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Fundamental movement skills in children with autism spectrum disorder: A systematic review

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ABSTRACT

Background: Fundamental movement skills (FMS) are basic movement skills (i.e. balance, object control, and locomotor skills) that form the foundation for more advanced movement patterns. These skills are a crucial but often an overlooked part of the development process, especially in populations with autism spectrum disorder (ASD). In view of this, the present review was undertaken with the purpose of determining the extent of FMS impairments in children with ASD compared to typically developing children and those with other developmental disorders.
Method: A total of 24 studies that measured FMS in children with ASD using product- and process-oriented standardized movement assessment batteries were included in the review.
Results: The results showed that impairments in FMS are highly prevalent across the ASD spectrum and that children with ASD exhibited greater impairments in FMS competencies especially object control and locomotor skills compared to typically developing children and those with other developmental disorders. Moreover, these impairments in FMS appear to emerge early in life and persist throughout late childhood years in the majority of children with ASD.
Conclusion: These findings provide preliminary evidence suggesting that FMS has the potential to be an early motor marker in children with ASD, and that practitioners should therefore be encouraged to consider movement skill evaluations as a routine investigation for children with ASD.

1. Introduction

Autism spectrum disorder (ASD) is an umbrella term for a group of neurodevelopmental disorders with a clinical presentation predominantly related to deficits in "social communication skills and poor social interaction", accompanied by "restricted, repetitive patterns of behavior, interest, or activities" (American Psychiatric Association, 2013). Globally, the presence of ASD has increased

Abbreviations: ASD, autism spectrum disorder; ADHD, attention deficit hyperactivity disorder; BDI, Battelle Developmental Inventory; BOT, Bruininks-Oseretsky Test of Motor Proficiency; BSID-2, Bayley Scale of Infant Development 2nd edition; FMS, fundamental movement skills; GMS, gross motor skills; HFA, high-functioning autism; JMAP, Japanese version of the Miller Assessment for Preschoolers; LD, language delay; MABC, Movement Assessment Battery for Children; MSEL, Mullen Scales of Early Learning; PDD-NOS, pervasive developmental disorder–not otherwise specified; PDMS, Peabody Developmental Motor Scales; SDD-MF, specific developmental disorder of motor function; TGMD, Test of Gross Motor Development

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exponentially, with 1 in 54 children being diagnosed with the disorder (Maenner, 2020). The economic burden related to the care of children with ASD is substantial and includes costs such as health care services, health education, ASD-related therapy, services provided for the families, and the labor costs of caregivers (Lavelle et al., 2014). The increasing prevalence and significant costs associated with ASD are fueling continuous efforts to further understand the biomarkers and symptoms of ASD for early detection and the development of effective interventions.

There is renewed interest in the motor development of young children with ASD due to growing evidence that suggests that impairments in motor skills precede, and even exacerbate, social- communicative symptoms in ASD (Harris, 2017; Leary & Hill, 1996; MacDonald, Lord, & Ulrich, 2014). For instance, a prospective study on infants at high risk of ASD demonstrated that parental concerns regarding children's motor development at six months of age were a significant predictor of ASD diagnosis, whereas parental concerns regarding social communication and repetitive motor behaviors were not predictive of ASD until after 12 months of age (Sacrey et al., 2015). Similarly, a recent longitudinal study using standardized developmental tests on high-risk infants demonstrated that fine and gross motor skills at six months of age were a significant predictor of ASD diagnosis at 24–26 months of age (LeBarton & Landa, 2019). These findings, along with the growing research evidence suggesting that motor disturbances are among the earliest detectable signs of ASD (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Gowen & Hamilton, 2013; Guinchat et al., 2012), provide new insights and indicate a need to shift the focus from socio-communicative deficits to a motor perspective in order to facilitate early diagnosis of ASD.

One important yet an overlooked aspect of motor development in the context of ASD are fundamental movement skills (FMS). These are the observable movement patterns of gross motor skills (GMS) that involve the "large, force-producing muscles of the trunk, arms, and legs" (Gabbard, 2012). Fundamental movement skills are the basis for more advanced skills and comprise object control, locomotor, and balance skills (Gallahue, Ozmun, & Goodway, 2012). Object control skills involve handling and controlling objects with the hand or foot. For example, throwing, catching, dribbling, kicking, underhand rolling, overhand throwing, and striking. Locomotor skills involve engaging the body in movement in different directions. These skills include hopping, galloping, leaping, jumping, sliding, and skipping. Balance skills keep the body in a controlled position during a specific task that is performed in situ or while in motion.

Fundamental movement skills emerge during early childhood years and continue to develop in an orderly manner on a developmental continuum of skills sequences until late childhood (Clark, 1994; Hardy, King, Farrell, Macniven, & Howlett, 2010). It is important to monitor FMS development during maturation, because mastery of FMS is critical for the overall development of the child and contributes to the child's cognitive functioning (Campos et al., 2000; Piek, Hands, & Licari, 2012), language development and communication skills (Bedford, Pickles, & Lord, 2016; Gernsbacher, Sauer, Geye, Schweigert, & Hill Goldsmith, 2008), and adaptive behavior (Clearfield, 2011; Iverson, 2010; Lubans, Plotnikoff, & Lubans, 2012). The significant impact of FMS on areas that are regarded as the defining characteristics of ASD, along with the current research imperative to identify the definitive motor markers of ASD (Zwaigenbaum et al., 2015), reinforce the importance of using assessment methods that can contribute to our understanding of the specific movement skills that are compromised in ASD.

