Assessment of Fine and Gross Motor Skills in Children

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Motor skills refer to the movement and coordination of one's muscles and body (Haibach-Beach, Reid, & Collier, 2011). Motor skills are typically divided into gross and fine motor abilities. Gross motor skills require coordination of an individual's arms, legs, and other large body parts for actions such as running, jumping, and throwing (Haibach-Beach, Reid, & Collier, 2011). Because these skills incorporate larger body parts and movements, the development of gross motor skills is necessary for proprioception, core stabilization, and body control (Piek, Dawson, Smith, & Gasson, 2008). Fine motor skills require coordination of smaller movements between the fingers, hands, and feet for actions such as picking up and grasping small objects (e.g., pincer grasp; Piek, Dawson, Smith, & Gasson, 2008). These actions involve dexterity in order to manipulate smaller movements and objects. Development of various gross and fine motor skills begins in infancy, and throughout childhood, individuals experience tremendous physical and developmental growth that typically progresses in a predictable sequence (Gerber, Wilks, & Erdie-Lalena, 2010); as such, tracking of developmental milestones allows for assessment of a child's developmental functioning, and monitoring of motor skills development in children is important for identifying children who may be at risk for various developmental delays (Gerber, Wilks, & Erdie-Lalena, 2010; Ghassabian et al., 2016).

The achievement of motor milestones is critical to overall development in children because as the child ages and progresses in motor development (e.g., crawling to walking), they are increasingly able to explore and interact with their environment (Gibson, 1988; Oudgenoeg-Paz, Mulder, Jongmans, van der Ham, & Van der Stigchel, 2017). This exploration of the environment provides the child with learning opportunities to develop cognitive, language, and social skills (Alcock & Krawczyk, 2010; Ghassabian et al., 2016; Gibson, 1988; Hitzert, Roze, Van Braeckel, & Bos, 2014; Houwen, van der Putten, & Vlaskamp, 2014; Piek, Dawson, Smith, & Gasson, 2008). As the child encounters novel stimuli in the environment, they are able to develop language (e.g., learning new words to label items in the setting), communicate with others, and develop social skills, as well as cognitive skills such as problem solving (Alcock & Krawczyk, 2010; Clearfield, 2011; Leonard & Hill, 2014; Walle & Campos, 2014).

Because motor skills emerge earlier in development, they are typically most noticeable by

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J. L. Matson (ed.), *Handbook of Childhood Psychopathology and Developmental Disabilities Assessment*, Autism and Child Psychopathology Series,
https://doi.org/10.1007/978-3-319-93542-3_25

parents and caregivers (Piek, Dawson, Smith, & Gasson, 2008). Due to their early nature and influence on subsequent development of other skills, motor skills should be monitored in case of developmental concerns (Gerber, Wilks, & Erdie-Lalena, 2010). This chapter will provide an overview of assessment of fine and gross motor skills as they relate to childhood disorders.

Typical Motor Development

Throughout childhood, individuals are interacting with their environments through direct and indirect actions which foster their development. Theoretically, individuals' learning and acquisition of knowledge has been tied to their development of various motor behaviors (Piaget, 1953). From very early ages, children are learning through exploration via motor development.

Therefore, understanding of normal developmental milestones is necessary for assessment and identification of developmental delays (Gerber, Wilks, & Erdie-Lalena, 2010). Although the rate of acquisition varies greatly across individuals, motor skills typically progress in a sequential order within a certain timeframe. Given the variation in skills achievement, skills are not considered delayed unless the individual has not met the milestone past the recommended age. Table 1 includes various early motor milestones and the typical age of achievement.

Table 1 Typical motor milestones

Age in months	Milestone
2	Holds head up, pushes up when lying on stomach
4	Holds head steady (neck control), starts to roll over, brings hands to mouth
6	Rolls over both directions, starts to sit unsupported
9	Stands with support, sits unsupported, crawls
12	Walks supported, stands independently
18	Walks independently, drinks from cup, eats with spoon
24	Runs, climbs on furniture unassisted
36	Climbs independently, runs smoothly, walks up and down steps
48	Hops, catches bounced ball, cuts with scissors (supervised)
60	Uses utensils, swings, stands on one foot for at least 10 s

Adapted from the World Health Organization (2006) and Centers for Disease Control and Prevention (2017)

Motor Skill Deficits

Comorbidity with Other Childhood Disorders

Motor deficits are common in various childhood disorders. This section will review a number of childhood disorders and the gross motor deficits associated with them.

Global Developmental Delay and Intellectual Disability Symptoms of global developmental delay (GDD) and intellectual disability (ID) include deficits in both intellectual and adaptive functions which affect one's skills in conceptual, social, and practical domains (American Psychiatric Association, 2013). Whereas individuals with ID have impairments in both cognitive functioning and adaptive behaviors, a diagnosis of GDD is reserved for children under the age of 5 who display significant delays in multiple developmental domains (American Psychiatric Association, 2013). Onset of GDD and ID is in the developmental period, with delayed developmental skills often apparent by age 2 (Institute of Medicine (U.S.), Boat, Wu, & National Academies of Sciences, Engineering, and Medicine, 2015). The motor deficits observed in individuals with GDD and ID range from mild to severe and across fine and gross motor skills. For individuals with mild ID, they may achieve motor milestones within normal limits but later exhibit difficulties with gross and fine motor skills (Vuijk, Hartman, Scherder, & Visscher, 2010). Often individuals with mild ID may not be identified until school age, when their academic and learning difficulties become more apparent (Institute of Medicine (U.S.) et al., 2015). Severe and profound ID are more commonly associated with an underlying genetic or neurological cause such as Down syndrome, Prader-Willi syndrome,

fragile X syndrome, and Angelman syndrome (Flint, 2001; Karam et al., 2015). Researchers have indicated that there is a relationship between cognitive and motor functioning such that more severe ID is associated with greater motor impairment (Vuijk, Hartman, Scherder, & Visscher, 2010). Given that GDD and ID are characterized by impaired adaptive behaviors, which are related to motor skills, assessment of the individual's fine and gross motor difficulties is an essential component of evaluation.

