

Current Perspectives on Motor Functioning in Infants, Children, and Adults With Autism Spectrum Disorders

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Autism spectrum disorders (ASDs) are the most common pediatric diagnoses in the United States. In this perspective article, we propose that a diverse set of motor impairments are present in children and adults with ASDs. Specifically, we will discuss evidence related to gross motor, fine motor, postural control, and imitation/praxis impairments. Moreover, we propose that early motor delays within the first 2 years of life may contribute to the social impairments of children with ASDs; therefore, it is important to address motor impairments through timely assessments and effective interventions. Lastly, we acknowledge the limitations of the evidence currently available and suggest clinical implications for motor assessment and interventions in children with ASDs. In terms of assessment, we believe that comprehensive motor evaluations are warranted for children with ASDs and infants at risk for ASDs. In terms of interventions, there is an urgent need to develop novel embodied interventions grounded in movement and motor learning principles for children with autism.

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Autism spectrum disorders (ASDs) are characterized by a range of social and communication impairments, as well as repetitive behaviors.¹ These disorders comprise 3 diagnostic subcategories based on number and type of symptoms: autism, pervasive developmental disorder—not otherwise specified (PDD-NOS), and Asperger syndrome (see Figure and Appendix for detailed symptomatology).¹ Autism and PDD-NOS are distinguished by number of symptoms as defined by the *Diagnostic and Statistical Manual of Mental Disorders—Text Revision* (DSM-IV TR).¹ Asperger syndrome is defined by the presence of social impairment accompanied by repetitive and stereotyped patterns of behaviors in the absence of cognitive impairment or history of language delay.¹

Although social impairments are the defining feature of ASDs, motor functioning often is abnormal in one or more ways. This article aims to highlight and support our perspective that motor abnormalities seen in individuals with ASDs, if more widely recognized, may affect ASD interventions and eventual outcomes. Specifically, this perspective article will focus on 5 major issues: (1) types of motor impairments; (2) a comparison between motor impairments in ASDs and other pediatric diagnoses; (3) a theoretical viewpoint on how motor impairments may contribute to the social communication impairments of ASDs; (4) clinical and research implications of the current evidence, including our perspective on current motor assessments used by clinicians and the literature on motor interventions for individuals with ASDs, as well as suggestions for new intervention directions based on the available theoretical and empirical work; and (5) limitations of the current evidence on motor findings and assess-

ments and embodied interventions for ASDs.

Autism spectrum disorders, with a prevalence of 1 in 110 children, are the most common pediatric diagnoses in the United States, with 36,500 new cases per year and a total of 730,000 cases.² They are also one of the most costly disabilities, with up to \$3.2 million in lifetime costs for an individual and family and \$34.8 billion in societal costs for all families having individuals with ASDs.³ As a result, there is worldwide research and clinical interest in understanding the progression of ASD-related symptoms during the course of development and in creating novel autism interventions to improve outcomes. Given the presence of motor impairments, physical therapists are increasingly becoming part of the treatment team for children with ASDs.

Motor Impairments in People With ASDs Performance on Standardized Tests in School-Age Children and Adults With ASDs

Children, adolescents, and adults with ASDs display a range of measurable motor impairments on current standardized motor assessments (Tab. 1). Specifically, children and adults with ASDs ranging between 7 and 32 years of age have shown poor upper-limb coordination during visuo-motor and manual dexterity tasks and poor lower-limb coordination during tasks requiring balance, agility, and speed.⁴⁻⁷ These studies typically quantified performance using standardized measures such as the Bruininks-Oseretsky Test of Motor Proficiency⁸ or the Movement Assessment Battery for Children.⁹ Earlier studies reported motor functioning in children with ASDs as a function of their cognitive development, as assessed by IQ scores. One of the first studies demonstrated more severe motor impairments in

children and adolescents with ASDs with IQ scores below 75 compared with those with IQ scores above 75.⁴ In contrast, some studies identified greater motor impairment in children with Asperger syndrome than in those with autism.⁵⁻⁹ Yet, a more recent and comprehensive, large-sample study showed comparable motor impairments in children with ASDs without any cognitive delays (autism and Asperger syndrome), with both groups performing worse than peers who were developing typically on a standardized neuromotor examination involving activities of gait, balance, and coordination.¹⁰ Therefore, we propose a shift in how the literature reports motor impairments in ASDs: prior research primarily emphasized motor impairments in children with ASDs and cognitive delays, whereas recent studies have recognized motor impairments in children without cognitive delays as well.

Functional Activities in Children and Adults With ASDs

Using motion analyses, individuals with ASDs have been found to display atypical movement patterns during locomotion, reaching, and aiming.¹¹⁻¹⁵ Earlier reports suggested a “parkinsonian gait,” characterized by longer stance duration, shorter stride lengths, lack of a heel-toe pattern, and reduced upper-limb movement.¹¹ In contrast, recent reports identified features of “ataxic gait,” characterized by instability, as observed in reduced range of motion at the ankle and increased variability of stride lengths.¹² One report identified differences in reaching and aiming movements between individuals diagnosed with autism with IQ scores below and above 75.¹³ For example, children with autism were asked to reach and grasp objects of 2 different sizes that were placed at 2 different reaching distances. Both groups performed well; however, those children with IQs below 75