There is no one gold standard movement assessment tool rather there are several different methods, each of which differ with respect to the purpose of the assessment. In order to select the appropriate tool of assessment, it is important to differentiate between "movement" and "motor", the two different concepts which are often interchangeably used in the context of movement skills assessment. Motor abilities refers to the underlying neuromuscular capacities that contributes to the performance of a particular movement skill (e.g., throwing velocity, hand-eye coordination and strength for throwing a ball at a distance) (Staples & Reid, 2010) whereas movement refers to the observable and goal-directed acts of moving such as hoping on one leg, where the performance can be inferred according to the final outcome (i.e., 5 of 10 successful hops) (for review see Burton & Miller, 1998).Technology-assisted measures such as accelerometers and motion capture systems are more suitable when the purpose of the assessment is to obtain description of motor processes rather than movement skills, per se (Ward, Thornton, Lay, & Rosenberg, 2017). Standardized movement assessment batteries on the other hand comprehensively evaluates the child's functional performance on broad range of movement related competencies (i.e. object control skills, locomotor skills and balance skills) (Hands, 2002) and therefore are commonly used when the purpose of the assessment is to identify children at risk of movement skills difficulties. Standardized movement assessment batteries usually employ either a product-oriented or process-oriented approach for the assessment of movement skills (Gabbard, 2012).The former approach, which is also referred to as norm-referenced assessment, measures the outcome of performance (e.g., time taken to complete a task, number of successful trials completed, or number of errors made), whereas the latter, also known as criterion-referenced assessment, focuses mainly on the technique used to perform a particular movement skill (e.g., whether or not the child extends his/her arms to catch a ball) (for details of these assessment batteries, see Appendix A). Both product and process-oriented assessment batteries have been found to adequately capture the multifaceted nature of FMS and are considered to be highly reliable in distinguishing the movement skills performance between children with and without FMS impairments (for review see Cools, De Martelaer, Samaey, & Andries, 2011; Wiart & Darrah, 2001; Yoon, Scott, Hill, Levitt, & Lambert, 2006), resulting in their use in several studies examining FMS in children with ASD (Berkeley, Zittel, Pitney, & Nichols, 2001; Breslin & Rudisill, 2011; Ghaziuddin & Butler, 1998; Green et al., 2002, 2009; Hauck & Dewey, 2001; Hilton et al., 2007; Iwanaga, Kawasaki, & Tsuchida, 2000; Jasmin et al., 2009; Landa & Garrett-Mayer, 2006; Liu, Hamilton, Davis, & ElGarhy, 2014; Liu, Breslin, & ElGarhy, 2017; Lloyd, MacDonald, & Lord, 2013; MacDonald et al., 2014; Mache & Todd, 2016; Matson, Mahan, Fodstad, Hess, & Neal, 2010; Pan, Tsai, & Chu, 2009; Paquet, Olliac, Bouvard, Golse, & Vaivre-Douret, 2016; Provost, Lopez, & Heimerl, 2006; Provost, Heimerl, & Lopez, 2007; Staples & Reid, 2010; Van Waelvelde, Oostra, Dewitte, Van Den Broeck, & Jongmans, 2010; Whyatt & Craig, 2012; Zachor, Ilanit, & Itzchak, 2010).

The current systematic review aims to summarize and interpret the above studies in order to have a deeper understanding of

actual performance of fundamental movement skills in children with ASD. Despite the fact that movement skills are associated with myriad of positive outcomes that are crucial for the optimum development of a child, the majority of the studies investigating movement behavior in children with ASD have narrowly focused on their motor abilities. Although these studies have been useful in providing evidence for a range of motor deficits associated with ASD such as motor incoordination, postural instability and altered gait patterns (for review see Fournier et al., 2010; Kindregan, Gallagher, & Gormley, 2015), they have not shed sufficient light on the degree to which impairments in basic movement skills (e.g. locomotor, object control, and balance skills) account for motor deficiencies in children with ASD. Furthermore, the existing literature on impairments in FMS have sampled individuals across broad age groups (Biscaldi et al., 2015; Hannant, Cassidy, Tavassoli, & Mann, 2016; Jansiewicz et al., 2006; Stins, Emck, de Vries, Doop, & Beek, 2015), thus obscuring the extent and developmental trajectory of FMS impairments in children with ASD. Additionally, it is not known whether the impairments in these movement skills competencies are specific to ASD, as they are also commonly observed in many developmental disorders such as Attention Deficit Hyperactivity Disorder (ADHD) and Developmental Coordination Disorder (DCD) (Green et al., 2002; Pan et al., 2009; Provost et al., 2007; Van Waelvelde et al., 2010). The purpose of the present systematic review therefore was to determine the prevalence and developmental trajectory of FMS impairments in children with ASD by comparing their performance on standardized movement assessment batteries with that of typically developing children and children with other developmental disorders, in an attempt to identify movement-related markers that are specific to ASD.

2. Method

2.1. Retrieval of studies

An exhaustive search for studies measuring FMS in children with ASD was undertaken in the following databases: (a) PubMed; (b) Science Direct; and (c) Google Scholar. The search keywords, which were used either individually or in combination, included "assessment," "gross motor skills," "movement competency," "locomotor skills," "balance," "object control skills," "fundamental movement skills," "standardized tests," "product oriented movement batteries," "process oriented movement batteries", "very young children," "school-age children," "autism," "Asperger syndrome", "high-functioning autism", "pervasive developmental disorder–not otherwise specified" and "autism spectrum disorder (ASD)."

The following definitions of certain keywords are used in the present review:

- Very young children: Children less than six years of age.
- School-age children: Children between six and 12 years of age.
- Fundamental movement skills (FMS): Movement competencies (i.e. locomotor skills, object control skills, and balance) based on the classification by Gallahue et al. (2012).
- Autism spectrum disorder (ASD): Includes Autism or childhood autism, Asperger syndrome (AS), high-functioning autism (HFA), and pervasive developmental disorder–not otherwise specified (PDD-NOS), or atypical autism (American Psychiatric Association, 2000).

2.2. Eligibility criteria

The search for studies across electronic databases was based on the following inclusion criteria: (a) participants diagnosed with ASD; (b) participants not older than 12 years of age; (c) studies that assessed at least one FMS competency i.e. object control, locomotor skills, and balance skills or overall FMS composite; (d) studies that used standardized movement assessment batteries based on a product-oriented and/or process-oriented approach to measure FMS competencies; (e) studies published in a peer-reviewed journal; and (f) studies printed in English. Studies were excluded if: (a) they evaluated FMS using retrospective data or other assessment methods, such as, accelerometers, motion capture systems, and so forth (n = 11); (b) they were intervention studies designed to alter FMS competencies (n = 5); (c) participants did not have a diagnosis of ASD (n = 19); (d) participants were over the age of 12 (n = 17); and (e) the studies were not published in English (n = 1). The list of excluded studies is available from the corresponding author.

