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Motor Skills Among Preschool-Aged Children Born Prematurely

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MOTOR SKILLS AMONG PRESCHOOL-AGED CHILDREN BORN PREMATURELY

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PREFACE

Premature births, as defined by births occurring before 37 weeks gestation, have been gradually increasing over the past 20 years. It has been estimated that in the United States, one in every eight births occurs prematurely (Centers for Disease Control and Prevention [CDC], 2013). The increased use of assisted reproduction techniques, environmental factors, and increasing maternal age at birth, are all factors which researchers have hypothesized to be contributing to the increase in the rate of preterm births.

Premature birth is one of the leading causes of infant mortality, and children who survive beyond birth may exhibit health, psychological, and behavioral difficulties (McCormick, Litt, Smith, & Zupancic, 2011). More specifically, children born preterm are more susceptible to cognitive deficits, fine and gross motor delays, learning disabilities, inattention, and hyperactivity.

Cerebral palsy (CP) refers to a group of motor and coordination disorders, and is the most severe of motor disorders that can result from premature birth. The rate of CP in the general population ranges from 1 to 4 per 1,000 live births; however, one study estimated that among children born prematurely, the rate of CP ranges from 6 to 60 per 1,000 live births, with those born at the younger gestational ages demonstrating the highest risk of developing CP (Winter, Autry, Boyle, & Yeargin-Allsopp as cited by CDC, 2014). Cerebral lesions have been identified as the most significant predictor of later development of CP in children born prematurely (Beaino et al., 2010) with MRI data indicating that 70 to 90 percent of children with CP have structural brain abnormalities (Ashwal et al. as cited in Hoon et al., 2009). Specifically, the presence of cystic periventricular leukomalacia (PVL), intraparenchymal hemorrhage (IPH), persistent echodensities or ventricular dilation, or grade I or II intraventricular hemorrhage (IVH) significantly increases a child's likelihood of developing CP (Beaino et al., 2010). Additionally,

CP is significantly associated with injury to the posterior thalamic radiation tracts, with the severity of injury being positively related to the degree of motor or sensory impairment (Hoon et al., 2009).

Cerebral palsy is difficult to diagnose around the time of birth, especially in premature infants due to the delayed development that is characteristic of prematurity. Thus, CP is often diagnosed at older ages in children born prematurely than in children born full term. Maitre, Slaughter, and Aschner (2013), for instance, found that among full term born children, those with CP had been diagnosed by 24 months of age, but only half of the preterm born children with CP had been diagnosed by this age (Maitre, Slaughter, & Aschner, 2013). Thus, preterm born children with CP were diagnosed much later with the condition than their full term born counterparts.

Because of the delayed diagnosis of CP in preterm born children, many of the studies on infant motor skills may have unknowingly included children who have undiagnosed CP. This reduces the generalizability of the results to the general preterm population. Thus, the infant motor skills literature will not be covered in the current review.

It should be emphasized that preterm-born children demonstrate higher rates of motor skills deficits compared to full term born controls, even in the absence of CP or other neurological abnormalities. It has been estimated that among school-aged children born prematurely who do not have cerebral palsy, 40.5% develop mild-to-moderate motor impairments, while 19% demonstrate moderate motor impairments (Williams, Lee, & Anderson, 2009). Although it is understood that preterm born children are more likely to exhibit motor skills deficits as a group, there is much within-group variability in functional outcomes during the early school years, and the factors that make preterm born children more susceptible to motor

skills deficits are not fully understood (Bos, Van Braeckel, Hitzert, Tanis, & Roze, 2013; Raz, DeBastos, Newman, & Batton, 2010); thus, the current study will focus on uncovering the perinatal factors that may potentially account for variability within the preterm-born population in preschool motor outcome.

As evident from the high rate of CP among preterm born children (Moore et al., 2012), preterm birth is associated with abnormal brain development, which can range from mild abnormalities to severe lesions and dysfunction. Rapid cortical growth occurs from 20 weeks gestational age on, and is characterized by a rapid increase in surface area relative to cerebral volume, or in other words, increased gyrification (Pitcher et al., 2011; Kapellou et al., 2006). Premature birth disrupts this process, altering growth trajectories in many brain regions and resulting in reduced gyrification of the cortex (Pitcher et al., 2011; Kapellou, 2006). Reduced cortical volume has been shown to persist into late childhood (Peterson et al., 2000) and adolescence (Isaacs, Edmonds, Chong, Lucas, & Gadian, 2003) in children born prematurely. It has even been demonstrated that there is a significant effect of gestational age at birth on cortical growth, in that the earlier the infant is born, the greater the disruption to cortical development. For example, among a group of prematurely-born infants, gestational age and gyrification of the brain, based on measurements recorded from 23 to 48 weeks of gestation, were found to be positively related, in that the earlier the child was born, the less gyrification they exhibited (Kapellou et al, 2006). MRI data shows reduced volume of various brain structures in nondisabled (i.e., after the exclusion of CP) preterm-born children compared to full-term born controls. These brain regions are often associated with motor function, and include the basal ganglia (Walsh, Doyle, Anderson, Lee, & Cheong, 2014), subcortical white matter (Lax et al., 2013 and Duerden, Card, Lax, Donner, & Taylor, 2013), and the cerebellum (Allin et al., 2000; Walsh et al., 2014). Because these various brain regions are involved in movement, the

