-2: locomotor; om-PDMS-2: object manipulation; s-PDMS: stationary; vmi-PDMS-2: visual motor quotient; m-VABS-II: Vineland Adaptive Behavior Scales, motor skills subsection; hr: hour; GQ-TGMD-2: gross quotient; partial η^2: effect size (ANOVA/ANCOVA); sb-BOT: static balance; db-BOT: dynamic balance; vmc-BOT: visual motor control; ulc-BOT: upper limb coordination; P: participation; CACS: Child Activity Card Sort; cm-CACS: community mobility subsection; hdl-CACS: high-demand leisure subsection; ldl-CACS: low-demand leisure subsection; COM: center of mass; COP: center of pressure; sf-BOT-2: short form; SIPT: Sensory Integration and Praxis Test; pp-SIPT: postural praxis; pvc-SIPT: praxis on verbal command; Peds-QL: Pediatric Quality of Life Inventory; PS-PedsQL: physical summary; pf-PedsQL: physical functioning; CHQ: Child Health Questionnaire; pf-CHQ: physical functioning subsection; GMC-BOT: gross motor composite; FMC-BOT: fine motor composite; partial eta2 = effect size (ANOVA/ANCOVA); ASC: Aquatic Skills Checklist, total score; bc-ASC: breath control; bf-ASC: back float skills; cp-ASC: changing position; ep-ASC: exiting the pool; n-ASC: navigation; p-ASC: propulsion; GAS: Goal Attainment Scaling; bc-GAS: breath control; bf-GAS: back float; p-GAS: propulsion; m-PEDI: Multidimensional Pediatric Evaluation of Disability Inventory Scale; SCS: Swimming Classification Scale; YMCA: Young Men's Christian Association; HAAR: Humphries Assessment of Aquatic Readiness, total score; s: seconds; PACER: Progressive Aerobic Cardiovascular Endurance Run; TGMD-3: Test of Gross Motor Development, third edition, total score; b-TGMD-2: bounce; c-TGMD-2: catch; g-TGMD-2: gallop; h-TGMD-2: hop; j-TGMD-2: jump; k-TGMD-2: kick; l-TGMD-2: leap; r-TGMD-2: run; s-TGMD-2: slide; st-TGMD-2: strike; t-TGMD-2: throw; ur-TGMD-2: underhand roll; PE: physical education; PH-CHQ: physical summary score; NoRMD: normalized root mean difference; NoRMS: normalized root mean square error; IF: internal focus; EF: external focus.

second edition (PDMS-2); Test of Gross Motor Development, second or third edition (TGMD-2, TGMD-3); and the mobility scale of the Pediatric Evaluation of Disability Inventory (m-PEDI). Standardized tests of swimming included the Aquatic Skills Checklist (ASC), Young Men's Christian Association (YMCA) checklist, Humphries Assessment of Aquatic Readiness (HAAR), and Swimming Classification Scale (SCS). Individualized outcome measures included Goal Attainment Scaling (GAS) for swimming.

Body structure and function was measured in 23 studies and included measures of body coordination/balance, speed and agility, strength, praxis, reaction speed, cardiovascular fitness, manual coordination, and flexibility. Body coordination/balance was measured in 15 studies using the bilateral coordination and balance subtests of the BOT or BOT-2, subtests and total of the Korperkoorinationstest fur Kinder (KTK) test, balance subtest of the MABC-2, center of mass and center of pressure measures using force plates or Wii balance board, or timed balance measures on various surfaces. Speed and agility were measured in 11 studies using the running speed and agility subtest of the BOT or BOT-2, subtests of the KTK, shuttle run test, standing long jump, 30-yard run, and 15-yard agility run. Strength was measured in 12 studies using the strength subtest of the BOT or BOT-2 or specific tests such as curl-ups, push-ups, and hand grip strength. Praxis was measured in three studies by a specific measure of praxis or the Sensory Integration and Praxis Test. Reaction speed was measured in four studies using the response speed subtest of the BOT or exergame software. Cardiovascular fitness was measured in three studies using the ½ mile walk/run, multistage progressive shuttle run test, or the Progressive Aerobic Cardiovascular Endurance Run (PACER). Manual coordination was measured in four studies using the upper limb speed and manual dexterity and upper limb coordination subtests of the BOT and movement analysis. Flexibility was measured in one study using the sit and reach test.