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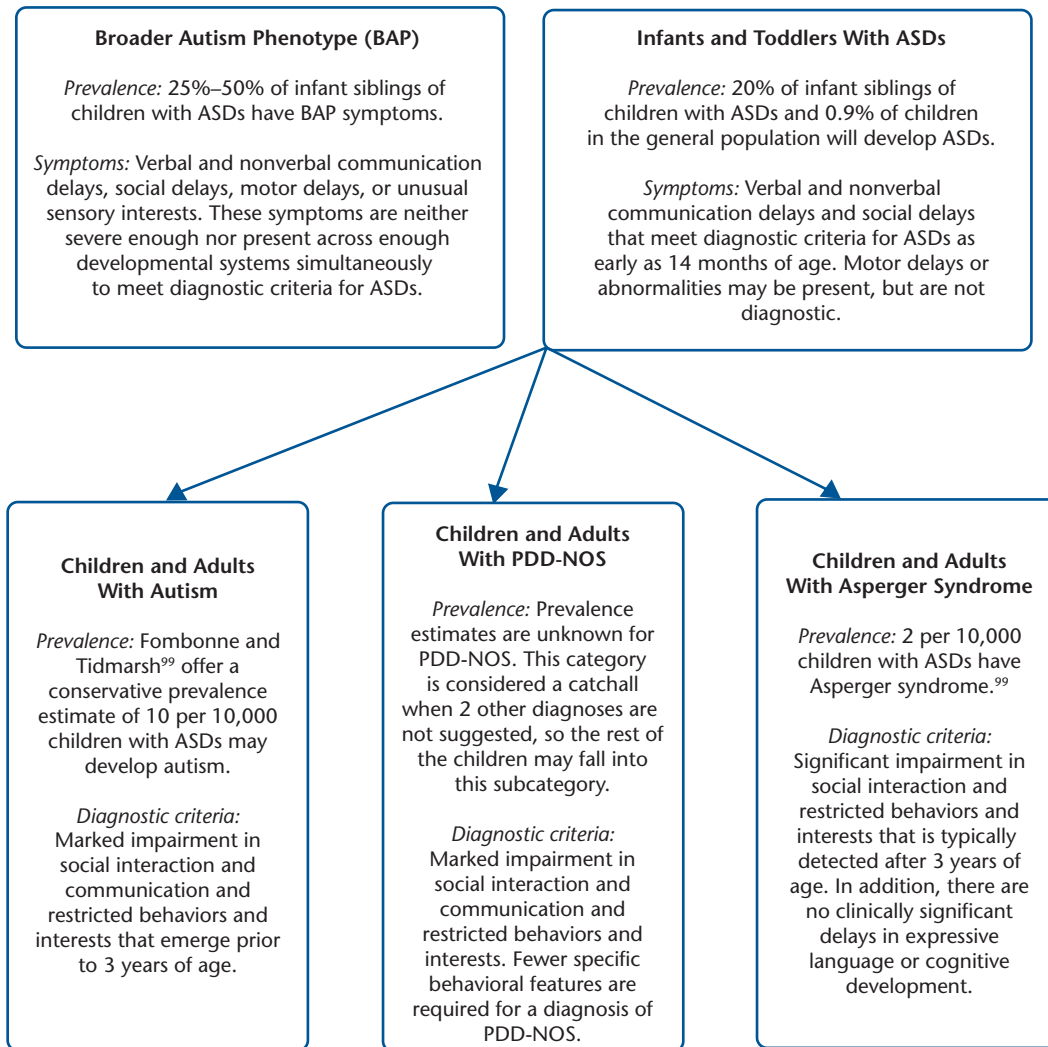


Figure.

Prevalence and key diagnostic impairments for the various subcategories of individuals with autism spectrum disorders (ASDs) and early symptoms in infants at risk for ASDs. PDD-NOS=pervasive developmental disorder–not otherwise specified.

performed slower reaches and began grasping later in the reach than those with IQs above 75.¹³ A recent analysis of aiming coordination of adults with autism with IQs ranging from 65 to 119, however, did not find IQ as a predictor of arm movement patterns.¹⁴ In addition, handwriting of children with ASDs without any cognitive delays is worse than that of age- and IQ-matched children who are developing typically and significantly correlated with their overall motor performance and not IQ levels.¹⁵ Together, these studies sup-

port the notion that motor impairments are commonly observed in individuals with ASDs and cannot solely be attributed to cognitive delays.

Early Motor Delays in Infants and Toddlers at Risk for ASDs

Given the aforementioned evidence that motor involvement is present in older children with ASDs, there is growing interest in using measures of motor development as markers for early detection in infants (birth–1 year of age) and toddlers (1–2 years

of age) who are more likely to develop ASDs than the general population.^{16–19} In addition to young children formally diagnosed with ASDs (termed “infants who later developed ASDs”), infant siblings of children already diagnosed with ASDs^{16,19,20} are a population of interest in studies of early ASD diagnosis and intervention because they are 20 times more at risk to develop ASDs than the general population.^{19,21} The risk for siblings of children already diagnosed with ASDs to develop ASDs was previously reported to be

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Table 1.