2.3. Study selection and data extraction process

The literature search was conducted independently by the author and two coauthors to ensure the reliability of the electronic database search. A total of 587 articles were identified at this stage. After removing duplicates, the remaining articles were screened by assessing the articles title and abstracts for eligibility, followed by a thorough assessment of the full- text of the articles to determine whether they met the inclusion criteria. A total of 75 articles were identified at this stage, 53 of which did not meet the inclusion criteria. Two additional studies were identified based on the recommendation from an expert in the field. In total, 24 studies were selected for the final review (Fig. 1). After the final selection of 24 studies, information pertinent to the current review was extracted. This included: (a) descriptive information (such as author(s), year of publication, and the country in which the data were collected); (b) sample characteristics (i.e. gender and age of participants, nature of clinical population); (c) study design (whether it was a case study, cross-sectional study, or longitudinal study); (d) comorbid psychiatric or neurological condition; (e) Intelligent Quotient (IQ) score; (f) the FMS competency measured; and (g) the type of FMS assessment used (e.g. product-oriented or process-oriented assessment). In order to ensure the accuracy of the information derived from these studies, five studies were randomly

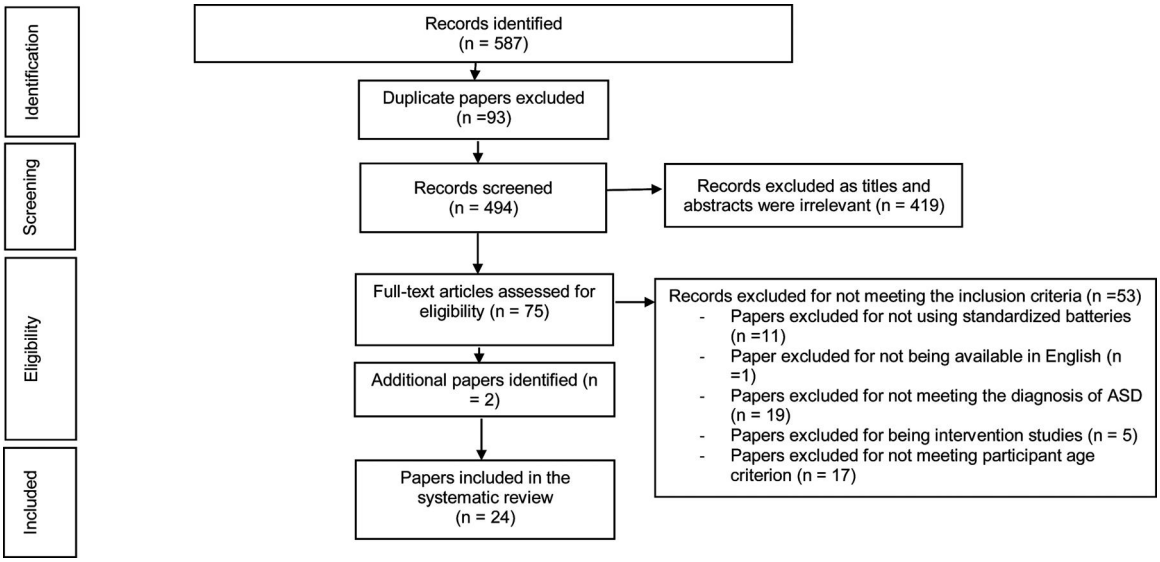

Fig. 1. PRISMA flowchart of study selection process.

selected and independently coded by two coders. Agreement between the coders ranged from 90 % to 95 %. The disagreement was resolved via consensus until 100 % accuracy was achieved.

2.4. Method of quality appraisal

The methodological quality of the studies was assessed according to the guidelines of Law et al. (1998). Based on this method, the quality of the studies was evaluated using 14 questions that can be broadly classified into the following categories: purpose of the study; background literature; research design; sample; reliability and validity of assessment tools; results; conclusion; study limitations; and clinical implications. Each question was given a score of 1 if it met the criteria, or 0 if it did not meet the criteria (see Table 1). The scores were calculated for each study. A score of 11 or above was considered high methodological quality; a score between 7 and 10 points was considered good methodological quality; and a total score below 7 was considered low methodological quality. Two authors independently assessed the methodological quality of the studies, and in case of disagreement reached a consensus via discussion.

3. Results

3.1. Study characteristics

The 24 studies considered in this systematic review provided data on 1094 participants with ASD. All except ten of the studies reported gender composition (n = 14). There was a preponderance of males (85 %) over females. Out of the 24 studies considered, 20 were cross-sectional studies, while the others used a longitudinal (n = 1), combined cross-sectional and longitudinal (n = 1), pre-test and post-test (n = 1), and case study (n = 1) research design. The majority of the studies were from the United States of America (n = 13), while others were conducted in Europe (n = 5), Canada (n = 3), and Asia (n = 3). Out of the total studies, 11 were conducted on very young children diagnosed with ASD. The most frequently used FMS assessment battery for this age group was the Peabody Developmental Motor Scales 2nd edition (PDMS-2) (Folio & Fewell, 1983, 2000) (n = 4), followed by the Mullen Scales of Early Learning (MSEL) (Mullen, 1989, 1995) (n = 3), the Japanese version of the Miller Assessment for Preschoolers (JMAP) (Tsuchida, Sato, Yamada, & Matsushita, 1989) (n = 1), the Bruininks-Oseretsky Test of Motor Proficiency 2nd edition (BOT-2) (Bruininks & Bruininks, 2005) (n = 1), the Bayley Scales of Infant Development 2nd edition (BSID-2) (Bayley, 1993) (n = 1), and the Battelle Developmental Inventory 2nd edition (BDI-2) (Newborg & Riverside Publishing Company, 2005) (n = 1). The remaining 13 studies were carried out on school-age children with ASD. The most commonly used FMS assessment was the Test of Gross Motor Development 2nd edition (TGMD-2) (Ulrich, 2000) (n = 4), followed by the Movement Assessment Battery for Children 2nd edition (MABC-2) (Henderson, Sugden, & Barnett, 2007) (n = 3), the Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1992) (n = 2), the Bruininks-Oseretsky Test of Motor Proficiency (BOT) (Bruininks, 1978) (n = 1), the Test of Gross Motor Development (TGMD) (Ulrich, 1985) (n = 1), the Test of Gross Motor Development 3rd edition (TGMD-3) (Ulrich, 2013) (n = 1) and the Battelle Developmental Inventory (BDI) (Newborg, Stock, Wneck, Guidubaldi, & Svinicki, 1984) (n = 1).

