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REVIEW PAPER

Fundamental Motor Skill Interventions for Children and Adolescents on the Autism Spectrum: a Literature Review

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Abstract

In addition to the core characteristics of ASD, recent research has demonstrated that children on the autism spectrum develop motor skills differently, often delayed, compared with peers. Motor skill interventions can help improve motor skills, which in turn can increase the likelihood of participating in physical activity (PA) and potential to build social skills. However, research in this area is limited. A search of several prominent databases revealed a total of five empirical studies focused on building gross motor skills for children on the autism spectrum. Although the reviewed studies varied in the delivery and focus of intervention, overall, the reviewed studies suggest a positive effect from any intervention for children on the autism spectrum. Further research in this area is necessary to better understand the most effective means of delivering a motor skill intervention.

Keywords Gross motor skills · Intervention · Autism spectrum disorder · Youth development

Autism spectrum disorder (ASD) is classified in the Diagnostic and Statistics Manual of Mental Disorders (DSM-5) by two defining traits: (1) severe deficits in social communicative behaviors and (2) highly restrictive, repetitive behaviors (American Psychological Association [APA], 2013). According to the DSM-5 (APA 2013), these deficits must be persistent and present from birth. Much of the previous research on ASD has focused on these two key areas, and for good reason. However, there has been a growing body of research in recent years focusing on the motor ability of children on the autism spectrum (Staples et al. 2012). Reports of motor issues have been present since the earliest writings of autism; yet these have, until recently, received little notice. Kanner (1943), in one of the first documented reports of autism, suggested that children appeared "clumsy" and lacking motor control. Further, the World Health Organization (WHO 1993) stated in the International Classification of Disease, Tenth Edition (ICD-10) that clumsiness appeared to be a common feature of ASD, but not required or essential for diagnosis. Ghaziuddin and Butler (1998) furthered the understanding of this topic by suggesting, in a study of 45 children with pervasive developmental disorders (PDD) using the Bruininks-Oseretsky Test of Motor Proficiency (Bruininks 1978), that all participants with PDD demonstrated issues of motor coordination. The highest rate of "clumsiness" was found in children diagnosed with autism.

It is unclear, currently, whether motor impairments are entirely derived from the disorder itself or through a combination of other factors (e.g., lack of access, poor instruction, decreased motivation) However, it is clear that children on the autism spectrum demonstrate delays in motor development when compared with children not on the autism spectrum that persist as children age (Fournier et al. 2010). For example, Berkeley et al. (2001) analyzed the motor characteristics of 15 children on the autism spectrum comparing them with age-

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matched norms for the Test of Gross Motor Development (TGMD; Ulrich 1985). Berkeley et al. (2001) demonstrated that nearly all participants were below average, with the majority falling in the "poor" and "very poor" range for the TGMD. While this study is very prominent, it is not without its limitations within the interpretations. Berkeley et al. (2001) reported that during locomotor testing, participants seemed to focus more on the product of the movement (e.g., getting from point A to B) than on the process (i.e., how to do it) of the movement. This subtle inconsistency in interpretation by the participant limits the reliability of the assessment.

Increasing Attention on Gross Motor Skills

Early identification and intervention have been identified as beneficial to the overall development of children on the autism spectrum (Bradshaw et al. 2014; Eldevik et al. 2009; Estes et al. 2015). This emphasis has drawn more attention to gross motor skills (Lloyd et al. 2013) as motor skills are much more easily recognized by parents and often appear before delays in social behavior can be seen, leading to some academics to suggest that motor skills be included within the diagnostic process (Liu 2012; Teitelbaum et al. 1998). However, it still is unclear if motor delays are attributable to ASD alone and not a consequence of a developmental disorder in general (Ozonoff et al. 2008), although evidence has demonstrated motor delays are persistent when controlling for non-verbal IQ, suggesting that delays occur independent of overall developmental delay or low IQ (Lloyd et al. 2013). It is evident, however, that differences in the development of motor skills are displayed in toddlers "at risk" for ASD (Liu 2012; Lloyd et al. 2013) and the delays only appear to become greater over time as the child ages (Fournier et al. 2010; Staples and Reid 2010). Further, demonstrated delays in motor skills have been shown to occur into adolescence (Green et al. 2009; Whyatt and Craig 2012) and are especially evident when comparing children on the autism spectrum with age-matched, typically developing peers (Liu and Breslin 2013; Liu et al. 2014; Pan et al. 2009) or—in certain cases—peers that are about half the individual's chronological age (Staples and Reid 2010).

Fundamental Motor Skills and Other Areas of Development

Not only have delays in motor development been demonstrated in children on the autism spectrum, but it has also been suggested that there is a link between motor skill development and social skills (MacDonald et al. 2013b) and adaptive behaviors (MacDonald et al. 2013a), as well as language and cognitive skills (Bedford et al. 2016). Furthermore, calibrated autism severity scores (i.e., the intensity of a person's symptoms relating to autism [Gotham et al. 2009; Gotham et al. 2007]) have been suggested to have an impact on motor ability (MacDonald et al. 2014). MacDonald et al. (2014) correlated gross and fine motor skills to autism severity, finding that children with higher calibrated autism severity had both lower fine and gross motor skills. This result mirrored the result of MacDonald et al. (2013b) in school-aged children. MacDonald et al. (2013b) found that object control skills, as measured by the TGMD-2 (Ulrich 2000), were related to calibrated autism severity, again, suggesting as severity in symptoms increases, the greater the impact it may have on object control skills. Further, cognitive and motor skill performances have been recognized as influential in the development of children on the autism spectrum (Helt et al. 2008; Landa et al. 2012; Sutera et al. 2007); however, little research has been done focusing on the gross motor skill aspect. Even when including research in occupational therapy, many interventions are play-based or have limited focus on the direct development of motor skills (Case-Smith and Arbesman 2008).