Motor activity interventions. Nine studies assessed outcomes of a motor activity intervention: two RCTs (Pan et al., 2017; Sarabzadeh et al., 2019), three non-randomized clinical trials (Arzoglou et al., 2013; Lourenco et al., 2015; Zamani et al., 2017), three prospective cohorts (Cei et al., 2017; Guest et al., 2017; Kokaridas et al., 2018), and one retrospective cohort (Hayward et al., 2016). These interventions included training of a motor activity, such as gymnastics, indoor climbing, a multi-sport camp, table tennis, Tai Chi Chuan, traditional Greek dance, trampoline, and soccer. Two of the 9 studies reported both group and individual instruction, 5 used group only and 2 did not report, with instructor-to-trainee ratios ranging from 1:1 to 1:6. The doses ranged from 5 days to 24 weeks, 1–3 times per week, for 34 min to a full day per session; total sessions ranged from 6 to 48. Intervention providers included camp counselors, coaches, physical therapists, physical education teachers, a national tennis player, a Tai Chi instructor, and volunteers.

The nine motor activity studies reported activity and body, structure, and function (BSF) outcomes. Between the experimental and control groups, 27 outcomes were compared after intervention, with the following number of outcome measures reaching statistical significance: 7 of 13 activity outcomes (e.g. BOT-2 total and subtest) and 8 of 14 BSF outcomes (e.g. body coordination/balance, speed and agility, strength, and upper limb speed and agility). One study reported a large between-group effect size in the area of activity (Pan et al., 2017). Within the experimental group, 38 outcomes were compared preintervention to post-intervention, with 16 of 25 activity outcomes (e.g. kicking accuracy and BOT-2 total and subsection) and 11 of 13 BSF outcomes (e.g. body coordination/balance, speed and agility, and strength) reaching statistical significance. Two studies reported large within-group effect sizes in activity (Cei et al., 2017; Guest et al., 2017) and one study in both activity and BSF (Pan et al., 2017).

Motor skill interventions. Seven studies assessed outcomes of a motor skill intervention: three RCTs (El Shemy & El-Sayed, 2018; Najafabadi et al., 2018; Rafie et al., 2017), three non-randomized clinical trials (Bremer et al., 2015; Cheldavi et al., 2014; Ketcheson et al., 2017), and one prospective cohort (Brand et al., 2015). These interventions included training of one or more motor skills, including balance, throwing, catching, running, and/or jumping. Two of five studies reported both group and individual instruction, two used group only, one used individual only, and two did not report, with instructor-to-trainee ratios ranging from 1:1 to 1:5. The doses ranged from 3 to 12 weeks, 1–5 times per week, for 40 min to 4 h per session; total sessions ranged from 9 to 40. The intervention providers included coaches, a certified athletic trainer, and primary investigators/research assistants.

The seven motor skill intervention studies reported activity and BSF outcomes. Between the experimental and control groups, 36 outcomes were compared after intervention, with the following numbers of outcome measures reaching statistical significance: 8 of 16 activity outcomes (e.g. PDMS-2 total and subtest, TGMD-2 totals, and BOT subtest) and 17 of 20 BSF outcomes (e.g. body coordination/balance, speed and agility, strength, and manual coordination). Two studies reported large between-group effect sizes in the areas of activity and BSF (Ketcheson et al., 2017; Rafie et al., 2017). Within the experimental group, eight outcomes were compared preintervention to post-intervention, with three of the three activity outcomes (e.g. ball skills and BOT subtests) and five of the five BSF outcomes (e.g. body coordination/balance, running speed and agility, and strength) reaching statistical significance. No studies reported within-group effect sizes.

Hippotherapy, equine-assisted, or simulated horse riding interventions. Six studies assessed outcomes of a hippotherapy, equine-assisted, or simulated horse riding intervention: two RCTs (Borgi et al., 2016; Gabriels et al., 2015), three non-randomized clinical trials (Gabriels et al., 2012; Lanning et al., 2014; Wuang et al., 2010), and one prospective cohort (Ajzenman et al., 2013). Five of six studies used a group component, and four of six studies reported instructor-to-trainee ratios ranging from 1:1 to 1:4. The doses ranged from 10 to 24 weeks, 1–2 times a week, for 45–70 min per session; total sessions ranged from 12 to 40. Intervention providers included Professional Association of Therapeutic Horsemanship International (PATH)-certified and Federazione Italiana Sport Equestri (FISE)-certified riding instructors, occupational therapists, and volunteers.