Autism Spectrum Disorder Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by marked deficits in social communication behaviors and the presence of restricted and repetitive behaviors and interests (American Psychiatric Association, 2013). Although not characteristic of ASD, motor deficits are also often observed in individuals with the disorder (Colombo-Dougovito & Reeve, 2017; Liu, 2013). Delayed achievement of motor milestones (e.g., crawling, walking) is often the first developmental concern reported by parents and caregivers of children who are later diagnosed with ASD (Chawarska et al., 2007; Lloyd, MacDonald, & Lord, 2013). An estimated 80% of children with ASD have motor difficulties, with the delays exhibited becoming more significant with age (Landa & Garrett-Mayer, 2006; Lloyd, MacDonald, & Lord, 2013). Common deficits include gross motor impairments such as difficulties in coordinating upper and lower limbs during balance, agility, and speed tasks (Bhat, Landa, & Galloway, 2011; Ghaziuddin & Butler, 1998; Miyahara et al., 1997). A number of researchers have also found that individuals with ASD display abnormal or ataxic gait (Calhoun, Longworth, & Chester, 2011; Kindregan, Gallagher, & Gormley, 2015; MacDonald, Lord, & Ulrich, 2014). Various motor deficits are common in individuals with ASD; however, the impairments observed have not been found to differ from the motor deficits observed in individuals with other developmental delays (Ozonoff et al., 2008). The presence of comorbid ID, though, has been found to be associated with more severe motor deficits in individuals with ASD (Smith, Maenner, & Seltzer, 2012). For individuals with ASD, motor deficits are common, and when assessing the difficulties experienced by those with the disorder, considerations such as functioning level and the presence of ID should be made.

Language Disorders Language disorders include impairments in the acquisition and use of speech and language, in which both expressive and receptive language skills may be affected (American Psychiatric Association, 2013). A number of children with various speech delays and disorders also display motor deficits (Missiuna, Gaines, & Pollock, 2002), with some researchers finding that between 40 and 90% of children with speech problems also have motor impairments (Hill, 2001). The types of motor impairments observed in children with speech and language disorders are non-specific, such that they may exhibit gross and/or fine motor difficulties (Gaines & Missiuna, 2007; Missiuna, Gaines, & Pollock, 2002). These deficits may include difficulty with visuomotor skills, coordination, and timing (Sanjeevan et al., 2015; Zelaznik & Goffman, 2010). The significant overlap between speech deficits and motor impairments may not only suggest a relationship between the two skills but also a common underlying etiology in these difficulties.

Cerebral Palsy Cerebral palsy (CP) is a neurological disorder that affects an individual's movement and muscle coordination, including muscle control, tone, posture, and fine and gross motor skills (Parsons, 2011). It is the most common cause of motor disability in children (Kirby et al., 2011). CP is caused by brain injury or abnormal brain development affecting motor skills (Bax, 2008). The motor impairments and severity of deficits exhibited by individuals with CP vary across those with the disorder, such that some individuals may have complete paralysis while others may display milder difficulties such as tremors (Parsons, 2011).

Given the range and severity of motor deficits due to CP, considerations must be made when assessing motor function in children with the disorder.

There are several classification systems to describe the individual's type and severity of CP, with the Gross Motor Function Classification System (GMFS) created to address the goals set by the World Health Organization and Surveillance of Cerebral Palsy (R. Palisano, Rosenbaum, Bartlett, & Livingston, 2007). The GMFS is a multi-level system that describes the individual's level of abilities and impairments and is often used with other classification systems to provide additional information regarding the location and severity of impairments (Palisano, Rosenbaum, Bartlett, & Livingston, 2007). The GMFCS has five levels across four age bands that focus on voluntary movements with particular emphasis on sitting and ambulation, with level I indicating functional limitations less than what is often associated with CP and level V indicating severe functional limitations. The system was designed for professionals familiar with a child's current motor abilities to quickly classify the appropriate functioning level. Initial development of the GMFCS involved nominal group process and Delphi survey methods to determine content validity (Palisano et al., 2008; Palisano, Rosenbaum, Bartlett, & Livingston, 2008). Interrater reliability has been demonstrated to be excellent ($G = 0.93$), while test-retest reliability was found to be adequate ($G = 0.79$; Wood & Rosenbaum, 2000).

Dysgraphia Dysgraphia is a learning disability characterized by fine motor difficulties that may result in poor or illegible handwriting below what would be expected based on the child's age and education level (Berninger, Richards, & Abbott, 2015; Döhla & Heim, 2016). In the *Diagnostic and Statistical Manual of Mental Disorders*, Fifth Edition (DSM-5; American Psychiatric Association, 2013), there is no specific diagnosis of "dysgraphia." Individuals with these difficulties may meet criteria for a specific learning disorder with impairments in written expression (e.g., spelling accuracy, grammar and punctuation accuracy, clarity or organization of written expression); however, this may not fully capture the individual's deficits in handwriting. The problems the individual may have with writing may include poor and inconsistent letter formation and spacing, difficulty with spatial planning, and impairments with composition (Chung & Patel, 2016). It has been suggested that these deficits may be due to difficulties with visual processing (Döhla & Heim, 2016), visual memory (Vlachos & Karapetsas, 2003), or other visuomotor skills (Mäki, Voeten, Vauras, & Poskiparta, 2001). Because difficulties with handwriting may affect a child's academic skills, it is necessary to assess motor skills to determine fine motor function.