Motor Impairments in Children and Adults With Autism and Motor Delays in Infants and Toddlers at Risk for Autism Spectrum Disorders (ASDs)

Motor Impairments or Delays	Impairments in School-Aged Children and Adults With ASDs	Delays in Infants at Risk for ASD and in Toddlers and Preschoolers With ASDs
Gross motor coordination	Poor upper-limb and lower-limb coordination, including bilateral coordination and visuomotor coordination	Gross motor delays in supine, prone, sitting skills are present in the first year of life. Delayed onset of walking may be present in the second year of life. Gross motor delays are also present in preschoolers recently diagnosed with ASDs.
Fine motor coordination	Poor fine motor coordination such as in performance on manual dexterity tasks (eg, Purdue Pegboard Test)	Reaching and grasping appear to be delayed in infants at risk for ASDs. Fine motor delays persist in the second and third years of life.
Motor stereotypies	Motor stereotypies are common in older children and adults with ASDs.	Motor stereotypies such as repetitive banging of objects or unusual sensory exploration may appear in the first year of life, but most often emerge in the second year of life.
Postural	Feedforward and feedback control of posture are affected in children and adults with ASDs. Overall, deficient postural control persists in adults with ASDs.	Delays are evident in postures such as rolling and sitting. There are suggestions of unusual postures held for brief to long periods in infants who later developed ASDs.
Imitation and praxis	Imitation impairments are present during postural, gestural, and oral imitation. Performance of complex movement sequences is poor during imitation, on verbal command, and during tool use, suggesting generalized dyspraxia not specific to imitation.	

10%²¹; however, most recently prospective studies cite rates of 20% (Figure).¹⁶ There is an additional risk of 25% to 50% for developing milder impairments such as language, social, and sensorimotor delays, which together define a broader autism phenotype.^{16,19,20} In contrast, the risk for developing ASDs in the general population is only 0.9%.¹⁹

Gross Motor Delays in Infants and Toddlers at Risk for ASDs

Earlier reports on motor impairments in infants at risk for ASDs were based on retrospective data such as home videos of first-year birthdays or parent reports.^{17,18,22-25} These reports suggested that infants who later developed ASDs showed a range of gross motor problems, including delays in motor milestones, abnormal muscle tone (velocity-dependent resistance to stretch), abnormal reflexes, and postural asymmetries.^{17,18,22-25} These infants also showed jitteriness and irritability or reduced motor activity, excessive stereotypical object play,

and excessive time looking at nearby objects within the first year of life. These infants also had social impairments such as reduced eye contact, reduced smiling, and difficulty responding to name prompts toward the end of the first year.²²⁻²⁵ Three recent retrospective studies have identified motor delays during infancy in children with ASDs.^{17,24,25} These studies included a comparison group of infants with developmental delays inclusive of children with global developmental delays of unknown or heterogeneous etiologies.^{17,24,25} Motor delays, including the acquisition of supine, prone, and sitting skills, in children with ASDs were comparable to or greater than motor delays in infants with developmental delays.^{17,24,25} A more detailed retrospective video analysis of supine postures revealed greater asymmetries during both static positions and movements in the infants who later developed ASDs compared with infants who were developmentally delayed and infants who were developing typically.²⁴

Motor delays have also been observed in the second and third years of life in young children with ASDs. Toward the second year of life, motor delays may include delayed onset of walking.^{16,25} Observational gait analysis of retrospective data from young children who later developed ASDs identified a lack of heel-toe pattern, a lack of reciprocal arm movements, and a more waddling gait compared with age-matched infants who were developing typically.²⁵ It is important to note that retrospective video data and parent reports, such as those cited above, have potential limitations such as lack of standardized methods and recall bias.¹⁹ These limitations can be overcome in prospective studies involving siblings of children already diagnosed with ASDs or by comparing and following the development of toddlers recently diagnosed with ASDs. Although, few prospective studies have described the developmental trajectories of motor development in siblings of children already diagnosed with ASDs, each of these

studies found that these siblings who later developed ASDs or language delays were likely to exhibit motor delays at 6, 12, 14, and 18 months.^{16,20}

Fine Motor Delays in Infants and Toddlers at Risk for ASDs

Fine motor delays have also been reported in siblings of children already diagnosed with ASDs and in toddlers diagnosed with ASDs.^{16,20} For example, a prospective study with a small sample using the Mullen Scales of Early Learning²⁶ identified fine motor delays as early as 6 months of age in siblings of children already diagnosed with ASDs who later developed language delays.¹⁶ Infants who developed ASDs by the end of their second year showed gross and fine motor delays by 14 months.¹⁶

A well-designed retrospective study with a large sample also identified fine motor delays in infants later diagnosed with ASDs.²⁷ These delays were observed in a range of behaviors over the first and second years of life, including reaching, clapping, pointing, playing with blocks and puzzles, and turning doorknobs.²⁷ Importantly, it was found that these manual motor delays in infancy correlated with speech delays.²⁷ Similarly, a prospective study with a smaller sample showed differences in the onset of rhythmic arm movements and babbling in siblings of children already diagnosed with ASDs (outcome diagnosis unknown) compared with age-matched children who were developing typically.²⁸ Specifically, at 9 to 10 months of age, infants who were developing typically peaked in both their babbling and the frequency of rhythmic arm movements such as banging. However, such co-occurrence was not observed in siblings of children already diagnosed with ASDs at this same age.²⁸

Lastly, toddlers and preschoolers recently diagnosed with ASDs displayed significant fine motor delays that were comparable to their gross motor delays, as reflected in the Peabody Developmental Motor Scales.²⁹ This finding suggests that both fine and gross motor skills are equally affected in many children with ASDs.²⁹ Given the link between movement and communication,³⁰ we propose that these early motor impairments contribute to the later development of gestural and verbal communication difficulties, a hallmark of ASDs. Therefore, we propose that upon detecting gross and fine motor impairments during early childhood, language and social development should be screened, and an autism-specific screening is warranted.