The six studies reported participation, activity, and BSF outcomes. Between the experimental and control groups, 18 outcomes were compared after intervention, with the following number of outcome measures reaching statistical significance: 0 of 3 participation outcomes, 1 of 4 activity outcomes (e.g. BOT subtest), and 7 of 11 BSF outcomes (e.g. body coordination/balance, speed and agility, strength, reaction speed, and manual coordination). One study reported large between-group effect sizes in the areas of activity and BSF (Wuang et al., 2010). Within the experimental group, 44 outcomes were compared preintervention to post-intervention, with 1 of 6 participation outcomes (e.g. Child Activity Card Sort (CACS) low-demand leisure subtest), 9 of 10 activity outcomes (e.g. BOT-2 short form, BOT totals, and subtests), and 25 of 28 BSF outcomes (e.g. body coordination/balance, speed and agility, strength, praxis, reaction speed, and manual coordination) reaching statistical significance. Two studies reported large within-group effect sizes in the areas of participation, activity, and BSF (Ajzenman et al., 2013; Wuang et al., 2010).

Aquatic interventions. Five studies assessed outcomes of an aquatic intervention: four non-randomized clinical trials (Caputo et al., 2018; Fragala-Pinkham et al., 2011; Pan, 2010, 2011) and one prospective cohort (Alaniz et al., 2017). All were group interventions with instructor-to-trainee ratios of 1:1–1:3. The doses ranged from 8 weeks to 10 months, 1–2 times a week, for 40–90 min per session; total sessions ranged from 20 to 28. Intervention providers included occupational therapists, physical therapists, and aquatic instructors with and without water exercise swimming program (WESP) or YMCA training. One study included typically developing peers or siblings as partners for participants with ASD (Pan, 2011).

The five aquatic studies reported activity and BSF outcomes. Between the experimental and control groups, 22 outcomes were compared after intervention, with the following numbers of outcome measures reaching statistical significance: 8 of 15 activity outcomes (e.g. HAAR) and 2 of 7 BSF outcomes (e.g. strength). Two studies reported large between-group effect sizes in the areas of activity and BSF (Pan, 2010, 2011). Within the experimental group, 52 outcomes were compared after intervention, with 34 of 41 activity outcomes (e.g. ASC total and subtests, GAS, HAAR total and subtests, SCS, m-VABS, and YMCA checklist) and 8 of 11 BSF measures (e.g. strength, cardiovascular fitness, and flexibility) reaching statistical significance. Two studies reported large within-group effect sizes in the areas of activity and BSF (Fragala-Pinkham et al., 2011; Pan, 2011).

Exergaming interventions. Four studies assessed outcomes of an exergaming intervention: one RCT (Dickinson & Place, 2014) and three prospective cohorts (Edwards et al., 2017; Hilton et al., 2014; Travers et al., 2018). Three of the four studies were individual interventions, with no studies reporting an instructor-to-trainee ratio. The doses ranged from 10 weeks to 3 academic terms, 3 times a week, for 2–60 min per session; total sessions ranged from 6 to 30. Intervention providers included teachers, parents, researchers, and graduate students. Two studies reported the setting where the intervention was conducted: one was performed in the home (Edwards et al., 2017) and the other, at the participants' school during physical education (PE) class (Dickinson & Place, 2014).

The four exergaming studies reported activity and BSF outcomes. Between the experimental and control groups, eight outcomes were compared after intervention, with the following numbers of outcome measures reaching statistical significance: zero of three activity outcomes and four of five BSF outcomes (e.g. speed and agility, strength, and cardiovascular fitness). No study reported between-group effect sizes. Within the experimental group, 19 outcomes were compared after intervention, with 1 of 7 activity outcomes (e.g. Wii Fit performance) and 11 of 12 BSF measures (e.g. body coordination/balance, speed and agility, strength, reaction speed, cardiovascular fitness, and flexibility) reaching statistical significance. One study reported a large within-group effect size for BSF (Hilton et al., 2014).