Table 1
Methodological Quality of Reviewed Studies.

Studies	*Questions														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Berkeley et al. (2001)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	13
Breslin and Rudisill (2011)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Ghaziuddin and Butler (1998)	1	1	1	1	0	1	1	1	1	1	0	1	1	1	12
Green et al. (2002)	1	1	1	1	1	1	1	1	1	1	1	1	1	0	13
Green et al. (2009)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Hauck and Dewey (2001)	1	1	1	1	1	0	1	1	1	1	0	1	1	1	12
Hilton et al. (2007)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Iwanaga et al. (2000)	1	1	1	1	1	0	1	1	1	1	0	1	1	1	12
Jasmin et al. (2009)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Landa and Garrett-Mayer (2006)	1	1	1	1	1	0	1	1	1	1	0	1	1	1	12
Liu et al. (2014)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Liu et al. (2017)	1	1	1	1	1	0	1	1	0	1	1	1	0	1	11
Lloyd et al. (2013)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
MacDonald et al. (2014)	1	1	1	1	1	0	1	1	1	1	1	1	1	1	13
Mache and Todd (2016)	1	1	1	0	1	1	1	1	1	1	1	1	1	1	13
Matson et al. (2010)	1	1	1	1	1	1	1	1	1	1	0	1	0	0	11
Pan et al. (2009)	1	1	1	1	1	1	1	1	1	1	0	1	1	1	13
Paquet et al. (2016)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Provost et al. (2006)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Provost et al. (2007)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Staples and Reid (2010)	1	1	1	1	1	0	1	1	1	1	1	1	1	1	13
Van Waelvelde et al. (2010)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Whyatt and Craig (2012)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Zachor et al. (2010)	1	1	1	1	1	0	1	1	1	0	1	1	1	0	11

**Note*: 1 = meets criterion; 0 = does not meet criterion.

* *Questions*: (1) Was the study purpose stated clearly? (2) Was relevant background literature reviewed? (3) Was the research design appropriate? (4) Was the sample described in detail? (5) Was the sample size justified? (6) Was informed consent obtained? (7) Were the outcome measures reliable? (8) Were the outcome measures valid? (9) Were results reported in terms of statistical significance? (10) Were the analysis methods appropriate? (11) Was clinical importance reported? (12) Were the conclusions appropriate? (13) Are there any implications of the results of the study? (14) Were the limitations of the study described?

3.2. Synthesis of results

3.2.1. Fundamental movement skills in very young children (six months to six years old)

Eleven studies were included in the category of very young children with ASD. All these studies were found to have high methodological quality. The studies included 712 participants with a mean age of 3.5 years. Participants did not have comorbid psychiatric or a neurological condition in any of the studies. Majority of the studies included participants with IQ score of above 70 (n = 5) followed by studies that included participants irrespective of their level of intellectual functioning (n = 4) and the remaining studies (n = 2) did not mention about the intellectual level of the participants. Some of the studies evaluated the performance of children with ASD by comparing it with the performance of typically developing children or normative sample on a particular assessment battery (n = 5), while other studies compared the performance of children with ASD to that of children with other developmental disorders (n = 4) and within the spectrum of autism disorders (n = 2) (seeTable 2).

In comparison to normative sample of typically developing children, majority of very young children with ASD showed borderline impairment (≤ 15th percentile) on overall FMS composite (Jasmin et al., 2009; Liu et al., 2017; Zachor et al., 2010). Sixty-three percent of the children were found to perform on average 6.4 months behind their chronological age (MacDonald et al., 2014). Moreover, the difference between chronological age and FMS age equivalent was found to increase progressively with age (the 12–24 month age group were on average 3.50 months behind; the 25–30 month group were 5.13 months behind; and children in the 31–36 month group were 9.18 months behind what would be expected for their chronological age), even after controlling for non-verbal IQ (Lloyd et al., 2013). A similar finding was demonstrated by a longitudinal study where it was found that the development trajectory of FMS was slowest between 14–24 months for children with ASD (M = 36.21 SD = 9.31) as compared to children with language delay (LD) (M = 46.64 SD = 12.61) (Landa & Garrett-Mayer, 2006).

Children with ASD also showed poor performance (M = 3.1, SD = 3.8) on FMS compared to the attention deficit hyperactivity disorder (ADHD) group (M = 5.6, SD = 3.7), even after controlling for IQ (Van Waelvelde et al., 2010). Their locomotor and object control profiles (M = 5.3, SD = 2.1; M = 5.9, SD = 1.6) were slightly different from children with developmental delays in the motor area (M = 5.7, SD = 2.4; M = 6.4, SD = 1.7) (Provost et al., 2007), although they differed considerably from the profiles of children with non-motor delays (NMD) (children with speech and language delays and social–emotional delays) (M = 8.8, SD = 1.0; M = 9.1, SD = 1.1) (Provost et al., 2006).

Within the ASD spectrum, children with autism were found to have a higher percentage of impairment (16.2 %) on overall FMS composite compared to children with PDD-NOS (10.7 %) (Matson et al., 2010). Some aspects of motor problems, such as poor

Table 2
Summary of Studies done on Very Young Children (0–6 Years).