Genetic Disorders Individuals with various genetic disorders, including Down syndrome, Williams syndrome, fragile X syndrome, and Prader-Willi syndrome, have also been found to exhibit motor deficits. Though the genetic causes and phenotypes of each disorder vary, researchers have found a number of motor deficits to also be present (Chapman & Hesketh, 2000; Loveland & Kelley, 1991; Mervis & Klein-Tasman, 2000; Summers & Feldman, 1999). The types of impairments as well as severity range across each disorder and individual. As such, clinicians should consider the possible influence of the symptoms of the individual's genetic disorder when assessing motor skills.

Relationship Between Motor Skills and Adaptive Behaviors

Adaptive behaviors are independent daily living skills, as expected by the individual's age and cultural standards of the community (American Psychiatric Association, 2013; Bullington, 2011). The domains of adaptive behaviors include conceptual, social, and practical adaptive behavior and are skills related to self-care, community living, communication, and socialization (Bullington, 2011). Adaptive behaviors are central to the assessment of developmental disabilities in individuals because they often predict severity and prognosis, as well as assist with determining eligibility for services (Tassé et al., 2012). Across developmental disabilities, both fine and gross motor skills

deficits have been found to be associated with difficulties with adaptive behaviors and daily living skills (Di Nuovo & Buono, 2011; Fu, Lincoln, Bellugi, & Searcy, 2015; MacDonald, Lord, & Ulrich, 2014; Tremblay, Richer, Lachance, & Côté, 2010; Vos et al., 2013). This may be due to the involvement of many fine and gross motor skills for successful independent living skills (e.g., pincer grasp for buttoning clothing). Coordination of both fine and gross motor skills is necessary for the development of various self-care and community living skills. Therefore, motor skills are a significant component of adaptive behaviors.

DSM-5 Motor Disorders

Developmental Coordination Disorder Developmental coordination disorder (DCD) is a neurodevelopmental disorder characterized by significantly impaired coordination of motor skills, which may manifest as clumsiness and delayed or inaccurate motor performance (American Psychiatric Association, 2013). Skill level is significantly below what would be expected for the child's age and learning opportunities, and these impairments interfere with the child's ability to perform adaptive and occupational behaviors (American Psychiatric Association, 2013). As these deficits may also be observed in other disorders, DCD is not diagnosed if these impairments may be better explained by ID, CP, or other disorders which may affect one's movement (Wilmut, Du, & Barnett, 2016). Although these symptoms begin to manifest during an individual's developmental period, due to the variation in attainment of developmental milestones, this disorder is not typically diagnosed until after age 5 to provide adequate learning opportunities (American Psychiatric Association, 2013). As such, DCD intends to describe children who are "clumsy" and have significant motor incoordination in the absence of any underlying neurological pathology (Cairney & King-Dowling, 2015). Therefore, when assessing for DCD, it is necessary to rule out other possible disorders which may be affecting the individual's motor coordination.

The impairments observed in children with DCD vary across individuals and with the individual's age. Across individuals with DCD, deficits may include skills related to motor planning, visual-spatial reasoning, and other gross and fine motor skills (P. H. Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). As the core feature of DCD is motor abilities that are significantly below what would be expected of same-aged peers, the deficits observed differ across ages (Cairney & King-Dowling, 2015). At younger ages, these skills may include walking, while at older ages, these deficits may refer to running and coordination with throwing and catching (Cairney & King-Dowling, 2015; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013).

Assessment of Motor Skills

The assessment of motor skills involves the examination of motor functioning and motor development. Developmental screening is frequently used to identify children who have delays in motor development, with primary care providers often performing screening with preschool-aged children as part of routine medical care (Tieman, Palisano, & Sutlive, 2005). After screening, children who appear to have a delay in motor development may be referred for more comprehensive neurodevelopmental or physical assessment.

A comprehensive assessment of motor functioning with children should include an interview with a parent/caregiver, during which information pertaining to pre- and perinatal health, developmental milestones, adaptive skills, motor functioning, and family history should be collected. A structured interview or parent/caregiver questionnaire may be helpful in obtaining such information (see Review of Assessment Measures for more information). Table 2 also outlines a series of questions that can easily be integrated into clinical interviews that are likely to reveal relevant information. Assessment of developmental functioning, cognitive functioning, academic achievement, and neuromotor status should be integrated with the assessment as necessary to provide

Table 2 Recommended questions for parents/caregivers related to motor functioning and development

Parent/caregiver interview
Was your child born prematurely? If so, at how many weeks gestation?
Where there any complications during the pregnancy?
How much did your child weigh at birth?
At what age did your child first:
Sit up independently?
Crawl?
Walk independently?
Do you have any concerns about your child's motor skills?
Does your child have difficulty with daily tasks, such as dressing, fastening buttons, tying shoes, using utensils, or brushing teeth?
Does your child seem overly clumsy?
Does your child have difficulty with handwriting or using scissors?
Does your child have difficulty throwing or kicking a ball?
How does your child's motor coordination compare to other children his/her age?
Has anyone in your family been diagnosed with a developmental, neurological, or psychiatric disorder?

information needed to understand contributing factors and to rule out possible causes.