Physical education interventions. Three studies assessed outcomes of a physical education intervention that occurred as part of the child's academic program: one RCT (Toscano et al., 2018) and two prospective cohorts (Henderson et al., 2016; Sarol & Cimen, 2015). All were group interventions, with instructor-to-trainee ratios of 1:3 in two studies. The doses ranged from 8 to 48 weeks, 2 times per week, for 40 min to 2 h per session; total sessions ranged from 16 to 96. Intervention providers included physical educators, adaptive physical education aides, and volunteers.

The three physical education studies reported participation and activity outcomes. Between the experimental and control groups, one participation outcome was compared after intervention and reached statistical significance (e.g. ph-CHQ) and reported a large between-group effect size (Toscano et al., 2018). Within the experimental group, 13 outcomes were compared preintervention to post-intervention, with 1 of 1 participation outcome (e.g. pf-PedsQL) and 10 of 12 activity outcomes (e.g. TGMD-2 subtests) reaching statistical significance. No study reported within-group effect sizes.

Effects of a motor learning variable on motor skill acquisition, retention, and transfer. Seven studies investigated the effects of a motor learning variable on motor skill acquisition, transfer, and/or retention. One study supported that children with ASD demonstrated similar acquisition but improved retention and transfer when given instructions that used visual analogy versus verbal analogy or explicit instructions (Tse & Masters, 2019). One study supported that children with ASD did not show improved skill acquisition or retention when provided with verbal feedback that was more positive than their actual performance during the task (Navaee et al., 2018).

Two studies on the use of an internal versus external focus of attention reported conflicting evidence. One study found that children with ASD demonstrated improved acquisition of a throwing skill using an external, versus an internal, focus of attention (Samsudin & Low, 2017), but the other study reported that children with ASD demonstrated similar acquisition but improved retention and transfer with an internal versus an external focus of attention (Tse, 2019). This could be due to differences in study design, including the length of the acquisition condition: 2 weeks for the study favoring an external focus of attention and 1 day for the study favoring an internal focus.

Three studies reported non-significant differences using various instructional models for children with ASD. One study supported that video versus live modeling resulted in similar acquisition and retention of an arm coordination pattern during a throwing task (Taheri-Torbati & Sotoodeh, 2019). One study supported that teacher-directed, peer-assisted, and sibling-assisted instructional conditions resulted in similar acquisition of swim skills (Chu & Pan, 2012). One study supported that instruction delivery from a robot versus a human resulted in similar acquisition of motor skills, motor imitation, and interpersonal synchrony (Srinivasan et al., 2015).

Strategies to support participants with ASD. Twenty-seven studies documented strategies to support participants with ASD to more fully participate in the intervention, summarized in Table 3. Strategies that promoted social communication included pictorial support ($n=16$ studies), social relatedness support ($n=12$), and communication support ($n=11$). Strategies that addressed the presence of restrictive, repetitive patterns of behavior or interests included predictable routines ($n=17$ studies) and behavioral support ($n=7$). In addition, strategies were used to support sensory needs ($n=3$ studies).

Strategies to support motor learning. Thirty-eight studies documented motor learning strategies, summarized in Table 4. Methods to organize practice included task modification ($n=23$ studies), contextual practice ($n=20$), and repetitive practice ($n=19$). Instructional methods included modeling ($n=16$ studies), verbal guidance ($n=11$), and physical guidance ($n=8$). Methods to provide feedback included encouragement ($n=13$ studies) and feedback on task ($n=12$).

Discussion

Overall, we found 34 group studies that investigated the effect of motor intervention on motor outcomes of children with ASD and 7 studies that assessed the effects of a motor learning variable on motor skill acquisition, transfer, and/or retention. Of these studies, none were level I, 13 were level II, and only 7 had strong or adequate research strength. Thus, recommendations for practice are weak. Below, we describe the intervention approaches that appear most promising for each level of the ICF-CY. We also provide recommendations for future research to strengthen the quality of the research evidence and for clinical and educational practice to improve the ability of professionals to apply the research to their practice.