Authors	Participant Characteristics	Study Design	Comorbid Psychiatric/ Neurological condition (ASD group)	Intelligent Quotient (IQ)	FMS Competency	FMS Measure		Results
						Product	Process	
Iwanaga et al. (2000)	n = 25 (males 17, females 8); participants with Asperger syndrome (AS) (n = 10); participants with high-functioning autism (HFA) (n = 15); ages 4–6 years old	Cross-sectional study	Absent	IQ above 70	Balance	JMAP		80 % of children with AS had poor (< 5th percentile) standing balance compared to children with HFA.
Jasmin et al. (2009)	n = 35 (males 32, females 3); ages 3–4 years; participants with ASD	Cross-sectional study	Absent	Range of IQs below and above 70	Locomotor and object control skills (ball skills)	*PDMS-2		a) 63 % of children showed lower performance (≤ 2 SD) on FMS compared to the normative sample; b) Definite (< 5th percentile) impairments were found in both, locomotor and object control skills
Landa and Garrett-Mayer (2006)	n = 87 (males 52, females 35); ages 6 months to 2 years; participants with ASD (n = 24); participants with language delay (LD) (n = 11); unaffected participants (n = 52)	Longitudinal study	Absent	Not mentioned	FMS composite	MSEL		ASD group performed worst (M = 36.21, SD = 9.31) at 24 months of age in comparison with LD group (M = 46.64, SD = 12.61) and unaffected group (M = 51.94, SD = 11.02).
Liu et al. (2017)	n = 1 male participant with ASD; age 5 years	Case study	Absent	IQ above 70	Balance, locomotor, and object control skills	1)BOT-2 2)MABC-2	3) TGMD-2 4) *PDMS-2	Below average performance was found on all the assessment batteries.
Lloyd et al. (2013)	n = 162 (males 140, females 22) participants with ASD; ages 1–3 years	Cross-sectional and longitudinal study	Absent	Non-verbal IQ above 70	FMS composite	MSEL		Children with ASD were behind their chronological age on FMS at each cross-sectional age point (12–24 months group were 3.50 months behind; 25–30 month group were 5.13 months behind; and 31–36 month group were 9.18 months behind what would be expected), with the delay being significantly (p < .001) more pronounced with age.
MacDonald et al. (2014)	n = 159 (gender not mentioned) participants with ASD; ages 1–3 years	Cross-sectional study	Absent	Range of IQs below and above 70	FMS composite	MSEL		Children performed 6.4 months behind what would be expected for their chronological age.
Matson et al. (2010)	n = 396 (males 284, females 112); ages 1–3 years; participants with autism (n = 116); participants with PDD-NOS (n = 112); participants with atypical development (n = 168)	Cross-sectional study	Absent	Not mentioned	FMS composite	BDI-2		Children with autism (16.2 %) had a higher percentage of impairment in movement skills compared to those with PDD-NOS (10.7 %).
Provost et al. (2006)	n = 56 (males 42, females 14); ages 1–5 years; participants with ASD (n = 19); participants with DD in motor area (n = 19); participants with developmental concerns without motor delay (NMD) (n = 18)	Cross-sectional study	Absent	Range of IQs below and above 70		BSID-2	* PDMS-2	ASD group performance on both locomotor and object control skills (M = 5.7, SD = 2.4; M = 5.9, SD = 1.6) differed considerably from NMD group (M = 8.8, SD = 1.0; M = 9.1, SD = 1.1) but did not differ

(*continued on next page*)

Table 2 (*continued*)

Authors	Participant Characteristics	Study Design	Comorbid Psychiatric/ Neurological condition (ASD group)	Intelligent Quotient (IQ)	FMS Competency	FMS Measure		Results
						Product	Process	
								much from DD group (M = 5.3, SD = 2.1; M = 6.4, SD = 1.7)
Provost et al. (2007)	n = 38 (males 30, females 8); ages 1–3 years; participants with ASD (n = 19); participants with DD (n = 19)	Cross-sectional study	Absent	Range of IQs below and above 70	Locomotor and object control skills	*PDMS-2		The majority of children in the ASD and DD groups showed similar performance on the two FMS competencies.
Van Waelvelde et al. (2010)	n = 49 (males 39, females 10); ages 4–6 years; participants with or at risk of ASD (n = 15); ADHD (n = 16); no diagnosis (n = 18)	Pre-test and post-test design	Absent	IQ above 70	FMS composite	MABC		Children with ASD showed poorer performance (M = 3.1, SD = 3.8) compared to children with ADHD (M = 5.6, SD = 3.7)
Zachor et al. (2010)	n = 25 (males 24, females 1) participants with ASD; ages 2–5 years	Cross-sectional study	Absent	IQ above 70	FMS composite		*PDMS	Children with ASD showed below average performance (≤ 15th percentile) relative to normative sample

JMAP = Japanese version of the Miller Assessment for Preschoolers; PDMS-2 = Peabody Developmental Motor Scales 2nd edition; MSEL = Mullen Scales of Early Learning (the gross motor skills subtest was used); BOT-2 = Bruininks-Oseretsky Test of Motor Proficiency 2nd edition; MABC-2 = Movement Assessment Battery for Children 2nd edition; TGMD-2 = Test of Gross Motor Development 2nd edition; BDI-2 = Battelle Developmental Inventory 2nd edition; BSID-2 = Bayley Scales of Infant Development 2nd edition; MABC = Movement Assessment Battery for Children; PDMS = Peabody Developmental Motor Scales. Note: *PDMS and *PDMS-2 use both product-oriented and process-oriented approach to movement assessment.

Table 3
Summary of Studies done on School-Age Children (6–12 Years).