probability that preterm born children will exhibit functional motor skills deficits as a result of disruption to brain growth of to one or more of these regions and/or pathways is high. Additionally, connectivity between hemispheres (via the corpus callosum) and between cortical regions can also be impaired (Pannek, Hatzigeorgiou, Colditz, & Rose, 2013; Melbourne et al., 2014; Pitcher et al., 2011), which can contribute to motor skills deficits. It is possible that disruptions during the period of fetal brain growth can lead not only to CP, but also to more subtle deficits in motor functions.

Developmental coordination disorder (DCD) is a diagnosis assigned, according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), when a child's motor functioning is thought to be significantly below age- and/or intelligence-based expectations to the extent that it interferes with daily functioning. Children born prior to 33 weeks gestation are six to eight times more likely than those born full term to develop DCD (Edwards et al. as cited in Zwicker et al., 2014). While CP has been linked to severe brain lesions, the underlying mechanisms associated with DCD are not well understood, and minor lesions visible on ultrasound at birth are not predictive of DCD diagnoses in early childhood (Jongmans et al., 1997). This suggests that in children with DCD, the underlying brain dysfunctions are subtle and more likely to be present among the general preterm-born population than the severe lesions associated with CP. Thus, the detailed review below includes studies of preterm-born children with DCD. Additionally, it should be emphasized that children born prematurely may experience deficits in motor skills that are more subtle, and will not qualify them for a diagnosis of DCD.

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CHAPTER 1: INTRODUCTION

Literature Review

There were 18 studies since 1990 that reviewed motor functioning in preterm-born children (Esbjorn, Hansen, Greisen, & Mortensen, 2006; Goyen et al., 2006; Janssen, van der Sanden, Akkermans, Oostendorp, & Kollée, 2008; Leversen et al., 2011; Prins, von Lindern, van Dijk, & Versteegh, 2010; Raz, DeBastos, Newman, & Batton, 2010; Davis, Ford, Anderson, & Doyle, 2007; Feder et al., 2005; Foulder-Hughes & Cooke, 2003; Goyen & Lui, 2009; Jakobson, Frisk, & Downie, 2006; Samsom et al., 2002; Larson et al., 2011; Marlow, Hennessy, Bracewell, & Wolke, 2007; Danks et al., 2012; Newman, DeBastos, Batton, & Raz, 2011; Raz, DeBastos, Newman, & Batton, 2012; De Kieviet, Piek, Aarnoudse-Moens, & Oosterlaan, 2009). These studies included children born after 1990, thus they were served in the modern neonatal intensive care unit (NICU). The modern NICU is characterized by the use of more "gentle" ventilators and the administration of surfactant for the treatment of neonatal respiratory distress syndrome, and therefore, the period after 1990 is often referred to as the "surfactant" or "post-surfactant" era (Bland, 2005). Additionally, this review will only discuss studies in which children with CP were either excluded or analyzed separately, as this review is intended to be an overview of motor skills deficits among the general preterm-born population.

Comparisons between Preterm- and Full-Term-Born Children

Prior to the examination of perinatal correlates of motor deficits *within* preterm-born children, it is necessary to establish whether this group differs in motor performance from full-term born children. In this section I review the literature pertaining to this topic. Nine of the 18 studies examined compared the motor abilities of preterm-born children to full-term-born children (Esbjorn et al., 2006; Janssen et al., 2008; Foulder-Hughes & Cooke, 2003; Goyen &

Lui, 2009; Davis et al., 2007; Jakobson, Frisk, & Downie, 2006; Larson et al., 2011; Feder et al., 2005; Marlow et al., 2007). Of these ten studies, all but one found significant group differences in motor skills between preterm- and full-term-born children.

Preschool age. Only two studies focused on the differences between term and preterm-born preschoolers in motor skills in samples served by the modern NICU. Both studies examined global motor skills, rather than assessing fine and/or gross motor skills independently.