Participation outcomes: research and practice implications

Previous systematic reviews have not reported motor outcomes for participation after motor interventions. In

Table 3. Interventions: strategies to support participants with ASD used in included studies.

Study	Type of intervention or motor learning study	Instructional method	Strategies to support participants with ASD					
			Restrictive interests		Social-communication			Other
			Predictable routine	Behavioral support	Pictorial support	Social relatedness support	Communication support	Sensory support
Arzoglou et al. (2013)	Motor activity	Both						
Cei et al. (2017)	Motor activity	Group	✓					
Guest et al. (2017)	Motor activity	Group						
Hayward et al. (2016)	Motor activity	Both	✓	✓	✓	✓	✓	
Kokaridas et al. (2018)	Motor activity	Group	✓					
Lourenco et al. (2015)	Motor activity	Group				✓		
Pan et al. (2017)	Motor activity	Group	✓			✓		
Sarabzadeh et al. (2019)	Motor activity	NR						
Zamani et al. (2017)	Motor activity	NR						
Brand et al. (2015)	Motor skill	NR	✓	✓	✓			
Bremer et al. (2015)	Motor skill	Both	✓		✓	✓	✓	
Cheldavi et al. (2014)	Motor skill	Individual						
El Shemy and El-Sayed (2018)	Motor skill	NR						
Ketcheson et al. (2017)	Motor skill	Both		✓	✓		✓	
Najafabadi et al. (2018)	Motor skill	Group						
Rafie et al. (2017)	Motor skill	Group				✓		
Ajzenman et al. (2013)	Hippo/EA/SHR	Both			✓			
Borgi et al. (2016)	Hippo/EA/SHR	Group			✓		✓	
Gabriels et al. (2012)	Hippo/EA/SHR	Group	✓		✓		✓	
Gabriels et al. (2015)	Hippo/EA/SHR	Group	✓	✓	✓			
Lanning et al. (2014)	Hippo/EA/SHR	NR	✓		✓			
Wuang et al. (2010)	Hippo/EA/SHR	Group					✓	✓
Alaniz et al. (2017)	Aquatic	Both	✓	✓	✓	✓		✓
Caputo et al. (2018)	Aquatic	Both						
Fragala-Pinkham et al. (2011)	Aquatic	Group	✓		✓			✓
Pan et al. (2017)	Aquatic	Group	✓		✓	✓		
Pan (2011)	Aquatic	Both	✓		✓	✓		
Dickinson and Place (2014)	Exergaming	Group	✓					
Edwards et al. (2017)	Exergaming	Individual						
Hilton et al. (2014)	Exergaming	Individual						

(Continued)

Table 3. (Continued)

Study	Type of intervention or motor learning study	Instructional method	Strategies to support participants with ASD					
			Restrictive interests		Social-communication			Other
			Predictable routine	Behavioral support	Pictorial support	Social relatedness support	Communication support	Sensory support
Travers et al. (2018)	Exergaming	Individual					✓	
Henderson et al. (2016)	Physical Ed.	Group		✓	✓		✓	
Sarol and Cimen (2015)	Physical Ed.	NR						
Toscano et al. (2018)	Physical Ed.	Group	✓			✓		
Chu and Pan (2012)	Motor learning	Group	✓	✓	✓	✓	✓	
Navaee et al. (2018)	Motor learning	Individual						
Samsudin and Low (2017)	Motor learning	NR		✓				
Srinivasan et al. (2015)	Motor learning	Group	✓		✓	✓	✓	
Taheri-Torbati and Sotoodeh (2019)	Motor learning	Individual						
Tse (2019)	Motor learning	Individual						
Tse and Masters (2019)	Motor learning	Individual			✓		✓	

ASD: autism spectrum disorder; NR: not reported; Hippo: hippotherapy; EA: equine assisted; SHR: simulated horse riding; Ed.: education.

our review, Toscano et al. (2018) reported a large effect size on participation after a 48-week physical education intervention. The only other study to assess between-group participation found non-significant differences after a 12-week equine-assisted intervention (Lanning et al., 2014). Considering the importance of motor participation for children with ASD, the limited research on participation outcomes is frustrating. However, there are two well-documented challenges associated with researching motor participation. First, standardized assessments that measure motor participation in children with disabilities measure different participation-related constructs, such as frequency of attendance at motor activities or involvement of the child while engaged in motor activities (Adair et al., 2018). Second, minimal information is available on the responsiveness of standardized assessments to assess participation in children with disabilities (Rainey, van Nispen, van der Zee, & van Rens, 2014).