Importance of Fundamental Motor Skills

In terms of motor development, fundamental motor skills (FMS, e.g., locomotor and object manipulation)—such as running, jumping, throwing, and kicking—are considered the essential building blocks for further, more complex gross motor movement (Clark and Metcalfe 2002). Moreover, suggestions have been made that successful ability in FMS performance can lead to a higher motor competency, which can potentially lead to higher rates of participation in physical activity (PA) in later years (Stodden et al. 2008; Stodden et al. 2014). If perceived motor competence is as impactful in individuals on the autism spectrum as in neurotypical populations, it stands to reason that FMS are essential prerequisites to be included in PA (Barela 2013). While higher rates of PA have been shown to be impactful for overall health (Warburton et al. 2006; Poitras et al. 2016), in regard to ASD specifically, increased PA participation has been suggested to have a positive influence on the occurrence of stereotypic behavior (Lang et al. 2010), social functioning (Healy et al. 2018), and health-related outcomes (Sorensen and Zarrett 2014); however, prerequisite motor skills are often necessary in order to effectively participate in PA (Haubenstricker and Seefeldt 1986).

Although early descriptive studies have detailed the "deficit" or "delay" of motor development in children on the autism spectrum, the focus of most interventions has been on social skill development and very few motor skill interventions have been implemented (MacDonald et al. 2012; MacDonald et al. 2014) and little research has focused on the relationship between motor skills and physical activity

participation. In a study of children aged 2–5 years, Ketcheson et al. (2018) found no relationship between motor skills and physical activity participation. Further, authors demonstrated that at young ages, children on the autism spectrum participate at similar or greater rates of PA compared with peers not on the autism spectrum. However, evidence suggests that the PA patterns of individuals on the autism spectrum decrease with age (MacDonald et al. 2011; Pan and Frey 2006) and motor skills become much more important for PA as an individual ages (Cattuzzo et al. 2016; Robinson et al. 2015; Stodden et al. 2014) Therefore, better motor skills in early development could provide children with the necessary foundational skills to progress toward a more optimal PA participation later in life (MacDonald et al. 2014). There exists, however, little empirical evidence as to how to build these foundational experiences for children on the autism spectrum.

Suggestions from Motor Skill Interventions

Within the myriad interventions developed for ASD (Wong et al. 2013), there is an overall lack of interventions aimed at addressing the motor skills of children on the autism spectrum. With the importance of FMS within life span motor development (Clark and Metcalfe 2002) and its implications for lifetime PA (Haubenstricker and Seefeldt 1986; Stodden et al. 2008, 2014), it is vital that these skills be developed. With an already high prevalence of overweight (14.8%) and obesity (23.2%) in children on the autism spectrum (Broder-Fingert et al. 2014), lifelong PA will play a vital role in maintaining a healthy quality of life (Raz-Silbiger et al. 2015). To inform motor interventions in ASD, it is important to understand what has been done in other populations. Recent systematic reviews and meta-analyses have been done on FMS intervention in children and youth (Logan et al. 2011; Lubans et al. 2010; Morgan et al. 2013), as well as those with developmental delay (Kirk and Rhodes 2011), with severe/profound intellectual disabilities (Houwen et al. 2014), and of motor intervention specifically built around behavior analytics (Alstot et al. 2013).

Overall major findings from each review and meta-analysis are shown in Table 1. When looking at the studies in aggregate, evidence for the use of motor interventions to improve FMS is strong. Regardless of population, the majority of studies reviewed demonstrated overall positive support for improving FMS. The meta-analyses, done by Alstot et al. (2013), Logan et al. (2011), and Morgan et al. (2013), reported moderate-to-large effect sizes. Further, Logan et al. reported no relationship between the effect size and duration of the intervention, suggesting that the overall length has little effect on the overall outcomes of the intervention. These findings taken together project that the duration of a motor intervention has little effect, as long as the intervention itself is strong enough to create change in motor skill patterns.

When considering children with developmental delays (Kirk and Rhodes 2011), motor interventions continue to demonstrate a positive overall effect. Kirk and Rhodes (2011) found that 81% of studies including children with developmental delays identify significant improvements of motor skills. Considering that the motor skill delay in children on the autism spectrum may be attributed to a developmental delay (Ozonoff et al. 2008), this is an important revelation; however, it cannot be assumed that the interventions designed for individuals with developmental delays will effectively meet the needs of those on the autism spectrum. Further, Kirk and Rhodes suggested that locomotor skills demonstrated the largest improvements from interventions, suggesting that these skills may not be inherently learned or "emerge" but must be taught. This concept of motor skills "needing to be taught" is further evidenced in the individual work of Goodway on FMS interventions targeting disadvantaged youth (Goodway and Branta 2003; Goodway et al. 2003), whereby Goodway and colleagues improved the FMS of youth through instruction, suggesting that motor skills, particularly locomotor skills, need instruction and individuals at any level can improve through appropriate support.