***Global motor skills*.** Esbjorn and colleagues (2006) found that five-year-olds born prior to 28 weeks gestation (N = 199) obtained significantly poorer overall motor development scores (combined gross and fine motor performance) on the Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1992) than their full-term peers (N = 76). The researchers did not analyze gross and fine motor performances independently. In another study, global motor performances of two- to three-year-olds born prematurely (≤32 weeks gestation, N = 437) were compared to the Bayley Scales of Infant Development, Second Edition (BSID-II; Bayley, 1993) normative data (Janssen et al.,, 2008). The preterm born toddlers/preschoolers were found to exhibit a significantly greater prevalence of delayed motor performance (as determined by a Psychomotor Development Index [PDI] score >1 standard deviation below the mean).

School age. While only two research groups studied motor performance in preterm-born preschoolers served by the modern NICU (Esbjorn et al., 2006; Janssen et al., 2008), seven groups compared motor performances of preterm and full term born (or normative) children during early school ages (Foulder-Hughes & Cooke, 2003; Goyen & Lui, 2009; Davis, Ford, Anderson, & Doyle, 2007; Jakobson, Frisk, & Downie, 2006; Larson et al., 2011; Feder et al., 2005; Marlow, Hennessy, Bracewell, & Wolke, 2007). Similar to the two investigations of

preschool age, all seven studies of motor skills in school-age preterm-born children reported significant group differences.

Global motor skills. Four of the seven studies compared combined gross and fine motor performances (in addition to analysis of separate motor skills) between school age children born prematurely and full term born peers (Foulder-Hughes & Cooke, 2003; Goyen & Lui, 2009; Davis, Ford, Anderson, & Doyle, 2007; Jakobson, Frisk, & Downie, 2006). Three of the four studies (Foulder-Hughes & Cooke, 2003; Goyen & Lui, 2009; Davis, Ford, Anderson, & Doyle, 2007) found that children born prematurely (N = 280, N = 45, N = 255 respectively) from six- to nine-years-old, obtained significantly poorer combined gross and fine motor scores on the MABC than their full term born peers (N = 210, N = n/a, N = 208). Similarly, 5-6 year old preterm born children (N = 32) with a history of retinopathy of prematurity and/or periventricular brain injury obtained significantly poorer overall motor scores on the MABC than full term-born peers (N = 19), although preterm born children without these early complications (N = 11) performed similarly to children born full term (Jakobson, Frisk, & Downie, 2006).

Gross motor skills. Four of the seven studies compared gross motor skills between preterm- and full term-born children during the early school years (Foulder-Hughes & Cooke, 2003; Davis et al., 2007; Larson et al., 2011; Goyen & Lui, 2009), and all but Goyen and Lui (2009) found significant group differences. Two of the seven studies (Foulder-Hughes & Cooke, 2003; Davis et al., 2007) found that in comparison to full term-born classmates, preterm-born children obtained significantly poorer scores on the gross motor indices of the MABC (Ball Skills, Static Balance, and Dynamic Balance). While the former sample included age seven- to eight-year-old children, the latter included eight- to nine-year-olds. Larson and others (2001) found that compared to classmates born full term (N = 23), a group of prematurely born (<26

weeks gestation, *N* = 66) 6-year-old children exhibited significantly poorer motor control on both gross motor tasks (heel-toe walking and 1-leg balance) of the MABC. In contrast to the group differences in motor skills reported by the studies above, Goyen and Lui (2009) found that a cohort of eight-year-old children born prematurely performed similarly to full term born peers on the balance tasks of the MABC.

Fine motor skills. Six of the seven studies comparing motor skills between term and preterm school age children investigated fine motor skills (Marlow, Hennessy, Bracewell, & Wolke, 2007; Foulder-Hughes & Cooke, 2003; Davis et al., 2007; Feder et al., 2005; Larson et al., 2011; Jakobson, Frisk, & Downie, 2006). All six reported significant group differences in fine motor skills. Marlow and others (2007) reported that six-year-old children born prematurely (*N* = 180) performed significantly poorer than full-term born peers (*N* = 158) on a single fine motor item of the MABC (time to post 12 coins, preferred and nonpreferred hands), and on several visual-motor integration (design copying) and sensorimotor (fingertip tapping, imitating hand postures, visuomotor precision, finger discrimination, and manual motor sequences) tasks of the NEPSY: A Developmental Neuropsychological Assessment (Korkman, Kirk, & Kemp, 1998). Foulder-Hughes and Cooke (2003) found that full-term-born six-year-olds outperformed their preterm-born peers on all fine motor items of the MABC and on a design copying measure (Developmental Test of Visual-Motor Integration [VMI]; Beery & Buktenica, 1989). Davis et al. (2007) documented poorer scores on the Manual Dexterity subscale of the MABC in 8-9 year old preterm-born children compared to term-born controls. A fourth study (Larson et al., 2011) found that among seven to eight year olds, those born prematurely performed significantly more poorly than full term born peers on the Purdue Pegboard (Tiffen, 1968), an index of fine motor skills, and on the VMI. Although nondominant hand performances were comparable between