Motor Stereotypies in Infants and Children With ASDs

Pediatric clinicians commonly assess gross and fine motor milestones. Yet, spontaneous movements, particularly those that can occur without a clear external stimulus, may not be a standard area of assessment. These include repetitive or stereotypical spontaneous movements such as rocking, arm flapping, or finger flicking, which are common in older children with autism.³¹ However, children who are on the autism spectrum and display fewer symptoms, as in PDD-NOS, show fewer repetitive behaviors compared with those with autism.³² Similarly, repetitive behaviors are less obvious in infant siblings of children already diagnosed with ASDs because a wide range of these movements are displayed by infants who are developing typically.³³

Using Thelen's taxonomy of rhythmic leg, arm, and body movements,³⁴ one study compared motor stereotypies at 12 and 18 months among siblings of children already diagnosed with ASDs who later developed ASDs, nondiagnosed sib-

lings of children diagnosed with ASDs, and toddlers who were developing typically.³³ Overall, there were no differences in frequencies of various limb and body movements except for more arm waving and, in some cases, more "hands to ear" postures in siblings of children diagnosed with ASDs who later developed ASDs.³³ In contrast, toddlers who later developed autism showed more atypical hand and finger movements and more stereotypical object play, such as excessive banging or preoccupation with spinning objects or with part of an object, compared with toddlers with milder forms of ASDs such as PDD-NOS.^{35,36}

Taken together, we propose that motor stereotypies in infants and toddlers with ASDs are not as obvious in the first year of life, except when they may be observed for prolonged durations, and clearly differ from those of their peers who are developing typically. Consistent stereotypic behaviors are more likely to emerge in the second year of life and could serve as "red flags" for ASDs.

Sensory Processing Deficits in Infants and Children With ASDs

Sensory modulation disorders (SMDs) are frequently reported in children and adults with ASDs and may directly affect their motor performance.³⁷ *Sensory modulation disorders* are defined as difficulties in regulating and organizing the nature and intensity of behaviors in response to specific domains of sensory input (tactile, olfactory, visual, auditory, proprioceptive, and vestibular).³⁸ Three categories of SMDs have been described in young and older children with ASDs: (1) "under-responsive" or slow to respond to sensory input (eg, failure to respond to name or react to pain), (2) "over-responsive" or exaggerated or prolonged response to sensory input (eg, covers ears to loud sounds or troubled by background noise), and

(3) “sensation seeking” or craving sensory input for extended periods (eg, performing stereotypical movements such as body rocking and arm flapping).^{18,39,40} These behavioral responses usually are reported by parents via questionnaires such as the Short Sensory Profile.⁴¹ Moreover, the severity of sensory modulation impairments appears to directly correlate with autism severity, level of functioning, and severity of social communication impairment.^{38,42}

Recent studies suggest that sensory modulation impairments of children with ASDs may involve mixed patterns of sensory processing, with varying levels of responsiveness in different sensory domains. Specifically, 3 subgroups of sensory modulation have been reported in children with ASDs between 3 and 10 years of age: (1) inattention/excessive attention, (2) atypical tactile/smell sensitivity, and (3) atypical movement sensitivity/low energy and weak motor responses.⁴² These subgroups appear to include both underresponsive and overresponsive categories of children with ASDs within specific sensory domains.⁴² The third subgroup is particularly important to physical therapists. Children with ASDs who have atypical movement sensitivity usually are overresponsive to proprioceptive and vestibular input, whereas children with low energy and weak motor responses have poor fine and gross motor skills.^{41,42} Therefore, children who perform poorly on the movement sensitivity/low energy sections of the sensory profile may be at a greater risk for motor delays and long-term motor impairments. We propose that both underresponsiveness and overresponsiveness to different sensory inputs may coexist in children with ASDs. Moreover, specific sensory modulation impairments may directly affect motor coordination and postural control of children with ASDs.

Postural Control Impairments in School-Age Children and Adults With ASDs

A few studies have examined postural control of children and adults with ASDs, and each identified some level of postural impairment. Impairments in adaptive postural responses (ie, postural muscle activity occurring in response to a sensory perturbation) to changing sensory input^{43,44} and in anticipatory postural responses (ie, postural muscle activity occurring prior to a voluntary movement)⁴⁵ have been identified in individuals with ASDs. The most comprehensive study compared postural responses of children and adults with autism with those of age- and IQ-matched individuals, aged 5 to 42 years, who were healthy using a somatosensory and visual perturbation paradigm.⁴⁴ This cross-sectional study showed that individuals with autism who were 12 years or older displayed adaptive responses in postural control, but even the oldest adults did not display levels comparable to those of individuals who were healthy. In addition, individuals with autism displayed poor postural stability when somatosensory or visual input was removed or altered, which the authors interpreted as impairments in multimodality sensory integration. A study that quantified anticipatory postural control showed that older children with autism were delayed in their responses and relied more on feedback rather than feedforward control during a bimanual, load-lifting task.⁴⁵ Collectively, these studies suggest that children and adults with autism may have impairments of adaptive or feedback-dependent mechanisms as well as anticipatory or feedforward-dependent mechanisms of postural control.