Motor Skill Intervention for ASD

Again, many children on the autism spectrum show a delay in gross motor skills (Fournier et al. 2010); however, delays are not universally reported (Dewey, Cantell, and Crawford, 2007). Demonstrated delays could be a result of some underlying constraint from the disability, lack of exposure to skills with instruction, or lack of understanding of how to get their body to move in a certain way coupled with a potential lack of interest in performing the skill at the highest level or motivation. Further, given the documented issues with motor coordination in individuals on the autism spectrum (Fournier et al. 2010), it may also be likely that there is an overlap of the neurological development of individuals that results in autistic behaviors and difficulties with performing gross motor tasks. Regardless of underlying condition, however, there is a demonstrated need for a well-controlled motor skill–based intervention for children on the autism spectrum (MacDonald et al. 2014). In order to understand how future motor interventions for children on the autism spectrum should be designed, it is important to understand what has been done to address the gross motor skills for children on the autism spectrum. Therefore, it was the purpose of this review to analyze the current literature to find gross motor interventions that have been used with children and adolescents on the autism spectrum.

Table 1 Major findings of previous motor intervention

Study	Focus population	Major findings
Alstot et al. (2013)	Non-specific	Use of behavioral principles (applied behavior analysis) has a large, positive effect on the acquisition of sport-specific motor skills. Analysis included participants from elementary to collegiate age. No further information was included about participants.
Houwen et al. (2014)	Intellectual disabilities	Despite limitations from cognitive impairment, individuals with severe or profound intellectual disabilities can benefit from interventions designed to improve motor skills. Sample sizes were relatively small throughout review, and little information was given about impact on cognitive or social outcomes.
Kirk and Rhodes (2011)	Developmental delay	81% (9 of 11) studies identified significant improvements in motor skills following an intervention with locomotor skills showing the largest improvements. Findings are in congruence with previous investigations identifying motor intervention in groups with low SES backgrounds.
Logan et al. (2011)	Typically developing	Motor skill interventions are an effective strategy to improve FMS in children; overall studies demonstrated a moderate effect size. Non-significant relationship was found between effect size of pre- to post-improvement of FMS and the duration of the intervention (in minutes).
Lubans et al. (2010)	Typically developing	Found strong evidence for a positive association between FMS competency and PA in children and adolescents, as well as a positive relationship between FMS competency and cardiorespiratory fitness and an inverse association between FMS competency and weight status. Suggested further longitudinal research is needed to make more concrete conclusions.
Morgan et al. (2013)	Typically developing	Of 22 eligible studies, 19 provided unique interventions for 1 or more FMS. Meta-analysis revealed statistically significant effects for overall gross, locomotor, and object control skill proficiency. Most interventions were given primarily by the physical education teacher in a school setting.

Method

The following databases were searched for relevant studies published prior to December 2016: Academic Search Complete, Education Full Text, Education Research Complete, ERIC, Physical Education Info, PsycINFO, ProQuest, PubMed, PubMed Central, SPORTDiscus, and Science Direct. Article references were searched for additional eligible studies. Studies were identified searching each of the identified electronic databases and scanning reference lists of identified articles. The search included three lines of search words, truncated where possible, including as follows: (a) *autism*, *autism spectrum disorder*, *Rett syndrome*, *childhood disintegrative disorder*, *PDD-NOS*, *Asperger syndrome*; (b) *fundamental motor skills*, *gross motor skills*, *motor abilities*, *motor intervention*; and (c) *youth*, *children*, *adolescents*. As the singular umbrella term autism spectrum disorder is a relatively new medical diagnosis as of the DSM-5 (APA 2013), it is likely that motor interventions prior would include individuals with associated disabilities. These disabilities were considered to be a part of autism until the most recent DSM-5 but were not included in order to simplify an already difficult disorder to diagnose effectively. Further, because fundamental motor skills are typically developed to maturity by adolescence, it is unlikely that interventions will include populations greater than 15; therefore, review was limited to younger than 15.

Inclusion Criteria

Studies were included in this review if published in the English language in a peer review academic journal in which fundamental motor skills were the primary outcome of an intervention. Motor intervention, in this review, was defined as an intentional and directed manipulation of motor skills through a set procedure taking place over a defined period of time to develop an overall change in motor skill performance, not simply to enact a change seen in a singular performance assessment. Testing a change in performance due to an added variable (e.g., video modeling or picture cards), for the purposes of this review, was not considered an intervention. Further, in order to capture what has been done collectively to address motor development needs for children on the autism spectrum, the inclusive published year was left open-ended, though the articles are limited to prior to December 2016 when this review was conducted. Additionally, interventions that occurred in the aquatic environment or used horses were not included. While aquatics have been suggested as a positive environment for the development of skills for children on the autism spectrum (Lee and Porretta 2013; Pan 2010) and are often very stimulating or soothing for sensory needs, FMS are not typically the focus of aquatics teaching. Additionally, equine or hippotherapy has been shown to have great benefits (Hawkins et al. 2014; Wuang et al. 2010) for individuals on the autism spectrum; however, the motor skills that are targeted are more related to the underlying concepts of movement, such as balance and coordination, and not gross motor

skills. Additional exclusion criteria included unpublished thesis or dissertations, duplication, conference proceedings, and practical position papers.