Authors	Participant Characteristics	Study Design	Comorbid Psychiatric/ Neurological condition	Intelligent Quotient (IQ)	FMS Competency	FMS Measure		Results
						Product	Process	
Berkeley et al. (2001)	n = 15 (males 10, females 5) participants with high-functioning autism (HFA); ages 6–8 years	Cross-sectional study	Absent	Not mentioned	Locomotor and object control skills		TGMD	53 % of children with HFA scored in the severe (< 5th percentile) to borderline (5th–15th percentile) impairments range in object control skills, whereas 80 % were between the severe and borderline range on locomotor skills.
Breslin and Rudisill (2011)	n = 22 (males 16, females 6) participants with ASD; ages 3–11 years	Cross-sectional study	Absent	Not Mentioned	FMS composite		TGMD-2	63 % of children had borderline impairment on overall FMS composite.
Ghaziuddin and Butler (1998)	n = 24 (males 21, females 24); age 11 years old; participants with Asperger syndrome (AS) (n = 12); participants with autism (n = 12); participants with PDD-NOS (n = 12)	Cross-sectional study	Absent	IQ above 60	FMS composite	BOT		All three groups showed poor performance relative to standardized normative sample. AS group (M = 33.1, SD = 16.3) was found to be relatively less impaired than the PDD-NOS group (M = 29.6, SD = 9.3) and the autism group (M = 20, SD = 12.5).
Green et al. (2002)	n = 20 males; ages 6–11 years; participants with AS (n = 11); participants with a specific developmental disorder of motor function (SDD-MF) (n = 9)	Cross-sectional study	Absent	IQ above 70	Object control skills and balance	MABC		The ASD group had higher mean impairment scores (M = 2.91, SD = 2.32) compared to the SDD-MF group (M = 1.86, SD = 1.36). Significant difference ($p < .05$) between the two groups was found on object control skills.
Green et al. (2009)	n = 101 (males 89, females 12) participants with ASD; ages 9–10 years	Cross-sectional study	Absent	Range of IQs below and above 70	FMS composite	MABC-2		1) 79 % of children with autism had definite motor impairment (< 5th percentile), and 10 % had borderline impairment (5th–15th percentile). 2) Majority (97.1 %) of children with a low IQ showed significant impairments than children with a high IQ (69.7 %; χ^2 (1) = 10.5, p = .001).
Hauck and Dewey (2001)	n = 20 (males 18, females 2) participants with autism; ages 2–7 years; participants with developmental delays (DD) (n = 20)	Cross-sectional Study	Absent	Range of IQs below and above 70	FMS composite	BDI		Poorer performance found in ASD group (M = 42.08, SD = 14.40) compared to DD group (M = 47.55, SD = 14.05)
Hilton et al. (2007)	n = 51 (males 44, females 7) participants with Asperger syndrome; ages 6–12 years	Cross-sectional study	Absent	IQ above 70	Object control skills and balance	MABC		65 % of children had definite levels of motor impairment, and 25 % had borderline motor impairment. Greater impairments were found in object control skills (82 %) in contrast to balance (33 %).
Liu et al. (2014)	n = 42 (males 30, females 12); participants with ASD (n = 21); typically developing participants (n = 21); ages 5–10 years	Cross-sectional study	Absent	Not mentioned	Locomotor and object control skills		TGMD-2	Significant ($p < .01$) differences were found between children with ASD and typically developing children on both the skills. A greater percentage of impairments were found in locomotor skills (67 %) than object control skills (60 %).
			Absent	Not mentioned			TGMD-3	

(*continued on next page*)

Table 3 (*continued*)

Authors	Participant Characteristics	Study Design	Comorbid Psychiatric/ Neurological condition	Intelligent Quotient (IQ)	FMS Competency	FMS Measure		Results
						Product	Process	
Mache and Todd (2016)	n = 22; participants with ASD (n = 11); typically developing participants (n = 11); ages 5–12 years	Cross-section study			Locomotor and object control skills			Significant differences were found between children with ASD and typically developing children on ($p < .001$) locomotor skills and ($p < .05$) object control skills.
Pan et al. (2009)	n = 91 (gender not mentioned); participants with ASD (n = 29); participants with ADHD (n = 28); typically developing participants (n = 34); ages 6–10 years	Cross-sectional study	Absent	Above 70	Locomotor and object control skills		TGMD-2	The ASD group performed significantly ($p < .01$) worse than the ADHD group on both locomotor and object control skills.
Paquet et al. (2016)	n = 34 (males 31, females 3) participants with ASD and a reference group of typically developing children; ages 4–11 years	Cross-sectional study	Absent	Range of IQs below and above 70	Balance and object control skills	MABC-2		30% and 24 % children with ASD scored 1 SD below the reference group on object control skills and balance.
Staples and Reid (2010)	n = 25 (males 21, females 4) participants with ASD: (1) age matched; (2) mental age matched (movement skill matched); ages 9–12 years	Cross-sectional study	Absent	Range of IQs below and above 70	Locomotor and object control skills		TGMD-2	Children with ASD performed movement skills similarly to typically developing children half their chronological age. Specific areas of impairment were noted in object control ($p < .01$) and locomotor skills ($p < .01$).
Whyatt and Craig (2012)	n = 18 (males 11, females 7) participants with ASD: (1) receptive vocabulary matched; (2) nonverbal IQ matched; ages 7–10 years	Cross-sectional	Absent	IQ above 70	Object control skills and balance	MABC-2		Children with ASD showed significantly ($p < .001$) lower performance on both the skills compared to the vocabulary matched and nonverbal IQ matched control groups.

TGMD = Test of Gross Motor Development; TGMD-2 = Test of Gross Motor Development 2nd edition; BOT = Bruininks-Oseretsky Test of Motor Proficiency; MABC = Movement Assessment Battery for Children; MABC-2 = Movement Assessment Battery for Children 2nd edition; BDI = Battelle Developmental Inventory.

standing balance, seemed to be specific for a larger number of children in the AS group (80 %) compared to the HFA group (Iwanaga et al., 2000).

3.2.2. Fundamental movement skills in school-age children (six to 12 years of age)

Thirteen studies were included in the category of school-age children with ASD. All these studies were found to have high methodological quality. The studies included 382 participants with a mean age of 9.3 years. Participants did not have comorbid psychiatric or a neurological condition in any of the studies. Most of the studies (n = 5) included participants regardless of their level of intellectual functioning followed by studies that included participants with IQ score of above 70 (n = 4) and the remaining studies (n = 4) did not provide information regarding the intellectual level of the participants. Some of the studies evaluated the performance of children with ASD by comparing it with typically developing children or with the normative sample of typically developing children on a particular assessment battery (n = 9), while the remaining studies compared their performance to children with other developmental disorders (n = 3) and within the spectrum of autism disorders (n = 1) (see Table 3).