the groups, significant group differences were observed on performance with the dominant hand and with both hands. Feder and others (2005) reported that in comparison to full-term-born peers (N = 69), six- and seven-year-old children born prematurely (N = 48) demonstrated significantly poorer scores on the VMI, the Fine Motor Composite and all of the fine motor subtests of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP; Bruininks,1978), and on a task that measures one's ability to manipulate objects with one's hands (In-hand Manipulation Skill Test; Exner, 1992). Additionally, these preterm born children exhibited significantly poorer handwriting legibility and speed than the full term born children, although the groups performed similarly on appropriateness of pencil grasp (measured using the Evaluation Tool of Children's Handwriting-Manuscript [ETCH-M]; Amundson, 1995). Jakobson, Frisk and Downie (2006) found that prematurely born children aged five- to six-years-old with a history of retinopathy of prematurity and/or periventricular brain injury performed significantly more poorly than full term born peers on the VMI and on additional measures of graphomotor skills (unpublished measures of number and letter formation). However, preterm- born children without histories of these conditions performed similarly to the term-born group.

Specific motor skills. One of the seven studies compared specific motor skills between preterm- and full-term-born children. Foulder-Hughes and Cooke (2003) compared motor postural skills, or the ability to maintain body posture to orient the body appropriately, between seven- and eight-year-olds born prematurely and full-term born peers. The children who were born prematurely obtained significantly poorer scores on all subtests and on an overall index of motor postural skills on the Clinical Observation of Motor Postural Skills (COMPS; Wilson et al., 1994).

Motor system abnormalities. Four of the seven studies described above also assessed signs of abnormal development among school-aged children (Larson et al., 2011; Foulder-Hughes & Cooke, 2003; Davis et al., 2007; Goyen & Lui, 2009). Larson and others (2011) found that a cohort of six-year-olds born prematurely performed significantly slower than their full-term born peers on several timed repetitive or patterned (i.e., patterns of movements) motor tasks (right heel-to-toe taps, right and left finger taps, Right and Total Slow For Age scores) of the Physical and Neurological Examination of Soft Signs, a soft signs battery (PANESS; Denckla, 1985). However, the two groups performed similarly on two tasks of the PANESS (right finger sequence and tongue wags). Children born < 26 weeks gestation performed significantly poorer than the full term born group on several of these timed fine motor tasks (Left Slow for Age score, right and left foot taps, left heel-to-toe taps, right hand pats, bilateral hand pronate/supinate), but the preterm-born born at 26 weeks or later performed similarly to the full-term born group on these tasks. Foulder-Hughes and Cooke (2003) compared the prevalence of superfluous movements, defined as movements of body parts not involved in the assigned task or abnormal posturing, between preterm- and full-term-born six-year-olds using the Clinical Observation of Motor Postural Skills (COMPS). The preterm-born children were found to demonstrate significantly more superfluous movements than full term born peers. The authors (Foulder-Hughes, 2003) state that this suggests "cortical system immaturity" (p. 68). Also, two of the seven studies analyzed prevalence of developmental coordination disorder diagnoses among children born prematurely (Davis et al., 2007; Goyen & Lui, 2009). Both studies reported that children born prematurely were significantly more likely than their term-born counterparts to have been diagnosed with developmental coordination disorder.

In summary, seven studies compared performances on various aspects of motor functioning between preterm- and full-term-born school-aged children (Davis et al., 2007; Feder et al., 2005; Foulder-Hughes & Cooke, 2003; Goyen & Lui, 2009; Jakobson et al., 2006; Larson et al., 2011; Marlow, Hennessy, Bracewell, & Wolke, 2007). Significant differences were found between the groups on the majority of measures, with the children born prematurely demonstrating significantly poorer motor skills than children born full-term; Specifically, preterm-born children were found to have poorer motor skills than their term-born peers in several areas of motor functioning: overall motor skills (Foulder-Hughes & Cooke, 2003; Goyen & Lui, 2009; Davis, Ford, Anderson, & Doyle, 2007; Jakobson, Frisk, & Downie, 2006), gross motor skills (Foulder-Hughes & Cooke, 2003; Davis et al., 2007; Larson et al., 2011; Goyen & Lui, 2009), fine motor skills (Marlow, Hennessy, Bracewell, & Wolke, 2007; Foulder-Hughes & Cooke, 2003; Davis et al., 2007; Feder et al., 2005; Larson et al., 2011; Jakobson, Frisk, & Downie, 2006), and postural skills (Foulder-Hughes & Cooke, 2003). Motor system abnormalities were also reported in preterm children compared to their normal peers. Foulder-Hughes and Cooke (2003) reported increased soft signs of abnormal neuromotor development and increased superfluous movements, and two studies (Davis et al., 2007; Goyen & Lui, 2009) reported increased prevalence of developmental coordination disorder diagnoses among preterm-born children. However, sporadic failures to detect group differences in motor skills between term and preterm-born school-age children were occasionally noted on measures of gross motor skills (Goyen & Lui, 2009), fine motor skills (Larson et al., 2011),visual-motor integration (Jakobson, Frisk, & Downie, 2006), and motor speed (Larson et al., 2011).