Overview of Articles Included

The full search process produced a total of 547 studies. Of those, 516 studies were excluded for failure to meet the inclusion criteria. Common reasons for excluding studies included article duplication, focus of intervention not on gross motor skills, and practical position papers that provided suggestions for motor intervention. After the initial search was completed, the authors searched the references of the identified studies for further references not included in the initial search. Two additional articles were identified for inclusion. The authors then searched the 33 qualifying articles for studies focusing on interventions targeting gross motor skills in children on the autism spectrum. A total of five articles were identified that met all criteria and were included for analysis. See Fig. 1 for procedure by which studies were selected. Further, Table 2 contains the essential characteristics extracted from each article, and Table 3 outlines the main findings of each study. The included studies were searched for similarities and differences in areas that could be informative for future motor skill interventions; those areas included (a) age range, (b) research design, (c) intensity and dosage of the intervention, (d) gross motor measure, and (e) theory or evidence-based practice.

Results

Study Characteristics

Participants

Of the studies identified, the majority (80%) used a very small sample size ($M_{participants}$ = 8.2). One study (Ketcheson et al. 2016) utilized a relatively large sample of 20 participants, which is fairly uncommon in many studies involving children on the autism spectrum. As expected, the majority of the participants included were males. Of the studies that reported gender, 20% (8/41) were female, 73% (30/41) were male, and 7% were unidentified (3/41). This is in line with the ASD prevalence rates among males and females of 4.3:1, respectively (Fombonne 2005), and closer to the most recent analysis of a 3:1 prevalence (Loomes et al. 2017). Furthermore, reported ages were between 4 and 10, which correspond to the typical ages for developing fundamental motor skills (Clark and Metcalfe 2002). Additionally, majority sampling for each study was done through purposive methods with only DeBolt et al. (2010) utilizing a convenience sample. As the focus of each of the research studies was to test the effects of a motor intervention on children on the autism spectrum, it is not surprising that researchers sought this population out. Arguably, this review could be seen as a critique of one of the included studies (Ketcheson et al. 2016) as this study provided 50% of the sample in this review. However, outside of critiquing overall sample included, this review focused on other areas of concern for future motor skill intervention. Additionally, small samples within the broad range of ASD research is typical, demonstrating a need for greater need to pool samples or do multisite studies involving the autism community in order to build larger samples and resulting sufficient evidence for motor skill interventions.

Diagnosis

Each of the 5 included studies reported the participants as having either autism or ASD. In one instance (Bremer and Lloyd 2016), researchers included children with ASD-like behaviors and due to the age of the participants, it was likely that a formal diagnosis had not yet been made. Only one studies used a confirmatory assessment for participants to ensure a diagnosis of ASD; Ketcheson et al. (2016) used the Autism Diagnostic Observation Schedule (ADOS). Two of the studies (DeBolt et al. 2010; Duronjić and Válková 2010) accepted prior diagnosis from physician, pediatrician, psychiatrist, psychologist, or psychological associate. One study (Bremer et al. 2014) included children from a local government-provided treatment center that only provided services for children with documentation from a physician, pediatrician, psychiatrist, psychologist, or psychological associate. This, however, does not always ensure uniformity in diagnosing practices and variances from diagnosis to diagnosis. The DSM-5 was recently updated to provide a more simplistic diagnosis of ASD, instead of the 5 previous categories, in order to limit variance between diagnoses (APA 2013). While it is likely that this information was not provided for a multitude of reasons (e.g., journal article space requirements, IRB assurances, peer-review assumptions of validity in diagnosis), without a follow-up measure within the study itself, it is difficult to validate an individual's diagnosis and, ultimately, limits the generalizations of the study due to the heterogeneity among each sample of children on the autism spectrum.

Research Design

The research designs of the studies varied greatly, despite that there is only a handful of studies. Bremer et al. (2014) employed a wait-list control design. However, with only eight participants, the possibilities for inferential statistics were severely limited. In Bremer and Lloyd's (2016) multiple-method study, the authors collected both quantitative and qualitative data. Interestingly, data types were separately analyzed, interpreted, and discussed. Additionally, Bremer and Lloyd's quantitative data were limited to visual analysis due to a