Compared to the normative sample, the majority of school-age children with ASD showed definite impairments (< 5th percentile) on the overall FMS composite (Breslin & Rudisill, 2011; Green et al., 2009; Hilton et al., 2007; Liu et al., 2014; Paquet et al., 2016). They also exhibited significant impairments (< .01) in overall FMS composite compared to chronological age and mental age matched control groups (Staples & Reid, 2010; Whyatt & Craig, 2012). In terms of specific areas of impairment across the different FMS competencies, between 67 % and 80 % of children with ASD had definite (< 5th percentile) to borderline (5th–15th percentile) impairments in locomotor skills (Berkeley et al., 2001; Liu et al., 2014; Mache & Todd, 2016); between 53 % and 82 % of children had definite to borderline impairments in object control skills (Berkeley et al., 2001; Hilton et al., 2007; Liu et al., 2014; Mache & Todd, 2016); and between 33 % and 58 % of children had definite to borderline impairments in balance skills (Hilton et al., 2007; Paquet et al., 2016).

In comparison to the clinical groups, children with ASD showed significantly ($p < .01$) lower performance on both locomotor and object control skills compared to children with ADHD, even after controlling for their IQ scores (Pan et al., 2009). Their performance on overall FMS composite was also worse (M = 42.08, SD = 14.40) than the performance of children with developmental delays (M = 47.55, SD = 14.05) (Hauck & Dewey, 2001) and those with specific developmental disorder of motor function (SDD-MF) (Green et al., 2002). The ASD group had a higher mean impairments score (M = 2.91, SD = 2.32) compared to the SDD-MF group (M = 1.86, SD = 1.36), with a significant difference ($p < .05$) between the two identified groups in terms of object control skills (Green et al., 2002).

Within the ASD group, movement impairments were found to be universal in all the children, with the AS group showing a lesser degree of impairments in overall FMS composite (M = 33.1, SD = 16.3) than the PDD-NOS (M = 29.6, SD = 9.3) and autism (M = 20, SD = 12.5) groups (Ghaziuddin & Butler, 1998).

4. Discussion

Fundamental movement skills are basic movement skills (i.e. locomotor, object control, and balance skills) that are crucial to childhood development however, it is often an overlooked aspect of motor development in children with ASD. Gaining a deeper insight into movement skills dysfunction can contribute to the identification of specific movement-related markers of ASD, which in turn may facilitate earlier diagnosis and development of innovative treatment strategies. The purpose of the present study was therefore to review the FMS performance of children with ASD, with the aim of determining the extent of their impairments in these skills compared to typically developing children and children with other developmental disorders. In total, 24 studies involving 1,094 participants who were classified into two groups, i.e. very young children (between six months and six years of age) and school-age children (six to 12 years of age) were included in the review. All the included studies examined FMS using either product-oriented or process-oriented standardized movement assessment batteries, as these assessment batteries have been found to be highly reliable in identifying children with movement difficulties over a wide range of skills i.e. locomotor skills, object control skills and balance skills.

The results of the review showed that majority of the children with ASD demonstrated significant impairments in FMS that lasts throughout childhood. Compared to their typically developing peers, a larger number of children in the ASD group were found to have greater impairments across all the categories of FMS, even after controlling for IQ scores, indicating that cognitive abilities alone cannot explain movement skills difficulties among children with ASD (Hilton et al., 2007; Staples & Reid, 2010; Whyatt & Craig, 2012). Children with ASD were also found to have delayed developmental trajectories of FMS from an early age (Landa & Garrett-Mayer, 2006; Lloyd et al., 2013; MacDonald et al., 2014), with the delays becoming increasingly pronounced with age. School-age children (between nine and 12 years old) with ASD performed movement skills similar to typically developing children approximately half their chronological age (i.e. four to six years old) (Staples & Reid, 2010). This increase in movement delays with age is indicative of the slow development of FMS in children with ASD, which is potentially due to severe dysfunctions in cerebellar and basal ganglia circuitry of ASD children (Allen, Müller, & Courchesne, 2004; Mostofsky et al., 2009; Qiu, Adler, Crocetti, Miller, & Mostofsky, 2010). Other factors that may contribute to the slowing of the development of FMS are impairments in imitation and perceptual-motor skills which are inherent characteristics of ASD and play a pivotal role in learning FMS (Vanvuchelen, Roeyers, & De Weerdt, 2007).

Children with ASD also demonstrated significant impairments in overall FMS composite across all the clinical groups (Green et al., 2002; Hauck & Dewey, 2001; Van Waelvelde et al., 2010). These findings can be explained by the social symptomatology uniquely observed in ASD. For instance, children with ASD have poor interpersonal skills, which often results in them withdrawing from social interactions, including playing games and participating with their peers in activities that involve different fundamental movement

skills. This, in turn, may limit their opportunities to successfully practice these skills, thus preventing them from developing the respective FMS competencies (Attwood, 2008; Ming, Brimacombe, & Wagner, 2007).

Across the different FMS competencies, specific areas of impairment were observed in object control and locomotor skills (Green et al., 2002; Pan et al., 2009). Impairments in these competencies were also prevalent among the ASD group compared to their age-matched typically developing peers (Mache & Todd, 2016; Staples & Reid, 2010; Whyatt & Craig, 2012). These findings suggest that children with ASD have significant underlying difficulty in performing tasks that rely heavily on perceptual-action coupling strategies, such as ball catching (Haswell, Izawa, Dowell, Mostofsky, & Shadmehr, 2009; Izawa et al., 2012) and tasks that requires coordinated movements between arms and legs, such as jumping and leaping. The findings with respect to locomotor skills impairments are further supported by a recent review (Kindregan et al., 2015) that demonstrated marked variability in gait parameters such as increased step width, reduced step length, higher cadence (steps per minute) and reduced range of motion in children with ASD.

Within the ASD group, almost all the children regardless of their specific diagnosis (of autism, AS and PDD-NOS) demonstrated impairments in FMS compared to the normative sample. However, children at the severe end of the spectrum exhibited greater impairments in movement skills (Ghaziuddin & Butler, 1998; Iwanaga et al., 2000; Matson et al., 2010). These differences can be attributed to the lower levels of cognitive functioning in children with autism (Baird et al., 2006), which appears to result in decreased or delayed neural pruning during motor activity (Akshoomoff, Pierce, & Courchesne, 2002; Ming et al., 2007), thereby leading to severe movement impairments in this group as compared to children at the milder end of the spectrum.