There are a number of standardized measures available to measure motor functioning in children. Norm-referenced measures allow for the comparison of an individual's score to the average performance of the normative sample and are helpful for identifying developmental delays and areas of impairment. Criterion-referenced measures assess an individual's performance related to a specific skill or area of functioning. For example, a norm-referenced measure would compare a child's ability to stand to typically developing children of the same age, while a criterion-referenced measure would assess the child's progress toward standing. Tieman, Palisano, and Sutlive (2005) outline five important factors to consider when selecting an appropriate measure for the assessment of motor functioning in children: the purpose of the evaluation (e.g., diagnostic, service eligibility, progress monitoring), characteristics of the child (e.g., age, functional abilities, language abilities), the developmental or functional areas requiring examination (e.g., gross/fine motor skills, self-care, mobility), the setting (e.g., home environment, clinic setting), and any external constraints (e.g., time, equipment, cost). The psychometrics properties of a measure should also be considered.

Standardized measures should be administered by a professional with a knowledge base in child development, experience testing children with disabilities, and knowledge related to test and score interpretation. Administration and scoring should be practiced several times with different children before clinically administering the measure, with particular attention paid to reviewing the test manual. During administration of a standardized measure, the examiner should simultaneously observe how the child performs tasks in order to gain information about the quality of movement in addition to evaluating the skill based on the measure's scoring criteria. Particular attention should be paid to oral motor skills (e.g., closing mouth, shaping lips), eye movements (e.g., eye tracking, pupil dilation), facial expressions, muscle bulk and texture, joint flexibility, grip strength, hand dominance, gross motor skills (e.g., running, hopping, balancing), fine motor skills (e.g., coloring, stacking blocks, using scissors), and motor planning.

Review of Assessment Measures

Fifteen measures of motor development and function for children have been selected for review in this chapter (see Table 3). These measures were selected as they are commonly used and have evidence of reliability and validity. For ease of reference, they are divided into three categories: those that assess motor skills through assessment of performance, those designed to assess developmental functioning overall, and those that are based on informant report.

Performance-Based Assessment of Motor Skills

Performance-based measures of motor skills require the examiner to observe and evaluate the performance of discrete skills based on predetermined criteria. Required tasks vary across measures and age bands, although

Table 3 Summary of motor skill assessment measures

Measure	Target population	Age	Type	Assessment time
AIMS	Infants with motor difficulties	0–18 months	Test of motor skills	20–30 min
BDI-2	Children at risk for developmental difficulties	0–7.11 years	Test of developmental functioning	60–90 min
Bayley-III	Young children at risk for developmental difficulties	1–42 months	Test of developmental functioning	30–90 min
Beery VMI	Individuals with visual-motor integration difficulties	2–99 years	Test of motor skills	10–20 min
BOT-2	Children and youth with typical development or moderate motor deficits	4–21 years	Test of motor skills	Full form, 45–60 min Short form, 15–20 min
DCDQ'07	Children with coordination disorders	5–15 years	Parent/caregiver questionnaire	10–15 min
DIAL-4	Young children at risk for developmental difficulties	2.6–5.11 years	Test of developmental functioning	30–45 min
ESI-R	Young children at risk for developmental difficulties	3–5.11 years	Test of developmental functioning	10–15 min
GMFM	Children with CP	2–12 years	Test of motor skills	45–60 min
MAP	Preschool-aged children at risk for developmental difficulties	2.9–5.8 years	Test of developmental functioning	30–40 min
Movement ABC-2 performance test	Children and adolescents with motor impairments	3–16 years	Test of motor skills	20–40 min
Movement ABC-2 checklist	Children with motor impairments	5–12 years	Checklist	10 min
MSEL-AGS	Young children	0–68 months	Test of developmental functioning	15–60 min
PDMS-2	Young children with motor impairments	0–5 years	Test of motor skills	45–60 min
Vineland-3 interview form	Individuals with disabilities	0–90+ years	Interview for parent/caregiver	20–40 min
Vineland-3 parent/caregiver form	Individuals with disabilities	0–90+ years	Parent/caregiver questionnaire	10–20 min
Vineland-3 teacher form	Individuals with disabilities	3–21 years	Teacher questionnaire	10–15 min

common gross motor tasks include those such as sitting, walking, running, balancing, throwing/catching large balls, and climbing stairs. Common fine motor tasks include grasping, manipulation of small objects, writing, and using scissors. These tests require that examiners be trained in test administration, scoring, and interpretation to ensure reliable results.

Alberta Infant Motor Scales (AIMS) The AIMS is an assessment scale designed to assess motor development in infants from birth until the attainment of independent walking (Piper, Pinnell, Darrah, Maguire, & Byrne, 1992). It is comprised of 58 items that assess infant movement in 4 positions (i.e., prone, supine, sitting, and standing) that typically can be scored within 20–30 min. Each item is scored by an administrator with knowledge of normal infant motor development as "observed" or "not observed" to generate subscale scores for each position as well as a total score, with higher scores indicating

more mature motor development. Percentile ranks, standardized scores, and age-equivalent scores are based on a standardization sample of 2220 infants between the ages of 1 week and 18 months living in the providence of Alberta between 1990 and 1992. Concurrent validity has been established with the Peabody Developmental Motor Scales (PDMS), $r = 0.97$, and the Bayley Scales of Infant Development (BSID-II), $r = 0.98$ (Piper, Darrah, Maguire, & Redfern, 1994; Piper, Pinnell, Darrah, Maguire, & Byrne, 1992). The predictive validity of the AIMS in classifying children with abnormal motor development was found to be good, with cutoff scores at the tenth percentile at 4 months (sensitivity of 77.3%; specificity of 81.7%) and the fifth percentile at 8 months (sensitivity of 86.4%; specificity of 93.0%) providing maximized specificity and sensitivity rates (Darrah, Piper, & Watt, 1998). Interrater and test-retest reliability have also been established (Piper, Darrah, Maguire, & Redfern, 1994; Piper, Pinnell, Darrah, Maguire, & Byrne, 1992). Despite these solid psychometric properties, concern has been raised regarding its outdated normative data (Fleuren, Smit, Stijnen, & Hartman, 2007).

The Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI) The Beery VMI is a measure designed to assess the integration of visual and motor abilities in individuals across the lifespan that can be administered in individual or group format (Beery & Beery, 2010). It is available as a full form and short form, with the full form being appropriate for all ages and the short form designed for children aged 2–7. The full form consists of 25 geometric forms that are copied by the examinee in a test booklet, the first 15 of which comprise the short form. Both versions of the Beery VMI can be administered in about 10–15 min. The Beery VMI is supplemented by two additional standardized tests, Visual Perception and Motor Coordination, which allow for the assessment of visual and motor contributions to performance on the Beery VMI. As these are timed tests, the Visual Perception test is administered in exactly 3 min and the Motor Coordination test in 5 min. The Visual Perception test consists of 30 items in which the examinee is asked to visually identify figures that are progressively smaller and more intricate. The Motor Coordination test consists of 30 increasingly complex shapes in which the examinee is asked to draw within a targeted area.

Raw scores from the Beery VMI and its two supplemental tests are converted into standard scores, scaled scores, percentile ranks, and age and grade equivalents. The Beery VMI has been normed 6 times with a total of 12,500 individuals over a span of 40 years, most recently in 2010. Internal consistency coefficients of the Beery VMI, Visual Perception, and Motor Coordination tests have been estimated to range from 0.83 to 0.96 across age ranges (Beery & Beery, 2010). Overall test-retest reliability coefficients were reported by the manual as 0.88 for the Beery VMI, 0.84 for Visual Perception, and 0.85 for Motor Coordination. Interrater reliability coefficients were reported as 0.93 for the Beery VMI, 0.98 for Visual Perception, and 0.94 for Motor Coordination. Construct validity of the Beery VMI has been examined, with Rasch analysis indicating that it is unidimensional (Brown, Unsworth, & Lyons, 2009; Mao, Li, & Lo, 1999). Predictive validity has also been established, with performance on the Beery VMI predicting performance in elementary school (Paro & Pianta, 2000; Pianta & McCoy, 1997).

Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2) The BOT-2 is a standardized measure of fine and gross motor skills in children and youth aged 4–21 years (Bruininks & Bruinicks, 2005). The assessment is designed for individuals with functioning ranging from typical development to moderate fine and/or gross motor difficulties. The BOT-2 consists of eight subtests (i.e., fine motor precision, fine motor integration, manual dexterity, bilateral coordination, balance, running speed and agility, upper limb coordination, strength) consisting of tasks that are scored by the examiner. Composite scores are generated in four motor areas (i.e., fine manual control, manual coordination, body coordination, strength and agility) as well as a total motor

composite. The full form consists of 53 items and is typically completed in 45–60 min. A short form is available for screening purposes which includes 14 total items from across the 8 subtests generating a single score of motor proficiency and which can be administered in 15–20 min. Scores from both the full and short forms can be converted into standard scores, while those from the full form can also be converted into age-equivalent scores. The normative sample for the BOT-2 included 1520 children and youth between the ages of 4 and 21 from across the United States (Deitz, Kartin, & Kopp, 2007). Both the short form and full form of the BOT-2 have been demonstrated to have good to excellent test-retest and interrater reliability in healthy children (Bruininks & Bruinicks, 2005). The full form has also been demonstrated to have excellent test-retest reliability in children with ID (Wuang & Su, 2009). Validity has been established through studies examining internal structure, differentiation of clinical and nonclinical groups, and correlation with the PDMS-2 (Bruininks & Bruinicks, 2005).

Gross Motor Function Measure (GMFM) The GMFM is a measure developed to assess the motor functioning of children with CP (Russell, Rosenbaum, Wright, & Avery, 2013). It is designed as an evaluative measure to assess change over time or response to intervention. The original 88-item measure (GMFM-88) has been updated to a 66-item measure (GMFM-66), which requires less administration time. According to the manual, the GMFM-88 is the preferred choice for children who are very young, those who have severe motor limitations, and children who may have motor difficulties unrelated to CP (Russell, Rosenbaum, Wright, & Avery, 2013). Due to differences in item weights between populations, the GMFM-66 is recommended for use only with children with CP. Items from both versions of the GMFM are grouped into five dimensions (i.e., lying and rolling; sitting; crawling and kneeling; standing; walking, running, and jumping). Based on observation, the examiner scores a child's performance on each item on a 4-point scale (i.e., 1, 2, 3, or 4). Scores for each dimension are calculated as a percentage of the maximum score, with a total score then calculated by averaging percentage scores across the five dimensions. The GMFM is criterion-referenced, and thus normative data is not available. Both the GMFM-66 and GMFM-88 have been demonstrated to have excellent test-retest reliability (intraclass correlation coefficient [ICC] = 0.99) and face validity (Russell et al., 2000).