Postural Delays in Infants and Toddlers at Risk for ASDs

Postural delays are also evident in young infants who later developed

ASDs, as mentioned briefly in the previous section.²³ A recent prospective study showed that siblings of children already diagnosed with ASDs spent less time in advanced postures used in sitting and crawling and more time in less-advanced postures such as prone play than age-matched infants who were developing typically.⁴⁶ Our own data comparing siblings of children already diagnosed with ASDs and a control group of infants who were developing typically, using the Alberta Infant Motor Scale at 3 and 6 months, suggest that siblings of children already diagnosed with ASDs have poor postural control, as reflected in lack of head holding and rolling at 3 months and lack of pivoting and side-prop postures at 6 months.⁴⁷ Overall, postural delays and impairments have been observed, yet are understudied in older children and adults with ASDs as well as infants at risk for ASDs.

Imitation and Praxis Impairments in Children and Adults With ASDs

In the second year of life, motor skills are used in increasingly complex ways in socialization and communication. Children often learn skills by observing and imitating adults during interactive games and play.⁴⁸ For example, during imitation, the child must attend to another person's movements and produce a response that is timed appropriately and spatially correct for the other person to consider the response to be truly reciprocal, coincident, and thus engaging to sustain the interaction. Not surprisingly, impairments in imitation distinguish children with ASDs from other children who are developmentally delayed and children who are developing typically as early as 2 years of age.⁴⁹ Moreover, these impairments persist into adulthood⁵⁰ and are connected to later impairments. For example, young children with ASDs who had imitation impair-

ments went on to have language delays in the preschool years.⁵¹

Some common imitation impairments are impaired orofacial, manual, and postural imitation; greater reversal errors (eg, while copying a palm facing forward, a child with ASD places the palm facing toward his or her body); and body-part-for-tool errors when performing actions on objects.⁵² An example of a body-part-for-tool error would be where a child uses his or her hand as a toothbrush versus demonstrating a grasp of the toothbrush when asked to show how he or she uses a toothbrush. Some authors⁵³ have proposed that imitation impairments are part of a larger deficit in performing complex movement sequences termed *dyspraxia*, which, in turn, is attributed to poor motor planning and sequencing. Taken together, imitation impairments in older children and adults are considered autism-specific, as they are significant enough to distinguish individuals with ASDs from other groups with developmental delays.

Comparing Motor Impairments Between ASDs and Other Pediatric Diagnoses

Limitations in daily activities such as locomotion and reaching could be due to common motor impairments such as abnormal muscle tone, muscle weakness, incoordination during fine and gross motor activities, poor balance, and involuntary movements or to secondary impairments such as muscle contractures.⁵⁴ The few studies examining motor impairments in children with ASDs suggest the presence of low muscle tone,²² significant motor incoordination,⁴⁻⁷ poor balance,^{4-7,43-45} imitation and praxis impairments,⁴⁹⁻⁵³ and the presence of motor stereotypies such as arm flapping or preoccupation with objects.^{32,35,36} There are suggestions

of abnormal movement patterns such as toe-walking in children with ASDs; however, there are no systematic studies on whether secondary muscle laxity or contractures develop in children with ASDs.⁵⁵

Other diagnoses commonly encountered by pediatric physical therapists, such as certain forms of cerebral palsy,⁵⁶ Down syndrome,^{57,58} developmental coordination disorders (DCDs),^{59,60} and spina bifida,⁶¹ also may be present with the aforementioned impairments such as tonal abnormalities, incoordination, or balance impairments. In addition, motor stereotypies are observed in children with Down syndrome,⁶² and specific types of involuntary movements such as choreoathetosis or tremors are observed in children with athetoid and ataxic cerebral palsy.⁵⁴ However, some studies^{63,64} suggest that impaired imitation and praxis appear to distinguish school-age children with ASDs from age-matched children with attention-deficit/hyperactivity disorder and DCDs.

The issue of motor impairments such as comorbidity (ie, an impairment in addition to the primary diagnostic impairments) often is described in various psychiatric disorders, including ASDs, attention-deficit/hyperactivity disorder, behavioral disorders such as oppositional defiant disorder, and anxiety disorders.⁶⁵⁻⁶⁸ Several studies⁶⁵⁻⁶⁸ have demonstrated significant motor impairments in balance and fine and gross motor coordination, as well as low levels of physical fitness, in children with psychopathologies indicative of common mechanisms of neurological dysfunction. Moreover, these studies emphasize the need for assessment and management of motor problems in children diagnosed with psychopathologies.⁶³⁻⁶⁸ Although there is some evidence that imitation and praxis impair-

ments may be autism-specific, we propose that the majority of the motor impairments observed in children with ASDs also may be seen in children with other movement disorders and psychiatric disorders. Thus, there is a need to compare motor impairments among various pediatric diagnoses to better understand whether there is a motor profile specific to autism and to determine whether novel motor assessments need to be developed. Lastly, motor impairments are highly prevalent in pediatric psychiatric disorders and must be addressed in clinical assessment and intervention.