Adolescents. No studies were found that compared motor skills during adolescence between those born prematurely and those born full term.

Meta-analytic studies. Only one meta-analytic study comparing preterm and term-born children on motor skills is currently available. De Kieviet and others (2009) quantitatively integrated data from 41 studies that compared motor skills in children between the ages of six months and 15 years of age born prematurely and/or very low birth weight (<33 weeks gestation and/or <1,500g) to performances of full-term born children or test norms. Results of the meta-analysis revealed that overall, children born prematurely obtained significantly poorer scores on the combined indices of gross and fine motor control derived from comprehensive motor batteries (Bayley Scales of Infant Development-II, Movement Assessment Battery for Children , Bruininks-Oseretsky Test of Motor Proficiency), as well as on subscale scores (of the MABC & BOTMP), than children born full term.

Examination of Perinatal and Sociodemographic Variables Associated with Lower Performance within the Preterm Population

Fifteen of the 18 studies that analyzed motor functioning in children born prematurely attempted to determine the source of individual differences in motor outcome amongst those children. To attain this goal, they examined the relationships between perinatal risk factors and motor performance within the preterm group. In each of these 15 studies, significant relationships were documented between perinatal risk factors and motor outcome. The details of these 15 studies are presented in Table 1.

Preschool age. As seen in Table 1, seven of the 15 studies examined correlates of motor outcome in preschool-age children born preterm, with all documenting significant relationships between perinatal risk factors and motor performance (Leversen et al., 2011; Raz et al., 2010; Goyen et al., 2006; Prins et al., 2010; Janssen et al., 2008; Newman et al., 2011; Raz et al., 2012).

Global motor skills. As seen in Table 1, four of the seven studies (Leversen et al., 2011; Raz et al., 2010; Newman et al., 2011; Raz et al., 2012) examined relationships between perinatal risk factors and combined gross and fine motor performances (in addition to analysis of specific motor skills). One study (Leversen et al., 2011) examined combined gross and fine motor scores among five-year-olds born extremely prematurely or of extremely low birth weight (N = 306). In the group of children born prior to 28 weeks gestation who did not have CP, blindness, or deafness, scores of overall motor functioning on the Movement Assessment Battery for Children were significantly related to gestational age and administration of prenatal steroids, in that higher gestational age and administration of prenatal steroids was associated with better motor performance. In addition, Leversen and others (2011) documented significant inverse relationships between overall motor functioning and male sex, small for gestational age (SGA) status, and retinopathy of prematurity (ROP) greater than stage 2. Cerebral ultrasound findings were not a significant predictor of overall motor performance. A second study by Raz and colleagues (2010) evaluated children aged 3- to 6-years-old who had been born prior to 27 weeks gestation (N = 40). A significant relationship between gestational age and overall motor performance was found, in that the children born at the younger gestational ages (23 to 24 weeks) obtained significantly poorer overall motor scores (Total Motor scores of the Peabody Developmental Motor Scales [PDMS-2]; Folio & Fewell, 2000) than the children born at later gestational ages (25 to 26 weeks). Among all of the preterm born children, higher socioeconomic status (SES) and administration of postnatal steroids was related to higher Total Motor scores. Another study by Raz and colleagues (2012) evaluated the associations between global motor functioning and intrauterine growth within 143 preterm-born children age 3 to 6. When the children with intrauterine growth restriction (IUGR) were compared to those who demonstrated

appropriate intrauterine growth, the IUGR group was reported to obtain significantly poorer mean scores on the Total Motor quotient (PDMS-2) than the group without IUGR. In addition, when intrauterine growth was treated as a continuous variable, there was a direct association between intrauterine growth and Total Motor scores. However, this association became nonsignificant when the children with intrauterine growth restriction were excluded from the analysis. Newman and colleagues (2011) evaluated 156 preterm-born children between the ages of 3- and 6-years-old. The researchers reported that children with and without bronchopulmonary dysplasia performed similarly on a measure of global motor skills, and that the number of days on ventilation was not associated with global motor performance; however, the number of days on supplemental oxygen, diagnosis of patent ductus arteriosus, number of total nonrespiratory complications, and male sex were inversely related to global motor performance. Additionally, a significant direct association between SES and global motor performance was reported.