We propose three research recommendations. First, we recommend using a standardized assessment that measures the motor participation construct that is expected to change with intervention and clearly defines the participation construct to allow comparison of participation outcomes across studies. Second, we recommend that the responsiveness of standardized assessments to assess motor participation in children with ASD be an area of focus for future research. Third, we recommend that research also focus on the dose of intervention required to make a change in participation outcomes, since an intervention with a longer duration or increased intensity may be needed to change motor participation outcomes.

In clinical practice, we recommend the use of participation outcome measures that can be individualized to the goals of the child and their family, such as the Canadian Occupational Performance Measure (Law et al., 2014) or Goal Attainment Scale (McDougall & Wright, 2009). Both measures are individualized, criterion-referenced assessments that allow clinicians to define a few specific goals for a child with ASD and then specify a range of specific outcomes for each goal. These types of measures may be more sensitive to change with intervention than standardized motor participation assessments.

Activity outcomes: research and practice implications

One previous systematic review combined the results of all types of motor interventions to assess activity outcomes and found a large effect on locomotor skills and manipulative skills (Healy et al., 2018). Other reviews that focused on one type of motor intervention concluded that aquatic interventions improved swim skills (Dillon et al., 2017) and equine therapy interventions showed limited evidence

Table 4. Interventions: strategies to support motor learning.

Study	Type of intervention or motor learning study	Strategies to support motor learning							
		Organization of practice			Instructional methods			Feedback	
		Repetitive practice	Task modification	Contextual practice	Modeling	Physical guidance	Verbal guidance	Feedback on task	Encouragement
Arzoglou et al. (2013)	Motor activity							✓	
Cei et al. (2017)	Motor activity		✓	✓					
Guest et al. (2017)	Motor activity		✓	✓					
Hayward et al. (2016)	Motor activity		✓	✓			✓		✓
Kokaridas et al. (2018)	Motor activity	✓		✓					
Lourenco et al. (2015)	Motor activity	✓	✓	✓	✓				
Pan et al. (2017)	Motor activity	✓	✓						✓
Sarabzadeh et al. (2019)	Motor activity			✓	✓				
Zamani et al. (2017)	Motor activity								
Brand et al. (2015)	Motor skill	✓	✓					✓	✓
Bremer et al. (2015)	Motor skill	✓	✓		✓	✓	✓		
Cheldavi et al. (2014)	Motor skill	✓	✓						
El Shemy and El-Sayed (2018)	Motor skill								
Ketcheson et al. (2017)	Motor skill	✓	✓	✓	✓		✓	✓	✓
Najafabadi et al. (2018)	Motor skill		✓	✓					
Rafie et al. (2017)	Motor skill	✓						✓	✓
Ajzenman et al. (2013)	Hippo/EA/SHR								
Borgi et al. (2016)	Hippo/EA/SHR								
Gabriels et al. (2012)	Hippo/EA/SHR	✓		✓					
Gabriels et al. (2015)	Hippo/EA/SHR	✓		✓	✓				✓
Lanning et al. (2014)	Hippo/EA/SHR		✓			✓			
Wuang et al. (2010)	Hippo/EA/SHR		✓					✓	✓
Alaniz et al. (2017)	Aquatic		✓	✓	✓	✓		✓	✓
Caputo et al. (2018)	Aquatic		✓	✓					✓
Fragala-Pinkham et al. (2011)	Aquatic		✓	✓	✓	✓	✓		✓
Pan (2010)	Aquatic		✓	✓	✓	✓	✓	✓	✓
Pan (2011)	Aquatic	✓	✓	✓			✓		
Dickinson and Place (2014)	Exergaming		✓						
Edwards et al. (2017)	Exergaming			✓					
Hilton et al. (2014)	Exergaming		✓						
Travers et al. (2018)	Exergaming		✓		✓			✓	✓

(Continued)

Table 4. (Continued)