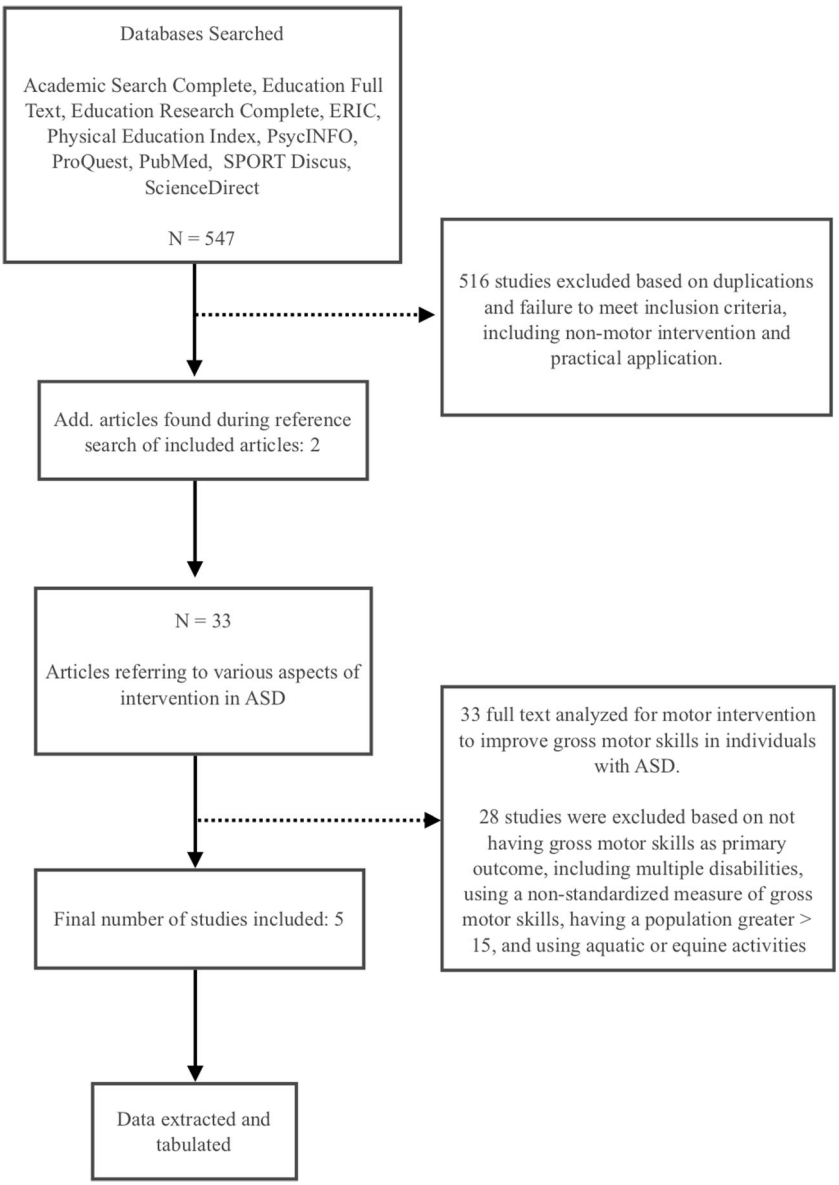

Fig. 1 Flow of literature analysis

limited sample size. Qualitative data were used to discuss the intervention's potential external effects on the perceptions of teachers who instructed individuals on the autism spectrum. Qualitative data analysis suggested that instructors would be more confident in working with individuals on the autism spectrum using a school-based intervention.

Intensity and Dosage

The intensity (i.e., frequency of sessions) and dosage (i.e., number of sessions) varied greatly between each of the studies. All included studies utilized different intervention schedules with intensity varying from one to three times per week and dosage from 5 weeks to 10 months. Further, no rational was given for the choice of intensity or dosage of intervention. However, when looking at how each was delivered, two of the studies (Bremer et al. 2014; Duronjić and Válková 2010) appear to resemble common physical education (PE) unit intensities and dosages, which typically would consist of either once or twice per week for 30 to 45 min per session. Bremer et al., for example, tested two methods of implementation (1/week for 12 weeks vs. 2/week for 6 weeks; each session 60 min) and found no differences in performance, although small numbers may have limited the statistical inference. Ketcheson et al. (2016) provided instruction at a highest frequency and dosage (4 h per day, 5 days per week, for 8 weeks) comparatively to other studies in this review.

Gross Motor Measure

Each study used some type of standardized motor assessment; the Test of Gross Motor Development first (Ulrich 1985) or

Table 2 Study characteristics

Study	Participants (*N*, age, gender)	Diagnosis	Research design	Intervention (intensity and dosage)	Gross motor measure	Sampling strategy	Theory/ EBP
Bremer et al. (2014)	8, 7 boys, 1 girl, 4 years old	ASD	Quasi-experimental, wait-list control	Group 1 1/week for 60 min/for 12 weeks Group 2 2/week for 60 min/for 6 weeks	PDMS-2 MABC	Purposive	None specified
Bremer and Lloyd 2016	5, 4 boys, 1 girl, 3–7 years old	4 ASD, 1 ASD-like behaviors	Multiple methods	3/week for 45 min/for 12 weeks	TGMD	Convenience	None specified
DeBolt et al. (2010)	3 children, gender n/a, 6–10 years old	Autism	Case study	1/week for 90 min/for 10 months	TGMD	Convenience	None specified
Duronjić and Válková (2010)	5, 4 boys, 1 girl, 62–81 months	ASD	Case study, observation	2/week for 60 min/for 8 weeks	MABC	Purposive	None specified
Ketcheson et al. (2016)	20, 15 boys, 5 girls, 4–6 years old	ASD	Quasi-experimental	5/week for 4 h/for 8 weeks	TGMD	Purposive	CPRT

PDMS-2, Peabody Developmental Motor Scales, second edition; *MABC*, Movement Assessment Battery for Children, first or second edition; *TGMD*, Test of Gross Motor Development, first or second edition; *ASD*, autism spectrum disorder; *CPRT*, classroom pivotal response treatment

second edition (Ulrich 2000) was the most common assessment. Two studies used the percentile rank from the normative data to determine change within study participants. Such analysis is often not recommended as normative data were not collected with that purpose, nor were normative data sets created with an ASD sample. Rather, raw scores are recommended for researchers looking for comparisons and change, which Bremer et al. (2014), Bremer and Lloyd (2016), and Ketcheson et al. (2016) used in their studies.

Theory

None of the studies were theory-driven or provided theoretical background. This is troublesome as most evidence-based practices are derived from theory in order to guide practice. One study (Ketcheson et al. 2016) modified classroom pivotal response treatment (CPRT) to focus on motor skill training and PA. CPRT is an accepted, evidence-based practice (EBP) and operates as a naturalistic form of instruction and has a foundational theoretical basis in the science of human behavior. Yet, this study did not use any guiding theory other than to build a motor skill intervention from a previous EBP. To best serve this population, future interventions should include a guiding theory framework.