Theories and Recent Evidence for Motor-Social Links in ASDs

To fully engage in social interaction, an individual requires a full repertoire of movement behaviors for use in communication and for understanding the communicative nature of others' movements. We propose that understanding the limitations in the planning and coordination of movement and posture is fundamental to a comprehensive understanding of the qualitative social impairment of ASDs. More specifically, we propose that a developmentally important linkage exists between motor and social communication impairments in autism. There is emerging empirical support for such a linkage. For example, motor delays at 18 months of age are highly predictive of ASDs at 3 years of age in toddlers at risk for ASDs.⁶⁹ Similarly, better motor performance in 2-year-old children newly diagnosed with ASDs significantly correlates with better future outcomes at 4 years of age.⁷⁰ Together, these empirical findings support the link between motor and social communication in autism and provide support for the hopeful hypothesis that enhancing the motor performance of children with ASDs

may facilitate their future motor and social communication development.

How Might Motor Impairments Contribute to Social Impairments in ASDs?

Our proposal that motor and social impairments in ASD are linked has its grounding in an ecological, dynamical systems perspective. This perspective emphasizes the multi-factor, cyclic nature of the development of perception-action-cognition and the critical role of daily exploratory interactions of a child and his or her world.⁷¹ A child requires a full movement repertoire of functional actions to engage in social interactions. Yet, many children with ASDs exhibit qualitative or quantitative abnormalities in one or more aspects of movement detected as early as infancy. Typical coordination and mobility are critical to begin and continue social interactions throughout the day. A child's poor coordination and slowed movement are linked to poor social participation and increased anxiety during playtime in the preschool and kindergarten years.⁷²⁻⁷⁴ Friendships and social connections are made through shared experiences among children during the several hours of playtime. Viewed this way, it is not surprising that motor clumsiness will result in missed opportunities and reduced engagement with coordinated and agile peers, which, in turn, limits the initiation and maintenance of friendships and may contribute to delayed social skills and long-term social impairments.⁷⁵⁻⁷⁷ Children with motor disorders such as cerebral palsy and DCDs have significant difficulties developing social and peer relationships.^{75,76} Moreover, difficulties with social adjustment in children are also linked to their emotional as well as behavioral problems.^{72,75}

A more specific example to autism is how slowed or uncoordinated head

and arm movements may limit effective and timely head turning, reaching, pointing, giving, and showing that are key components of initiation and response to the social overtures of others, also known as *joint attention*.⁷⁸ It is important to point out that coordinated movement is required to fully perceive the world, so actions are not only enabling children to perform social communicative acts but also improve their ability to receive perceptual information from their surroundings.⁷⁹ For example, the emergence of locomotion is a causal factor across a host of developmental areas, including depth and distance perception and object perception such as size and shape constancy.^{79,80} Locomotor experiences are known to directly facilitate social communication behaviors such as gestural communication and object sharing with caregivers.⁸¹ In summary, we propose that basic perceptuo-motor impairments present in infancy and early childhood significantly contribute to the motor and social communication impairments observed in older children and adults with autism. We are not proposing that social impairments in autism are solely anchored to motor impairments. Rather, our proposal is that early in life, when social engagement is first emerging, motor limitations may impede social development. Therefore, early motor delays, in particular, must be addressed through motor interventions not just for enhancing motor development, but also for enhancing social development.

Implications for Clinicians Assessment

Based on the literature reviewed above, we propose that comprehensive motor evaluations are warranted for children with autism, regardless of age, and for infants at risk for ASDs. Children with autism may have basic fine and gross motor impairments or more complex imita-

tion and planning impairments. These aspects of development are an important focus of physical therapy assessments, and physical therapists often address such abnormalities in their intervention practices. Infants at risk for ASDs may not always have motor delays within the first year. For example, delayed onset of walking may be the first delayed motor milestone in some toddlers at risk for ASDs. Thus, we propose that clinicians continue to perform follow-ups of infants at risk for ASDs, particularly infant siblings of children with ASDs, even if motor delays are not observed within the first year. Infants who have a family history of ASDs and are being evaluated as a result of parental or professional concerns must be closely monitored to detect and address even minor motor delays, especially if they coexist with other minor communication delays such as delayed emergence of babbling or sensory-perceptual impairments such as difficulty shifting attention or reduced attention to social cues. Finally, when a child with ASD is recommended for early intervention, the multisystem nature of autism calls for an interdisciplinary team approach wherein educators, psychologists, speech-language therapists, occupational therapists, and physical therapists work together with families to screen, assess, intervene, and prevent further progression of autism symptoms early in life.

Valid and reliable standardized motor assessments that have been reported in the available literature pertaining to ASDs include the Bruininks-Oseretsky Test of Motor Performance⁸ and the Movement Assessment Battery for Children⁹ (Tab. 2). Imitation and praxis can be measured using the Modified Florida Apraxia Battery⁵² and the Sensory Integration and Praxis Test.⁸² Although motor impairments have been observed in children with ASDs

of all cognitive levels, one clear limitation of all motor assessments is that, in children with cognitive and language impairments, we are unable to discern whether poor motor performance is reflective of primary motor impairment or compromised by cognitive or language issues leading to poor comprehension of what was being asked. Therefore, there is a clear need to further develop observational motor measures during functional activities that address this limitation. The Autism Observation Schedule for Infants^{69,83} is the only autism-specific measure available to assess motor behaviors in infants. The Autism Observation Schedule for Infants is considered a reliable measure of early identification of autism-related abnormalities during the first 2 years of life.⁸³ Overall, physical therapists have a significant role to play during assessment of a child with ASD, and there is a need to further develop comprehensive, reliable measures for evaluating imitation and praxis performance as well as overall functional performance of children with ASDs.