Gross motor skills. Four of the seven studies examined the relationships between perinatal risk factors and gross motor performance within preschoolers born prematurely, as demonstrated by Table 1 (Goyen et al., 2006; Raz et al., 2010; Newman et al., 2011; Raz et al., 2012). Goyen and colleagues (2006) studied the relationships between various stages of retinopathy of prematurity (ROP) and motor skills within a group of three-year-olds born prior to 29 weeks gestation (N = 45). They found that children with stage 3 ROP obtained significantly poorer scores than children with stages 1 or 2 ROP on the Locomotor subscale of the Griffiths Mental Development Scales (Griffiths, 1970) and on the Gross Motor scale of the Peabody Developmental Motor Scales. A second study by Raz and others (2010) found a nonsignificant trend for an association between gestational age and gross motor performance (Peabody Developmental Motor Scales-2 [PDMS-2]) in a group of three- to six-year-olds, although a

significant relationship between gestational age and overall (combined gross and fine) motor performance had already been documented. Additionally, significant direct associations between SES, postnatal steroids and Gross Motor scores were found, as was a significant inverse relationship between number of nonrespiratory complications and Gross Motor scores. Another study by Raz and others (2012) reported a direct association between intrauterine growth and Gross Motor scores (PDMS-2) within preterm-born children born between 23 and 34 weeks gestation. However, this association became nonsignificant when the children with intrauterine growth restriction were excluded from the analysis. Newman and others (2011) reported an inverse association between scores on a gross motor index (GMQ PDMS-2) and the presence of patent ductus arteriosus within a group of 3- to 6-year-old children born prior to 32 weeks gestation. However, they did not report an association with the number of days on supplemental oxygen.

Fine motor skills. Four of the seven studies examined the relationships between perinatal risk factors and fine motor performance in preschoolers born prematurely, as is evident by examination of Table 1 (Goyen et al., 2006; Raz et al., 2010; Newman et al., 2011; Raz et al., 2012). Goyen and colleagues (2006) failed to find a significant relationship between retinopathy of prematurity and fine motor performance (fine motor scores on the Griffiths Mental Development Scales and the within a group of three-year-olds, in contrast to the significant relationship Peabody Developmental Motor Scales) between retinopathy of prematurity and gross motor performance noted above. A second study by Raz and colleagues (2010) documented a nonsignificant trend for a relationship between gestational age and fine motor performance (Peabody Developmental Motor Scales-2) in a group of three- to six-year-olds, although a significant relationship between gestational age and overall (combined gross and fine)

motor performance had already been documented. Additionally, neither SES nor administration of postnatal steroids were significantly related to fine motor outcome. Another study by Raz and others (2012) reported a direct association between intrauterine growth and Fine Motor scores (Peabody Developmental Motor Scales -2) within a group of preterm-born children age 3 to 6. However, this association became nonsignificant when the children with intrauterine growth restriction were excluded from the analysis. Newman and others (2011) reported a significant inverse association between the number of days on supplemental oxygen and an index of fine motor skills (Fine Motor Quotient, Peabody Developmental Motor Scales -2) within a group of 3- to 6-year-old preterm-born children. Of the two subtests that make up the fine motor index, performance on the Grasping subtest was inversely associated with the number of days on supplemental oxygen, but performance on the Visual-Motor Integration subtest was not. There also was no association between the diagnosis of patent ductus arteriosus and fine motor index score, although an association was reported with gross motor index scores.

Motor system abnormalities. Two of the seven studies, as displayed in Table 1, examined correlates of abnormal motor development classifications in preschoolers born prematurely (Prins, von Lindern, van Dijk, & Versteegh, 2010; Janssen et al., 2008). Prins and others (2010) followed a cohort of children born prematurely (N = 70) from 3 months until 4 years of age (corrected). They compared motor scores obtained at three ages: 3 months (Alberta Infant Motor Scales [AIMS]; Piper, Darrah, Maguire, & Redfern, 1994), 9 months (AIMS), and four-years-old (M-ABC). They found a significant direct association between age of testing and overall motor scores, in that children who exhibited "abnormal motor development" ($<10^{th}$ percentile on the AIMS or $<16^{th}$ percentile on the M-ABC) at the early ages tended to exhibit normal motor skills by 4-years-old. In other words, the children demonstrated a catch-up effect in that those who

initially demonstrated abnormal motor development improved by the time they were in preschool. In a second study, Janssen and others (2008) analyzed the prevalence of "delayed motor performance" (defined as BSID-III PDI score >1 SD below the mean) among two- to three-year-olds born prematurely (N = 437). They found a significant effect of age at testing in that children who were older at the time of testing obtained significantly better motor development classifications than those who were younger. Thus, they demonstrated a catch-up effect. Additionally, presence of neonatal convulsions, chronic lung disease, male sex, and low maternal education were all significantly related to delayed motor performance classification.