Movement Assessment Battery for Children (Movement ABC-2) The Movement ABC-2 is a measure designed to assess motor performance in children and adolescents aged from 3 to 16 years, developed from the Test of Motor Impairment (TOMI; Henderson, Sugden, & Barnett, 2007; Stott, Moyes, & Henderson, 1972). The Movement ABC-2 Performance Test is complementary to the Movement ABC-2 Checklist, which is described below (see the "Informant-based Measures" section). The Movement ABC-2 Performance Test consists of eight items involving fine and gross motor tasks grouped into three subscales (i.e., manual dexterity, aiming and catching, static and dynamic balance) and takes approximately 20–40 min to administer. Norms have been established based on a standardization sample of 395 children across three age bands (i.e., 3–6, 7–10, 11–16 years). Estimates of test-retest reliability across the subscales range from adequate to good among typically developing children (Henderson, Sugden, & Barnett, 2007). Internal consistency, $\alpha = 0.90$, and test-retest reliability, ICC = 0.97, have been demonstrated to be excellent among children with DCD (Wuang, Su, & Su, 2012). Research related to the validity of the Movement ABC-2 Performance Test is limited, although extensive evidence is available for previous versions of the measure (Brown & Lalor, 2009).

Peabody Developmental Motor Scales, Second Edition (PDMS-2) The PDMS-2 is a standardized test of motor functioning designed for children aged 5 and under (Folio & Fewell, 2000). The test includes 249 items across 6 subtests, which are subdivided into fine motor (FM) and

gross motor (GM) composites and that combine to create a total motor (TM) composite. The FM composite consists of 98 items from 2 subtests (i.e., grasping, visual-motor integration), while the GM composite consists of 151 items from 4 subtests (i.e., reflexes, stationary, locomotion, object manipulation). A child's performance on each item is scored by the examiner on a 3-point scale (i.e., 0, 1, or 2) based on specified item criteria. Standard scores, percentiles, and age-equivalent scores are available for each subtest. Scores from the FM, GM, and TM composites are converted into developmental quotient (DQ) scores. Research has demonstrated the PDMS-2 composite scores to have good to excellent test-retest reliability (ICC = 0.88–1.00) and acceptable sensitivity to change among children with CP (Wang, Liao, & Hsieh, 2006). Among a group of children with and without fine motor problems, the FM composite of the PDMS-2 was found to have excellent test-retest and interrater reliability (r = 0.84–0.99; van Hartingsveldt, Cup, & Oostendorp, 2005). Convergent validity has been established between the TM composite and the Bayley Scales of Infant and Toddler Development (Connolly, McClune, & Gatlin, 2012; Provost et al., 2004).

Measures of Developmental Functioning

Measures of developmental functioning aim to provide a comprehensive assessment of global development and are used frequently in the assessment and screening of developmental disorders. These measures are particularly helpful when assessing children who may be experiencing delays in multiple areas of development. Results from these measures yield valuable information regarding an individual's overall level of functioning as well as areas of strength and weakness, which can be used to inform diagnostic evaluations, determination of service eligibility, treatment planning, and the need for continued evaluation. Motor functioning is a common domain within measures that assess general developmental functioning. Some of the measures have scales addressing motor skills that can be administered independently, while others are designed to be administered within the full test battery. The assessment of motor skills within developmental measures involves the observation and assessment of skills, requiring that examiners be well trained in administration and scoring.

Battelle Developmental Inventory, Second Edition (BDI-2) The BDI-2 is a standardized assessment of developmental skills for children aged birth through 7 years and 11 months (Newborg, 2005). It is comprised of 450 items grouped into 5 domains (i.e., adaptive, personal/social, communication, motor, and cognitive), which can be administered independently of one another. When all five domains are administered, total assessment time is estimated to range from 60 to 90 min. The standardization data was collected in 2002–2003 based on a sample of 2500 children from across the United States; this original standardization data was reweighted in 2016 with the BDI-2 Normative Update. In regard to psychometric properties, the BDI-2 manual indicates internal consistency coefficients ranging from 0.98 to 0.99 for the total score, with averages across domains ranging from 0.85 to 0.95 (Newborg, 2005). Test-retest reliability coefficients for total BDI-2 score ranged from 0.93 to 0.94 across age groups and from 0.77 to 0.90 across domains and age ranges. Interrater reliability coefficients ranged from 0.97 to 0.99. The BDI-2 was found to correlate with the Bayley Scales of Infant and Toddler Development, the Wechsler Preschool and Primary Scale of Intelligence (WPPSI), and the Vineland Adaptive Behavior Scales (Newborg, 2005).

Bayley Scales of Infant and Toddler Development, Third Edition (Bayley-III) The Bayley-III is an individually administered assessment of developmental functioning for young children aged 1 month to 42 months (Bayley, 2006). It is comprised of two scales based on parent/caregiver questionnaires (i.e., social-emotional, adaptive behavior) and three scales scored by the examiner (i.e., cognitive, language, motor) based on observation of skills.

Scoring for the testing components of the Bayley-III is either 1 (credit) or 0 (no credit). The Adaptive Behavior Assessment System, Second Edition (ABAS-II), serves as the adaptive behavior scale of the Bayley-III. The motor scale consists of fine motor and gross motor subtest. Total administration time ranges from 30 to 90 min, depending on the age of the child. Scaled scores, percentile ranks, and developmental age scores are available for scales and subtests. The total raw score of the Bayley-III can be converted into a standard score. Normative data for the cognitive, language, and motor scales is based on a standardization sample of 1700 children across 17 age groups; the normative sample for the social-emotional scale is based on a sample of 465 children, while that of the adaptive behavior scale is based on a sample of 1350 children. According to the manual, the Bayley-III has been demonstrated to have internal consistency coefficients ranging from 0.76 to 0.98 across scales (Bayley, 2006). The majority of test-retest reliability coefficients across scales and age ranges were in the .70s and .80s, with correlation increasing as age increased. Interrater reliability coefficients of the adaptive behavior scale were estimated to range between 0.59 and 0.86. Validity has been established through confirmatory factor analysis and correlation with the PDMS-2 and the WPPSI-III (Bayley, 2006; Connolly, McClune, & Gatlin, 2012).