Treatment

Even though there is sufficient evidence that motor impairments are present in infants and children with ASDs, we know of no major studies that have quantified the effects of motor interventions on motor and social communication outcomes of children with autism. Most autism interventions focus on enhancing the social, communication, cognitive, and preacademic skills of children with ASDs using contemporary and traditional applied behavioral analysis approaches, which, in turn, are based on principles of operant conditioning and learning.⁸⁴ Moreover, these interventions tend to be highly individualized due to significant variations in impairment across the autism spectrum.⁸⁴ Our infancy work suggests that associative forms of learning are intact in infants at risk

Table 2.

Reliability and Validity Data on Motor Assessments for Autism Spectrum Disorders (ASDs)

Motor Assessments	
For Young and Older Children	For Infants and Toddlers
Movement Assessment Battery for Children Concurrent validity with Bruininks-Oseretsky Test of Motor Proficiency=.76 Interrater reliability=.96 Test-retest reliability=.77 ¹⁰⁰	Gross and fine motor subtests of Mullen Scales of Early Learning Validity=.5 or higher Reliability=.65 or higher ²⁶
Bruininks-Oseretsky Test of Motor Proficiency Concurrent validity with Movement Assessment Battery for Children=.88 Reliability=.90 ¹⁰⁰	Alberta Infant Motor Scale Concurrent validity with Peabody Motor Developmental Scales, second edition>.9 Interrater reliability=.99 Test-retest reliability=.99 ¹⁰¹
Peabody Motor Developmental Scales, second edition Concurrent validity with Bayley Scales of Infant Development: high to very high Test-retest reliability=.73-.89 across subtests ¹⁰²	
	Autism Observational Schedule for Infants has a motor control component that predicts ASDs at 3 years of age ^{69,83} Interrater reliability=.7-.9 Test-retest reliability=.7
Praxis and Imitation Batteries	
Modified Florida Apraxia Battery Interrater reliability=.85-.95 ⁵²	
Sensory Integration and Praxis Testing Concurrent validity=.46-.71 for some subtests Interrater reliability=moderate to high ⁸²	

for ASDs and could be used to facilitate relevant social and motor behaviors.⁸⁵ For example, cause-and-effect play with toys often is used with preterm infants⁸⁶ and has the potential to facilitate visual, movement, verbal, and affective exploration in infants at risk for ASDs. Some other approaches, such as FLOOR-TIME⁸⁷ and sensory integration training, implement some aspects of motor intervention⁸⁸; however, there is no clear evidence to support the efficacy of these approaches.⁸⁴

We propose that motor learning principles could be applied to ASD interventions.⁵⁴ Intervention ideas can be broadly divided into ideas for practice, feedback, and types of motor skills. In terms of practice, evidence suggests that older children with ASDs have the ability to learn simpler motor skills in a procedural or implicit manner (ie, using a learning-by-doing approach).^{89,90} In

contrast, individuals with ASDs may have a difficult time learning complex, multistep motor skills.⁹¹ Therefore, if a child has difficulty improving motor performance despite continued practice or repetitions, highly explicit forms of guidance such as visual modeling or physical guidance (ie, hand-on-hand instruction), along with brief verbal explanation of each step within the entire activity, may be helpful. Evidence also suggests that children with ASDs have difficulty understanding movement goals.⁹² Therefore, it is important to emphasize the end goal within any task (eg, one could provide immediate visual or verbal feedback when a goal is achieved). Additionally, when goals are achieved, previously defined rewards such as stickers or small toys could be offered to the child, based on the applied behavioral analysis approach.

Children with ASDs may have difficulty with perceptual processing; therefore, the type of feedback provided may be important when teaching motor skills. It is unclear whether children with ASDs show a strong preference for using visual or proprioceptive feedback.⁹³⁻⁹⁵ Recent data suggest that individuals with ASDs have the ability to use both proprioceptive and visual feedback to improve their coordinated arm movements; however, they took longer to process visual information compared with proprioceptive information.⁹⁵ These results suggest that proprioceptive feedback such as physically guiding the child through the action sequence may better assist in improving motor skills compared with visual feedback. However, if visual feedback is used, clinicians can choose to provide models using clear 2-dimensional visual maps of the steps involved or input from technologies such as computerized video feedback.⁹³

We propose that clinicians must capitalize on the social interactions that will occur between themselves and the children during therapy activities to create a rich context for stimulating social engagement. These motor activities must be developmentally appropriate and tailored to the functional needs of the child and family to facilitate generalization into daily life. Based on the variety of motor delays present, motor activities utilized in intervention could target fine motor and gross motor skills, balance skills, imitation skills, postural skills, and joint action during group play with other children, 2 or more at a time, such as “follow the leader” games. Examples of autism interventions that implement principles of joint action are music-based interventions such as creative music therapy. Although music-based interventions look promising due to the embodied nature of the social interactions offered, there currently is

limited evidence to support this approach.⁹⁶

A group of researchers at the forefront of early detection and management of ASDs comprise the Infant Sibling Research Consortium.⁹⁷ The recommendations made by the consortium confirm the lack of evidence for autism interventions during infancy.⁹⁷ As clinical researchers, they recommend the use of caregiver-facilitated, reciprocal social play contexts, particularly infant-initiated social interactions that require the child to actively engage with the caregiver. They recommend facilitating not only the social communication systems but also the motor systems.⁹⁷ Moreover, they advocate individualized interventions based on the delays observed in the infant. Toward the end of the first year, joint attention and pretend play using appropriate objects could be encouraged.⁹⁷