Overall, these findings provide preliminary evidence suggesting that impairments in FMS are fairly prevalent in majority of children with ASD, although the severity of these impairments varies across the different FMS competencies. Moreover, these impairments are present by the time the child reaches preschool age and persist well into late childhood, which strongly suggests that clinicians should consider the evaluation of movement skills as a routine investigation in children with ASD. In addition, clinicians should also target movement skills especially object control and locomotor skills, as an important focus of early interventions. Movement-based interventions, in the form of play and physical activities, would not only improve FMS in children with ASD, but would also indirectly contribute to improving their socio-communication skills by providing them with opportunities for active involvement with other children.

5. Strengths and limitations

The present review contributes to our understanding of the prevalence of movement skills by showing that impairments in FMS are widespread in children with ASD, regardless of their cognitive abilities. Furthermore, it demonstrates that impairment on certain FMS competencies, such as object control and locomotor skills are more prominent in children with ASD, thus adding to our limited knowledge of the specific motor profiles of children with ASD.

The present review is however subject to several limitations that should be taken into consideration. Firstly, the movement assessment batteries that were used to measure FMS in children with ASD were designed primarily for typically developing children and may not provide a completely accurate representation of FMS impairments in children with ASD. For instance, the verbal method used in these assessment batteries to give task instructions makes them less acceptable to children with ASD, who have inherent difficulties in communication and social interactions. Future researchers are therefore recommended to incorporate and make use of visual aids when assessing movement skills competencies in children, in order to help them understand how the tasks are to be carried out. Secondly, our knowledge of the developmental patterns of movement skills in children with ASD comes mainly from studies that used cross-sectional research design. In future research, a longitudinal examination of the rate of FMS development in children with ASD across all its three components would therefore be valuable. Thirdly, the review included published studies only. Although an attempt was made to search for grey literature, this search was not comprehensive and may have resulted in the omission of relevant studies. Finally, the sample size in the majority of the studies was small, with most of the participants being male, which potentially jeopardizes the generalizability of the results.

6. Conclusion

The review demonstrated that children with ASD have significant and widespread impairments in fundamental movement skills compared to typically developing children and children with other developmental disorders on various standardized movement assessment batteries. Our present findings thus provide preliminary evidence suggesting that FMS have the potential to be an early diagnostic marker of ASD.

Ethics approval and consent to participate

Not applicable.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A

Product-Oriented Batteries

The Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1992; Henderson et al., 2007) is one of the most commonly used tests to detect delay or impairment in a child's movement skills development. The test has four different age bands between four and 12 years, making it suitable for preschool children. It assesses movement skills from three perspectives: manual dexterity skills, object control skills, and balance skills. The test has excellent test–retest reliability for three-year-old children (Brown & Lalor, 2009).

The Bruininks-Oseretsky Test of Motor Proficiency (2nd edition) (BOT-2) (Bruininks & Bruininks, 2005) is a norm-referenced test that identifies mild to moderate motor coordination deficits in individuals between four and 21 years of age. It has eight subtests. The first two assess fine motor precision and integration, while the other subtests assess object control, bilateral coordination, balance, running speed and agility, upper limb coordination, and strength. Although it is a proven test for assessing psychometric properties in children aged four years and older (Slater, Hillier, & Civetta, 2010), there is insufficient evidence of content validity, contrast validity, test–retest reliability, and interrater reliability for children under two years of age.

The Battelle Developmental Inventory (BDI) (BDI) (Newborg & Riverside Publishing Company, 2005; Newborg et al., 1984) is both a norm-referenced and a criterion-referenced test intended for the developmental assessment of children from birth to eight years of age in five domains: adaptive, personal-social, communication, motor, and cognitive. The motor domain measures gross, fine, and perceptual motor abilities.

The Bayley Scales of Infant Development (2nd edition) (BSID-2) (Bayley, 1993) is suitable for children from birth to 42 months old. The scale has three components i.e. the mental scale, the motor scale, and the behavior rating scale which all contribute to the final score. The motor scale assesses bodily control, muscle coordination, dynamic movement, and the finer manipulation skills of the hands and fingers.

The Mullen Scales of Early Learning (MSEL) (Mullen, 1989, 1995) is a developmental measure of cognitive development for infants and preschoolers from birth to the age of 68 months. The main areas assessed include gross motor, fine motor, visual reception, receptive language, and expressive language skills.

The Japanese version of the Miller Assessment for Preschoolers (JMAP) (Tsuchida et al., 1989) is a standardized developmental assessment intended for Japanese preschool children aged between 33 and 74 months. In addition to verbal and cognitive abilities, it also measures motor abilities.

Process-Oriented Batteries

The Test of Gross Motor Development (TGMD) (Ulrich, 1985, 2000, 2013) is a criterion-based test that assesses 10–12 fundamental movement skill tasks in children between the ages of three and 10 years, based on three to five performance criteria identified from motor development literature and consensus among content experts. These tasks are subsumed under the categories of locomotion and object control skills. In the locomotor category, tasks such as running, galloping, hopping, leaping, horizontal jumping, and sliding are assessed. The object control subtest consists of the two-handed striking of a stationary ball, stationary dribbling, catching, kicking, overhand throwing, and underhand rolling. Each task includes three to five performance criteria, and scoring is based on the presence or absence of each performance criterion. The reliability of TGMD-2 for children with ASD has not been established empirically, although for typically developing children it has a test–retest reliability of 0.88 for the locomotor subtest and 0.85 for object control (Ulrich, 2000).

The Peabody Developmental Motor Scales (PDMS) (PDMS) (Folio & Fewell, 1983, 2000) is a criterion-referenced and norm-referenced scale. It is highly sensitive in detecting motor skills deficits in children from birth to six years of age (Rosenbaum, Missiuna, & Johnson, 2004). It has six subtests i.e. four gross motor subtests (reflexes, stationary performance, locomotion, and object manipulation. and two fine motor subtests (grasping and visual-motor integration).

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