Developmental Indicators for the Assessment of Learning, Fourth Edition (DIAL-4) The DIAL-4 is an individually administered screening of developmental function for children aged 2 years and 6 months to 5 years and 11 months (Mardell & Goldenberg, 2011). The test is designed to be used to screen large groups of children efficiently through the use of multiple testing stations for each of the three domains scored based on performance (i.e., motor, language, concepts), making it particularly useful for school settings. Items on these scales are scored on a scale of 0–4 based on task and skill demonstration. Two additional domains (i.e., self-help development, social-emotional development) are scored based on ratings on a 3-point Likert scale from a parent/caregiver or teacher. The full measure can be administered in approximately 30–45 min. The motor domain assesses both gross and fine motor functioning; it is not designed to be administered independent of the other domains. Standard scores and percentile ranks are available for a total score and each of the domains following completion of the fully assessment. The normative sample included 1400 children, 700 parents, and 700 teachers from across the United States. The DIAL-4 manual reports internal reliability coefficients across ages to range from the .80s to .90s (Mardell & Goldenberg, 2011). Test-retest reliability coefficients ranged from 0.64 to 0.95 between the English and Spanish versions, and interrater reliability ranged from 0.89 to 0.98. Moderate correlation was found between the concepts and language domains and the ESP cognitive/language domain (0.51 and 0.61), although correlation was low (0.21) between the DIAL-4 motor and ESP motor domain (Mardell & Goldenberg, 2011). The DIAL-4 and the ESP examine different motor tasks, which may account for the low correlation between the two motor scales. The DIAL-4 total score was found to correlate highly with the Differential Ability Scales, Second Edition (DAS-II) General Conceptual Ability score (0.73), supporting its use as a screener for possible cognitive delays (Mardell & Goldenberg, 2011).

Early Screening Inventory-Revised (ESI-R) The ESI-R is an individually administered test designed to screen young children for special education services (Meisels et al., 2008). Two forms of the ESI are available based on age group: the ESI Preschool (ESI-P) is appropriate for children aged 3 years to 4 years and 5 months, and the ESI Kindergarten (ESI-K) is appropriate for those aged 4 years and 6 months to 5 years and 11 months. It is comprised of three scales (i.e., visual-motor/adaptive, language and cognition, gross motor skills). The visual-motor/adaptive scale includes items targeting fine motor skills and visuomotor integration, while the gross motor scale includes those targeting gross motor coordination. The ESI-R is typically administered in 15–20 min.

Cutoffs are available for total scores on the ESI-P and ESI-K across age bands indicating into which of three classifications (i.e., "OK," "Rescreen," "Refer") the examinee scored. The ESI-R was originally standardized using a sample of 6031 children from across the United States and updated in 2006 with an additional 1200 cases. The ESI-R manual reports that both the ESI-P and ESI-K have sensitivity of at least 0.92 and specificity of 0.80 (Meisels et al., 2008). In regard to the ESI-K, interrater reliability was reported to be 0.97, and test-retest reliability coefficients ranged from 0.79 to 0.84. Reliability was not examined in the ESI-P. A strong correlation (0.73) was found between both the ESI-K and ESI-P, respectively, with the McCarthy Scales of Children's Abilities establishing convergent validity.

Miller Assessment of Preschoolers (MAP) The MAP is an individually administered test designed to assess the developmental functioning of children aged 2 years and 9 months up to 5 years and 8 months (Miller, 1988). As a broad developmental measure, the MAP provides a developmental overview and is designed to identify young children who may be at risk for developmental difficulties. It is comprised of five performance indices (i.e., foundations, coordination, verbal, nonverbal, complex tasks), two of which target motor skills: the foundation index assesses basic fine and gross motor skills and the coordination index assesses complex gross, fine, and oral motor skills. The MAP can typically be completed in 30–40 min. The total raw score of the MAP as well as the raw score of each of the indices can be transformed into percentile scores. The normative sample for the MAP was comprised of 1200 preschoolers from across the United States (Miller, 1988). The test manual reports good to excellent interrater and test-retest reliability across performance indices (Miller, 1988). More recently, construct validity has been demonstrated via strong correlation with the Pediatric Examination of Educational Readiness (PEER), another developmental measure (Parush, Yochman, Jessel, Shapiro, & Mazor-Karsenty, 2002). Additionally, the MAP has been demonstrated to differentiate between 5-year-olds with extremely low birth weight and those born full term (Leosdottir, Egilson, & Georgsdottir, 2006), as well as between preschool-aged children with and without prenatal drug exposure (Fulks & Harris, 2005). While the psychometrics appear to be sound, updated normative data and research pertaining to reliability are needed.

Mullen Scales of Early Learning: American Guidance Service Edition (MSEL:AGS) The MSEL:AGS is a widely used multidomain test designed to assess the development of young children (Mullen, 1995). It consists of 5 individual scales, 4 that cover children aged 0–68 months (i.e., visual reception, fine motor, receptive language, expressive language) and 1 for children aged 0–33 months (i.e., gross motor), which can be administered independently of one another. The fine motor scale consists of 30 items, requires minimal language skills, and measures visual-motor planning and control, motor imitation, and manipulation of objects. The gross motor scale consists of 35 items that measure motor control and mobility. The time required for administration for the full test varies by age, with the manual estimating 15 min for 1-year-olds, 30 min for 4-year-olds, and 60 min for 5-year-olds. Raw scores for each scale can be converted into standardized *T* scores, percentile ranks, and age equivalents. Administration of the full test generates an Early Learning Composite (ELC) standard score. Standardization is based on a normative sample of 1849 children aged 2 days–69 months from across the United States between 1981 and 1989 who did not have physical or mental disabilities. The manual reports psychometric properties of the original MSEL. Convergent validity was established through moderate correlation with the BSID and Peabody Developmental Motor Scales (Mullen, 1995). Test-retest reliability was high for the gross motor scale (0.96) and ranged from 0.82 to 0.85 for the other scales, while interrater reliability was reported to be high (0.91–0.99; Mullen, 1995). Concerns related to this measure include outdated norms and the exclusion of children with disabilities from the standardization sample (Lee, 2013).