Given these recommendations, we propose a multisystem approach to autism intervention during infancy wherein caregiver handling and interactions should be used to facilitate both perceptuo-motor and social communication development. Infants at risk for ASDs could receive a variety of social, object-based, or postural experiences that facilitate general and specific movement patterns, positive affect, and verbalizations. In the first half year of life, social cues could be provided through verbal reinforcement as well as physical handling of the infant.⁸⁶ Similarly, object-based cues could be provided by cause-and-effect toys.^{86,98} Specifically, parents could encourage hands and feet reaching by offering objects near the infant’s arms or legs.

As stated earlier, infants at risk for ASDs have intact associative learning, which could be used to facilitate age-appropriate, perceptuo-motor

and social communication development. As infants grow into the second half of the first year of life, it is important to encourage age-appropriate locomotor and object exploration skills. During object-based interactions, caregivers should incorporate triadic contexts wherein relevant social behaviors such as joint attention (ie, sharing of object play with caregivers) are encouraged. Postural experiences could be provided by passively placing or actively moving the child within the postures that appear to be delayed. Finally, we acknowledge that the various treatment ideas proposed in this section are our perspectives on how physical therapists could offer embodied, multisystem interventions that address both motor and social communication development. The majority of these ideas are based either on basic motor control studies or treatment studies in other at-risk populations or on anecdotal evidence from clinicians on successful treatment strategies for children with ASDs.

Limitations and Future Directions for Research

Based on the above theoretical and empirical work, we believe that the current literature has significant limitations. First, there is lack of substantial evidence on *how* motor impairments are associated with social communication impairments in children with autism. Although we identified a few studies that link motor and social development in autism, there is a clear need to further examine this question. Second, there is limited information on the pattern of onset, progression, nature, and severity of motor impairments in ASDs within the first 3 years of life. Third, we know little about whether and how motor impairments vary in nature and severity across the different diagnostic subcategories of ASDs and how they differ from other pediatric diagnoses.

Fourth, the lack of evidence on how motor interventions affect the future motor and social communication functions of children and adults with autism is a significant research gap. Together, these questions open numerous avenues of inquiry for clinical researchers in the physical therapy profession.

Conclusions

In this perspective article, we provide evidence that motor behaviors are qualitatively and quantitatively different in infants, toddlers, and school-aged children with ASDs compared with those without autism. Significant impairments in motor coordination, postural control, imitation, and praxis are present in individuals with ASDs. We also provide evidence that motor delays are present in infants and toddlers who later develop ASDs along with recent findings in infant siblings of children with ASDs. Finally, we provide empirical support for a link between motor and social impairments in individuals with ASDs and general and specific implications for physical therapy clinicians and researchers. Although several studies have confirmed the presence of motor impairments in people with ASDs, substantial research focused on motor functioning in people with ASDs is needed. We are hopeful that future clinical trials to improve motor functioning may contribute to improved overall outcomes for children with this chronic developmental disability.

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Appendix.

Definitions and Symptoms of Various Categories Under Autism Spectrum Disorders Based on the American Psychiatric Association's *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR)*¹

1. *Autism* is characterized by the presence of markedly abnormal or impaired development in social interaction and communication and a markedly restricted repertoire of activities and interests. The manifestations of this disorder emerge prior to 3 years of age in the domains of social behaviors, communication, or pretend play. The number and severity of symptom manifestation vary greatly from child to child. Qualitative social impairments mainly include impairments in nonverbal behaviors such as gaze modulation, facial expressions, body postures, and gestures used during social interactions. Failure to develop peer relationships, lack of spontaneous sharing of interests and enjoyment, and lack of social or emotional reciprocity are also characteristics of autism. Communication impairments include a delay in or lack of spoken language, impaired ability to initiate or sustain a conversation with others, use of repetitive or idiosyncratic language, and a lack of spontaneous pretend play or imitative play. Restricted repetitive and stereotyped behaviors and interests include atypical preoccupation with one or more stereotyped patterns of interest, inflexible adherence to routines and rituals, stereotypic and repetitive motor mannerisms, and persistent preoccupation with parts of objects. The entire range of IQ is represented in children with autism; therefore, the level of functioning varies from one child to another.
2. *Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS)* is defined by the same characteristics as those listed above for autism, but is distinguished from autism by having fewer of these symptoms. The IQ range for children with PDD-NOS has not been specified in the *Diagnostic and Statistical Manual of Mental Disorders-Text Revision (DSM-IV-TR)*, so all levels of IQ and functioning may be represented.
3. *Asperger syndrome* is characterized by a significant and sustained impairment in social interaction and the presence of restricted, repetitive patterns of behaviors and interests. Although qualitative aspects of communication may be impaired, individuals with Asperger syndrome exhibit no clinically significant delays in acquisition of expressive language. In addition, there are no clinically significant delays in cognitive development or in the development of age-appropriate self-help skills or adaptive behaviors in childhood.