In summary, several perinatal risk factors were found to be associated with motor performance. Gestational age was found to be directly associated with motor functioning in two studies (Leversen et al., 2011; Raz et al., 2010), with both reporting an association with global motor skills, and the latter documenting nonsignificant trends for relationships with fine and gross motor skills individually. A single study reported a direct relationship between administration of prenatal steroids and global motor skills (Leversen et al., 2011). One study documented a direct relationship between the administration of postnatal steroids and both global and gross motor skills, although there was no association with fine motor skills independently (Raz et al., 2010). Three studies documented an inverse relationship between male sex and motor skills, with two reporting an association with global motor skills (Leversen et al., 2011; Newman et al., 2011) and the other reporting an association with abnormal motor system development (Janssen et al., 2008). One study reported small for gestational age status to be directly related to poorer global motor skills (Leversen et al., 2011). Two studies reported a significant inverse relationship between retinopathy of prematurity and motor skills. One study reported an association with global motor skills (Leversen et al., 2011), while the other reported an

association with gross motor skills, but failed to find an association with fine motor skills (Goyen et al., 2006). Two studies reported an indirect relationship between number of nonrespiratory complications and motor skills, with one reporting an association with gross motor skills (Raz et al., 2010) and the other reporting an association with global motor skills (Newman et al., 2011). Age at time of testing, or a catch-up effect, was reported by two studies to be associated with abnormal motor development classifications (Prins et al., 2010; Janssen et al., 2008). A single study also reported indirect relationships between abnormal motor development classifications and neonatal convulsions and chronic lung disease (Janssen et al., 2008). One study reported significant associations between the number of days on supplemental oxygen and global motor and fine motor skills, although there was no association with gross motor skills (Newman et al., 2011). The same study did not find an association between the number of days on ventilation or diagnosis of bronchopulmonary dysplasia and global motor skills (Newman et al., 2011). One study reported significant indirect associations between patent ductus arteriosus diagnoses and global and gross motor skills, but no association with fine motor skills (Newman et al., 2011). A single study found an inverse association between diagnosis of intrauterine growth retardation and global motor scores, as well as associations between intrauterine growth (as a continuous variable) and global, gross, and fine motor skills (Raz et al., 2012).

Two studies found significant associations between SES and motor skills. Two studies reported associations between SES and global motor skills (Newman et al., 2011; Raz et al., 2010), while one reported an association with gross motor skills, but not with fine motor skills.

School age. Six studies have studied the relationships between perinatal and sociodemographic variables and motor skills within samples of school age children born preterm (Foulder-Hughes & Cooke, 2003; Larson et al., 2011; Samsom et al., 2002; Davis et al., 2007;

Goyen & Lui, 2009; Feder et al., 2005) . As seen in Table 1, four of these studies reported significant relationships between perinatal risk factors and motor performance (Foulder-Hughes & Cooke, 2003; Larson et al., 2011; Samsom et al., 2002; Davis, Ford, Anderson, & Doyle, 2007).

Global motor skills. As seen in Table 1, two of the six studies (Foulder-Hughes & Cooke, 2003; Goyen & Lui, 2009) examined correlates of combined gross and fine motor performance in school-aged children, with only one of the two studies (Foulder-Hughes & Cooke, 2003) reporting significant relationships between perinatal variables and motor outcomes. The former group found significant statistical associations between gestational age or birth weight and overall performance on the Movement Assessment Battery for Children (MABC) in a sample of 280 7- to 8-year-old children born prematurely. Increased gestational immaturity and lower birth weight were associated with lower overall MABC scores. Goyen and Lui (2009) studied the relationships between combined motor functioning and diagnosis of visual problems among 8-year-olds born prematurely (N = 50). They were unable to demonstrate significant group differences on total MABC scores between school-age children with and without diagnosed visual problems.