Informant-Based Measures

Informant-based measures of motor functioning are based on report of skills from adults familiar with the child's functioning, such as a parent/caregiver or teacher. They are particularly useful for screening purposes, as they take less time to complete, require less training for administration and scoring, and are typically less expensive than performance-based measures. They are also frequently administered within testing batteries to allow for data collection from multiple sources.

Developmental Coordination Disorder Questionnaire 2007 (DCDQ'07) The DCDQ'07 is a brief parent questionnaire designed to assist in the identification of DCD in children aged 5–15 years (B. N. Wilson, Kaplan, Crawford, & Roberts, 2007). It consists of 15 items that ask parents to compare their child's motor performance to that of typically developing peers on a 5-point Likert scale. As the measure is brief, it can typically be completed by parents in about 10–15 min. The measure consists of three factors (i.e., control during movement, fine motor and handwriting, and general coordination). Scores from each of the three factors are computed along with a total score. Scores are interpreted across three age bands and two score ranges: "Indication of, or Suspect for, DCD" and "Probably not DCD." Overall sensitivity of the DCDQ'07 is reported to be 84.7% and the specificity to be 70.8% (Wilson, Kaplan, Crawford, & Roberts, 2007). Construct validity has been demonstrated through moderate correlation ($r = 0.55$) with the Movement ABC (Wilson et al., 2009) in addition to exploratory and confirmatory factor analysis (Hua et al., 2015). Internal consistency and test-retest reliability were found to be excellent (Hua et al., 2015).

Movement Assessment Battery for Children Checklist (Movement ABC-2 Checklist) The Movement ABC-2 Checklist is an informant-based checklist that is complementary to the Movement ABC-2 Performance Test (Henderson, Sugden, & Barnett, 2007). It is comprised of 30 items and takes approximately 10 min to complete. The checklist is designed to be completed by an adult familiar with the child, such as a parent/caregiver, teacher, or service provider. It has been found to discriminate between children with and without motor impairment when completed by teachers (Schoemaker, Niemeijer, Flapper, & Smits-Engelsman, 2012). Internal consistency was found to be excellent, $\alpha = 0.94$, and moderate correlation with the Performance Test and DCDQ'07 has been established (Schoemaker, Niemeijer, Flapper, & Smits-Engelsman, 2012). However, evidence is needed regarding test-retest and interrater reliability.

Vineland Adaptive Behavior Scales, Third Edition (Vineland-3) The Vineland-3 is a group of measures of adaptive behavior that are widely used in the assessment of individuals with disabilities (Sparrow, Cicchetti, & Saulnier, 2016). It is available in three formats: (1) the Interview Form, which is administered by a professional to a respondent who can reliably report on the adaptive behavior on the individual; (2) the Parent/Caregiver Form, which is completed by a parent or caregiver using a rating scale format; and (3) the Teacher Form, which is completed by a teacher using a questionnaire format. The Interview Form and Parent/Caregiver Form provide normative scores for individuals of all ages, from birth to over 90 years of age, whereas the Teacher Form provides normative scores for individuals aged 3–21. All three formats follow the same domain/subdomain format, which includes three domains that comprise the Adaptive Behavior Composite (i.e., communication, daily living skills, socialization) and two optional domains (i.e., motor skills, maladaptive behavior). For each of the domains and for the Adaptive Behavior Composite, standard scores, percentile ranks, and age equivalents are available.

The normative sample for Vineland-3 was recently updated. The Interview and Parent/Caregiver Forms included 2560 aged 0–80+ years from across the United States; the sample for the Teacher Form included 1415 students aged 3–18 years from across the United States. Both samples included individuals with a range of dis-

abilities, including ID, developmental delay, autism, and speech/language impairments. The motor skills domain is comprised of two subdomains (i.e., gross motor, fine motor) and is normed for individuals aged 0–9 years. While optional for the Adaptive Behavior Composite, the motor skills domain is not designed for administration independent of the other domains. According to the Vineland-3 manual, all forms of the Vineland-3 demonstrate strong psychometric properties. ICCs ranged from 0.83 to 0.9 across domains and forms (Sparrow, Cicchetti, & Saulnier, 2016). Test-retest reliability coefficients ranged from 0.71 to 0.94 across domains and forms, and interrater reliability coefficients ranged from 0.61 to 0.87. Validity has been established through correlation with the Bayley-III and Adaptive Behavior Assessment System (ABAS-3) as well as through differential scoring of clinical subsamples.

Conclusion

Motor development is directly tied to the development of cognitive, language, and social skills. The assessment of motor skills and functioning in children provides valuable information toward the screening of developmental delays, the identification of neurodevelopmental disorders, intervention planning, and progress monitoring. There are a number of standardized measures that assess motor functioning in children, including those specifically examining fine and/or gross motor skills, measures of developmental functioning, and informant-report-based interviews and questionnaires. When selecting an appropriate measure, attention should be paid to child characteristics and the purpose of the evaluation. As part of a comprehensive assessment, standardized measures should be paired with parent/caregiver interview and clinical examination of cognitive, adaptive, and physical functioning.

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