Study	Type of intervention or motor learning study	Strategies to support motor learning							
		Organization of practice			Instructional methods			Feedback	
		Repetitive practice	Task modification	Contextual practice	Modeling	Physical guidance	Verbal guidance	Feedback on task	Encouragement
Henderson et al. (2016)	Physical Education	✓	✓	✓	✓	✓	✓	✓	✓
Sarol and Cimen (2015)	Physical education		✓						
Toscano et al. (2018)	Physical education								
Chu and Pan (2012)	Motor learning		✓		✓	✓	✓	✓	
Navaee et al. (2018)	Motor learning	✓						✓	
Samsudin and Low (2017)	Motor learning	✓					✓		
Srinivasan et al. (2015)	Motor learning	✓			✓	✓	✓	✓	
Taheri-Torbati and Sotoodeh (2019)	Motor learning	✓		✓	✓				
Tse (2019)	Motor learning	✓		✓	✓		✓		
Tse and Masters (2019)	Motor learning	✓		✓	✓		✓		

Hippo: hippotherapy; EA: equine assisted; SHR: simulated horse riding.

for improving motor skills (Srinivasan, Cavagnino, & Bhat, 2018). We report improvements in swim skills after aquatic intervention (Pan, 2010, 2011); locomotor skills after motor skill intervention (El Shemy & El-Sayed, 2018; Ketcheson et al., 2017; Sarabzadeh et al., 2019; Zamani et al., 2017); and manipulative skills after motor skill (Bremer et al., 2015; Ketcheson et al., 2017; Rafie et al., 2017; Sarabzadeh et al., 2019), motor activity (Lourenco et al., 2015), and simulated horse riding (Wuang et al., 2010) interventions. In these studies, a consistent finding is that children with ASD demonstrate improvement in the motor skills practiced. However, aside from the aquatics research, the outcome measures used to document change in activity with motor intervention were often a standardized motor test (BOT, PDMS, and TGMD) and all its composites and subtests.

We propose three research recommendations. First, although using a standardized motor test is appropriate for studies that practice the motor skills assessed in the tests, for other interventions, such as hippotherapy, we also recommend assessing the motor skills that were practiced. Second, since children with ASD demonstrate improvement in the motor skills practiced, we recommend that researchers delineate primary outcome measures most likely to change with intervention from other outcome measures used for exploratory analyses. Third, we recommend using standardized motor tests with strong psychometric properties, and avoiding analyzing subtests or individual test items, which may not demonstrate the documented psychometric properties of the full standardized test. For a current review on the psychometric properties of standardized motor assessments to evaluate children with ASD, refer to Wilson, McCraken, Rinehart, and Jeste (2018).

We propose two practice recommendations. First, since a frequent finding is that children with ASD demonstrate improvement in the motor skills practiced, we recommend that clinicians directly practice the motor skills that are important to the child and family and will result in more opportunities to positively interact with peers through movement. Second, we recommend the use of GAS, in addition to standardized motor assessments to document an individual child's change with intervention, since it may be more sensitive to change with intervention than standardized motor assessments (McDougall & Wright, 2009).

Body structure and function outcomes: research and practice implications

One previous systematic review combined the results of all types of motor interventions to assess BSF outcomes (Healy et al., 2018). It reported a large effect on skill-related fitness, a moderate effect on muscular strength/endurance, and no effect on cardiovascular endurance

(Healy et al., 2018). Similar results were found in this review, but our review adds the types of interventions that resulted in improvements in specific outcomes. Based on between-group comparisons, body coordination/balance improved with simulated horse riding (Wuang et al., 2010), motor skill (Cheldavi et al., 2014; El Shemy & El-Sayed, 2018; Najafabadi et al., 2018; Rafie et al., 2017), and motor activity interventions (Lourenco et al., 2015; Sarabzadeh et al., 2019; Zamani et al., 2017). Reaction speed improved with a simulated horse riding intervention (Wuang et al., 2010). Strength improved with simulated horse riding (Wuang et al., 2010), motor skill (El Shemy & El-Sayed, 2018; Rafie et al., 2017), aquatic (Pan, 2011), motor activity (Lourenco et al., 2015), and exergaming interventions (Dickinson & Place, 2014). Speed and agility improved with simulated horse riding (Wuang et al., 2010), motor skill (El Shemy & El-Sayed, 2018), motor activity (Lourenco et al., 2015), and exergaming interventions (Dickinson & Place, 2014). Manual coordination improved with simulated horse riding (Wuang et al., 2010), motor skill (Bremer et al., 2015; Ketcheson et al., 2017), and motor activity interventions (Zamani et al., 2017). Cardiovascular fitness improved with an exergaming intervention (Dickinson & Place, 2014).