Major Findings

Overall, the five included studies reported positive effects from their respected motor interventions; however, each intervention differed in their delivery, as well as their assumption of what constitutes gross motor skills (see Table 3). The limited motor intervention research with children on the autism spectrum suggests it is possible to alter the trajectory of a child's motor development, although it is unknown if short-term changes in motor performance are indicative of long-term growth, as there was little follow-up in the reviewed studies. Duronjić and Válková (2010) suggested that simple participation in PA at a preschool age is enough to improve

Table 3 Major findings of reviewed studies

Study	Major findings
Bremer et al. (2014)	Intervention focused on developing FMS significantly improved motor skills but did not show an effect on adaptive behavior or social skills. No significant differences between the two intensities of interventions.
Bremer and Lloyd (2016)	Results demonstrated a slight improvement on individual items of the TGMD-2, as well as overall improvement in locomotor skills for 4 of the participants and object-control skills for 3 of the participants. Qualitative responses from the APE teacher suggest an increase in confidence when instructing individuals on the autism spectrum in the physical education setting.
DeBolt et al. (2010)	Improvements were greater than what would have occurred with age. A community-based APE program can be beneficial for building FMS in children on the autism spectrum.
Duronjić and Válková (2010)	Preschool children on the autism spectrum can improve motor and social skills if involved in PA at least twice per week.
Ketcheson et al. (2016)	Classroom Pivotal Response Teaching (CPRT) provides a suitable framework for providing instruction to children on the autism spectrum in order to build gross motor skills. Further, CPRT provides opportunity to increase social interaction.

both motor and social skills. Further, focused motor interventions (Bremer et al. 2014) and APE instruction (DeBolt et al. 2010) provided a statistically significant impact on FMS development.

Discussion

Several outcomes have emerged to guide future research and motor intervention for youth on the autism spectrum. First, gross motor intervention—seemingly in any form—can have an impact on the development of motor skills in children on the autism spectrum. Second, the intensity and duration of the intervention do not seem to have an effect on the overall effectiveness of the intervention itself. For the reviewed studies, the frequency and dosage of each intervention resembled a format of a typical physical education or adapted physical education lesson; by doing so, the researchers made the transference from the lab to practitioners more available and accessible. Lastly, while all of the studies included have occurred in the last 5 years, the limited amount of interventions and the lack of theoretical foundation are concerning. Therefore, suggestions are offered to build future motor interventions for children on the autism spectrum.

Four of the studies (Bremer et al. 2014; Bremer and Lloyd 2016; DeBolt et al. 2010; Ketcheson et al. 2016) focus directly on clearly identified FMS in children on the autism spectrum, while the remaining study focused on general gross motor skill development through physical activity practice (Duronjić and Válková 2010). The findings of these studies suggest that motor skill interventions can improve the motor skill outcomes of individuals on the autism spectrum, though due to the overall positive outcomes, one must consider a potential bias of publication. When considering the intensity and dosage of studies, there was limited similarity across the studies and even less argument for why the authors chose the duration that they did. Bremer et al. (2014) tested two different durations and frequencies, finding that neither provided an advantage to learning. However, the sample size was small and the findings should be interpreted with care. Overall, these findings mirror those of Logan et al. (2011) that demonstrated there was no relationship between the duration of the intervention and effect size.

Additionally, the variety of potential benefits should be considered in unison with a number of non-reviewed studies. For example, multiple studies (Breslin and Rudisill 2011, 2013; Allen 2017; Liu and Breslin 2013) showed significant improvement in motor development was possible by using visual cues alone. As most of the included studies state that cues were provided in a modified way, much of the improvements in FMS performance could be attributed to the way the instruction is provided and in no way related to the type or delivery of intervention. In other words, the key to intervention might be how the information is presented so that children on the autism spectrum understand "what to do" and "how to do it" rather than any unique motor-specific intervention. Focused practice, also, may have a positive influence on motor improvements, especially if participants have had limited practice opportunities with feedback prior to participation in the study. Given the evidence that practice has an impact on overall motor skill learning and performance (Wulf et al. 2010), it could be suggested that it is a combination of modifying instruction and multiple attempts to practice the skill with explicit feedback guided the participant's improvement. Unfortunately, it is difficult to determine how long improvements last, as no reviewed studies had long-term retention measures. Ultimately, however, there is still a need for research to determine how much and how long interventions need to be to (a) insure a higher likelihood of improvement and (b) increase the likelihood that improvements persist, though this may be difficult given the limited consensus in general populations (Logan et al. 2011). Further, given the heterogeneity of ASD populations, evidence may never lead to a clean, clear directive; instruction may always need to be given on an individual, case-by-case level.

In addition to the great differences in growth from individual to individual, there is great heterogeneity among autism diagnoses and the children comprise a constellation of behavioral possibilities (Bernier and Gerdts 2010, p. 179), it is vital that studies include some measure of diagnosis, description of symptoms, or "severity" measure. Measures of diagnosis and severity not only provide confirmation that the participants are on the autism spectrum, but also offer a basis for comparison to other participants in the study and to other studies of children on the autism spectrum. In addition, information about participants' characteristics can help researchers and practitioners relate study findings to their students. For example, if an intervention is found to work with children on the autism spectrum who are verbal with little other behavioral issues, it is likely that intervention will be beneficial to children displaying similar characteristics. It is unlikely, however, that the same intervention will be beneficial for children who display more intense autism characteristics or who are non-verbal without additional modifications or adjustments to the protocol.

While independent diagnostic assessments would be ideal to ensure the validity of the sample population, it is important to highlight that this procedure is time-consuming and may be unobtainable by many conducting field-based research or working in non-clinical settings. Yet, there are a plethora of options to provide confirmation of diagnosis that does not need to submit the researcher or the participant to an array of additional assessment batteries. While the ADOS would be optimal to provide in-depth characteristic and standardized data of the sample, screening assessments, such as the Social Communication Questionnaire (SCQ), can provide

confirmation without large additional time constraints on the participant, researcher, or practitioner. Further, researchers can provide sample demographic information, such as the DSM-V outlined "Levels of Support" that would give readers a better understanding of the composition of the sample.

In considering each of the studies individually, the studies by Duronjić and Válková (2010) and Debolt et al. (2010) provide helpful insight into what is needed for future interventions. However, both ultimately fall short in providing the necessary detail for replication. Duronjić and Válková, for example, used 18 exercise "lectures" spread over an 8-week period, but included scant information about each lecture. As a result, little insight about future motor skill interventions can be gained beyond the benefits of providing opportunities to engage in PA. It is likely that simple exposure will be beneficial for some children on the autism spectrum; however, many children on the autism spectrum do not often demonstrate the necessary intrinsic motivation for many physical activities or do not provide necessary information in an accessible way. Further, both studies utilized normative data to demonstrate change across the intervention (pre to post), which provides little information in terms of growth. For example, in the study from Debolt et al., one participant moved from the "poor" to "below average" percentile rank in normative data, but only raised her/his raw score from 16 to 18. For the TGMD-2, that is the equivalent of performing an additional one skill component of one gross motor skill. With little guiding information about the intervention, limited inference from statistics, and little demonstrated growth, replication of these results is limited.

The studies by Bremer et al. (2014), Bremer and Lloyd (2016), and Ketcheson et al. (2016) provide a much better foundation to build future interventions in addition to providing strong support for FMS motor interventions for children on the autism spectrum. Bremer et al. studied participants in a one-on-one or one-on-two intervention focused on core FMS (e.g., running, hopping, throwing, catching) to test the effectiveness of an FMS intervention and compare two intervention intensities. Bremer et al. found a significant effect for the motor intervention but little effect for treatment intensity, suggesting that an intervention of any length can be beneficial; which is similar to previous evidence (Logan et al. 2011). More importantly, this finding provides support for the motor skill delays in ASD being secondary to the condition and not an innate feature given that any amount of instruction can improve motor skills. As with all but one of the studies, a small sample size limits generalizability and statistical interpretations of Bremer et al.'s findings. However, Bremer et al. acknowledge this limitation and suggest that future studies increase the sample size and length of intervention (> 18 weeks) to gain better insight into the intervention's effects not only on FMS but also on social skills and adaptive behavior.

In another included study, Bremer and Lloyd (2016) looked at the effects of a school-based FMS intervention for children on the autism spectrum. Participants were given 27 h of instruction on 12 FMS (e.g., jumping, galloping, throwing, kicking) and balance over the course of 12 weeks. The intervention was performed three times each week for 45 min, which allowed approximately 1 week of instruction for each of the 12 skills. Instruction was given to the whole group, but each child received one-on-one instruction from one of the authors, a special physical educator, or a graduate student. Similar to Bremer et al., Bremer and Lloyd's intervention provided a warm-up, review of previous skill, introduction of new skill, skill practice, skill activity, obstacle course, cleanup, and bike activity. The obstacle course focused on components of the practiced skill for that session, while the bike activity was used as a motivational tool. No inferential statistics were analyzed due to the limited sample size. Visual analysis demonstrated improvement in many areas across the individual skill items, but it is unknown whether skill development was due to the motor intervention, the opportunity to practice test items, or simple maturation, as there was no control group. Further, while there is merit to providing instruction within the constraints of the classroom setting, devoting 1 week to each skill may not provide enough instruction to sustain growth in motor abilities. It is likely that the training sessions offered guidance to participants and familiarized them with the skill they were being asked to perform. Further, it is impossible to determine whether the effects of the intervention were sustained or merely temporary as there was no follow-up.

Ketcheson et al. (2016), in their use of Classroom Pivotal Response Teaching (CPRT), provided a unique framework for motor interventions that was not present in the aforementioned studies. CPRT, unlike direct instruction, is considered an evidenced-based practice (EBP) for children on the autism spectrum (Wong et al. 2013). During data collection, participants were provided instruction one-on-one following the 8 key components of the CPRT program. Components are listed as antecedent (student attention, clear and appropriate language, easy and difficult task, shared control, and multiple cues) and consequence strategies (direct reinforcement, contingent consequence, and reinforcement of attempts; Ketcheson et al. 2016). As with previous reviewed studies, Ketcheson et al. found significant increases between pre- and post-measures, demonstrating further evidence to the benefit of motor programs are for children on the autism spectrum. However, the dosage and intensity of this intervention may make transference to other situations potentially problematic.