Since the majority of the BSF results were based on a single study for each intervention, further research is urgently needed. We recommend that research on interventions that target BSF outcomes follow exercise guidelines and training schedules for the specific outcome (Ganley et al., 2011; Srinivasan et al., 2014). For example, interventions to improve strength should follow resistance training guidelines and recommended dose (frequency, intensity, and duration).

We also recommend that educators and clinicians follow exercise guidelines and training schedules when providing intervention for children with ASD (Ganley et al., 2011; Srinivasan et al., 2014). In addition, if the goal of intervention is to change a BSF outcome to improve an activity outcome, it is recommended that a portion of the intervention focus specifically on incorporating the BSF gains into the targeted activity.

Motor learning strategies: research and practice implications

A systematic review that characterized motor learning in children and adults with ASD concluded that the mechanisms underlying acquisition and generalization of motor skills may differ in persons with ASD, requiring the use of different strategies for optimal learning (Moraes et al., 2017). Our findings support the use of visual, versus verbal, instructions in improving motor skill acquisition in children with ASD (Tse & Masters, 2019). In addition, we found that instructional models using video, siblings, peers, and robots were just as effective as an adult instructor in improving motor skill acquisition for children with ASD (Chu & Pan, 2012; Srinivasan et al., 2015; Taheri-Torbati & Sotoodeh, 2019).

Further research in this area is crucial because it generalizes across motor interventions. We propose two research recommendations. First, given the social communication differences of children with ASD, it is recommended that research focus on the efficacy of promising instructional methods (visual supports) and modes of feedback. Second, we recommend that the associated conditions of children with ASD who participate in research studies be fully described because some common associated conditions, that is, attention-deficit hyperactivity disorder or intellectual disability, may influence the efficacy of specific motor learning strategies. For practice, we recommend that educators and clinicians consider motor learning principles when providing intervention for children with ASD and that they document the child's response to determine efficacy.

Strategies to support participants with ASD: research and practice implications

Specific recommendations to support children with ASD to participate in physical activity and exercise interventions have been reported in the literature (Srinivasan et al., 2014), but these types of strategies were reported in only 66% of studies included in this review. It is crucial for future studies to explicitly document the strategies utilized to support children with ASD. The following studies are examples of how this goal can be accomplished: documenting the use of the Treatment and Education of Autistic and Related Communication-Handicapped Children (TEACCH) approach (Casey, Quenneville-Himbeault, Normore, Davis, & Martell, 2015; Todd & Reid, 2006), Breslin and Liu's (2014) best practice guidelines for teaching physical education to children with ASD (Bremer & Lloyd, 2016), and Applied Behavior Analysis (ABA) strategies (Coleburn, Golub-Victor, & Paez, 2017). Future research is needed to investigate the efficacy of these strategies to support children with ASD to participate in motor intervention. In addition, it is recommended that educators and clinicians carefully consider and document the strategies they use to support children with ASD to optimize participation in physical activity and exercise interventions (Srinivasan et al., 2014).

Limitations. Incomplete retrieval of references through database searching constituted a limitation at the review level. Manual search via cross-referencing relevant studies was undertaken to address this limitation.

Conclusion

Evidence is accumulating that specific types of motor intervention improve specific motor participation, activity, and body structure and function outcomes in children with ASD. However, the overall quality of the evidence is low. More rigorous research is needed, which should include a comprehensive description of the study population, adequate sample size, intervention and control conditions that are defined using manuals and protocols, and clearly identified primary outcome measures that are expected to change with intervention. Evidence is also emerging on the effects of motor learning strategies on motor skill acquisition, retention, and transfer in children with ASD. Future research in this area is warranted, as it generalizes across motor interventions.

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Supplemental material

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