While Bremer et al. (2014), Bremer and Lloyd (2016), Ketcheson et al. (2016), and the other included studies support the effectiveness of motor interventions to build motor skills

in children on the autism spectrum, only limited information is available about what should be done or how interventions should be delivered. Bremer et al. provide some insight into instructions and content, but information is limited. Given the current evidence, at minimum, providing children and adolescents on the autism spectrum the opportunity to practice motor skills can create a situation where individuals can improve their FMS performance. Although this finding is vague, practitioners may find relief in it, as much of the treatment or therapy for ASD is highly structured and limited in its flexibility to assist in the development of skills. Evidence from this review suggests that in the motor domain, any amount or type of practice can provide benefit. Given this finding, it will be important for future research to find the most effective solutions for building motor skills and build structure to ensure the efficacy of intervention across settings and individuals included. Further, many of the reviewed studies did not include a follow-up assessment to understand the retainment of motor skills over time in the absence of the intervention. Although the current reviewed studies universally showed improvement, this improvement may have only been short-term. In order to ensure that FMS improvements are maintained, researchers will need to find not only the most effective frequency and dosage, but also the most effective method of delivery. Studies by Bremer et al. and Bremer and Lloyd do provide evidence that "single-step instructions, progressive skill acquisition, and visual prompts" (Bremer et al. 2014, p. 68) can be effective in relaying information to children on the autism spectrum to assist with FMS development, and Ketcheson et al. suggest that "direct and intensive instruction on targeted motor skills delivered within an evidence-based framework" may result in positive outcomes (p. 11); continued research in this area will need to provide greater structure to those instruction methods.

Further, research into the effect of visuals (Allen 2017; Breslin and Rudisill 2011, 2013; Liu and Breslin 2013) on performance of motor tasks has demonstrated the potential importance of ensuring that the most effective instructional methods are used with children on the autism spectrum. Although research on evidence-based practices in other domains has demonstrated the positive effects of visual communication with children on the autism spectrum (Wong et al. 2013), Bremer and Lloyd (2016) and Ketcheson et al. (2016) were the only studies that mentioned the use of visuals during the intervention. This is a huge limiting factor for future interventions. If the method for delivering the intervention is not effective, the impact of the intervention itself will be limited. This trend is also demonstrated overall in FMS interventions for general populations (Logan et al. 2011; Morgan et al. 2013). Even when demonstrating overall positive potential, it is unlikely that the study outcomes could be replicated without including vital details of the intervention.

Limitations

This review is limited ultimately by the key terms used and the authors' biases of included studies. It is possible that search terms did not fully encompass the necessary search terms to capture all of the published research regarding FMS interventions for children on the autism spectrum. Further, the authors' exclusion of aquatic and hippotherapy interventions—while similar to previous reviews in this area—may have inadvertently excluded potential impactful interventions. Additionally, this review was limited to manuscripts published prior to December 2016, as that is when the review was conducted. Given the trend of several articles being published in 2016 and the authors' knowledge of at least one manuscript (Guest et al. 2017) published after this review was conducted, there are likely interventions that were not included in this review. As with all reviews, the included studies are limited to the published literature, which may not include interventions that did not show some kind of benefit. While the included studies demonstrate the potentially positive effects of designed motor skill interventions, there is a possibility that studies showing no effect or negative effect exist. Furthermore, it is these studies that ultimately future research could benefit from by giving insight into what works, but also what does not. Lastly, the implications found in this review are hindered by the oversampling of male participants. Of the 41 participants included across the 5 studies of this review, 73% (30/41) were male, 20% (8/41) were female, and 7% (3/41) were unknown. While this data is similar to the reported gender differences in diagnosis (Baio et al. 2018), it is suggested that girls are often missed due to camouflaging or a limited understanding of how autism may present in female populations (Gould 2017). Regardless, the lack of female participants limits findings to male populations, and practitioners should be careful to generalize the broader autism community, as there simply is no evidence to suggest that females on the autism spectrum will benefit the same as their male counterparts.

Conclusion

Motor skill interventions may provide opportunities to build skills and change the trajectories of development to match the rate of their peers. While most motor interventions in general have provided a positive outlook on the overall effects on the development of skills (see Tables 1 and 2), little information is provided regarding practical strategies for future development and practical application of interventions (Morgan et al. 2013). In interventions focused at populations on the autism spectrum, evidence is consistently positive. This could be due to a publication bias and a reluctance to publish studies that do not show statistical significance, or it could demonstrate that

an intervention, in any form, may provide opportunities for improvement, although these findings have rarely been checked for persistence in the absence of the intervention. Three of the reviewed studies (Bremer et al. 2014; Bremer and Lloyd 2016; Ketcheson et al. 2016) provided strong evidence for future inquiry and a frame for current practitioners. According to the aforementioned studies, providing direct instruction in a progressive manner that is individualized to the child on the autism spectrum will be of the greatest benefit. Further, if verbal instruction is augmented with visuals or is given in a very visual way, this can also increase the likelihood of success. However, the appropriate frequency and dosage of FMS interventions remain a mystery. Only in one study (Bremer et al. 2014) did researchers attempt to discern frequency differences, finding little to no effect. In other studies, authors suggested providing the intervention for a significant amount of time (> 18 weeks). Regardless, practitioners looking to build FMS in children and adolescents on the autism spectrum should look to provide individualized instruction on a regular basis with frequent opportunities to practice previously mastered skills. In the area of autism research, there is a critical need for quality, theory-driven research that will, ultimately, provide evidence-based practices aimed at building the FMS of children on the autism spectrum that is not only the most effective, but provides the greatest opportunity for continued high levels of performance.

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Compliance with Ethical Standards

Ethical Approval This article does not contain any studies with human participants performed by any of the authors.

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