Fine motor and visuomotor skills. Three of the six studies (Foulder-Hughes and Cooke, 2003; Larson et al., 2011; Feder et al., 2005) analyzed correlates of fine motor functioning in school-aged children born prematurely, with all three reporting significant relationships between perinatal variables and fine motor outcome. As seen in Table 1, Foulder-Hughes and Cooke (2003) reported significant associations between gestational age or birthweight, and performance on the Developmental Test of Visual-Motor Integration (VMI) in 7- to 8-year-olds born prematurely. Increased gestational immaturity and lower birth weights were associated with

lower VMI scores. Larson and colleagues (2011) studied fine motor skills in a group of 66 6-year-old children born prematurely. They also reported a significant effect of gestational age, as children born <26 weeks gestation performed significantly more poorly on a speeded task of motor dexterity (Purdue Pegboard Test of Manual Dexterity) than children born ≥26 weeks. Feder and colleagues (2005) examined correlates of handwriting skills in a sample of 48 6- to 7-year-olds born prematurely, and found a significant relationship between sex and handwriting legibility. Boys' handwriting legibility was significantly poorer than girls'. No sex differences were observed in handwriting speed within this sample. More importantly, however, no significant relationships were observed between handwriting legibility or speed and gestational age, birth weight, presence of intraventricular hemorrhage grade I or II, bronchopulmonary dysplasia (Stages 1-3) or retinopathy of prematurity.

Motor speed. As seen in Table 1, only one of the six abovementioned studies (Larson et al., 2011) analyzed the relationships between perinatal variables and motor speed and efficiency performances in school-aged children born prematurely. Larson and colleagues (2011) examined the relationships between medical variables (i.e., days on Dexamethasone, days in the NICU, and total number of complications) and Physical and Neurological Examination of Soft Signs (PANESS) summary indices in a group of 6-year-old children born prematurely. They reported a significant statistical association between Total Slow for Age (SFA) scores and NICU length-of-stay. Children who required longer hospitalizations also demonstrated motor slowness on gross and fine motor tasks. A significant association between gestational age and fine and gross motor speed and efficiency was also found. Specifically, children born prior to 26 weeks gestation performed significantly more poorly than children born at 26 weeks or later on three speeded motor tasks of the Physical and Neurological Examination of Soft Signs (PANESS), which

consisted of timing how long it took each child to complete a designated number of alternating movements (right foot taps, left heel-to-toe taps, and right hand pronate/supinate tasks). However, the groups performed similarly on slow-for-age (SFA) scores. No significant relationships were observed between days on Dexamethasone or number of complications and any of the fine and gross motor speed or efficiency variables.

Specific motor skills. Four of the six abovementioned studies (Foulder-Hughes & Cooke, 2003; Samsom et al., 2002; Davis et al., 2007; Goyen & Lui, 2009) also examined correlates of specific aspects of motor functioning, with all but one (Goyen & Lui, 2009) reporting significant associations between perinatal variables and performance on specific motor tasks. Foulder-Hughes (2003) examined correlates of postural stability in school-aged children born prematurely. They reported significant direct associations between gestational age or birth weight and Clinical Observation of Motor Postural Skills (COMPS) total weighted score. Lower gestational age or birth weight was associated with less developed postural stability.

Abnormal motor system development. Four studies examined correlates of abnormal motor system development in school-age children born prematurely (Samsom et al., 2002; Davis et al., 2007; Goyen & Lui, 2009; Larson et al., 2011), as demonstrated by Table 1. Samsom and others (2002) examined correlates of abnormal neuromotor functioning in 63 school-aged children born prematurely. They administered a clinical neurological evaluation (Touwen, 1979), which assessed subtle signs of neurologic dysfunction by assessing "hand function, quality of walking, postural control, passive muscle tone, coordination, and diadochokinesia" (p. 327). The investigators reported significant sex differences within their sample, with boys receiving lower scores on an overall index of neurologic functioning, as well as significantly lower scores for each subtask except for diadochokinesia (i.e., the ability to complete series of antagonistic

movements). Severity of perinatal illness was also found to be related to functional neuromotor abnormalities. When the children were categorized in regard to the severity of their medical status at birth based on the Neonatal Medical Index (Korner et al., 1994), those categorized as having more severe medical conditions obtained significantly poorer total neurological scores and subtask scores except for diadochokinesia. Birth weight, gestational age, dysmaturity (defined by the authors as birth weight $<10^{th}$ percentile), abnormal cranial ultrasound, and ventilation days were not related to neuromotor outcomes. In regard to associated movements (i.e., overflow) and motor asymmetry (when comparing right and left sided motor skills), indicative of underdeveloped motor functioning, there was a trend for a relationship between severity of perinatal medical status and degree of motor asymmetry. Those belonging to the group of the most severe medical status demonstrated significantly more motor asymmetry across the motor tasks than those of less severe medical statuses. However, there were no significant relationships between gender, birth weight, gestational age, dysmaturity, or pathological cranial ultrasound findings on degree of motor asymmetry or associated movements. Two studies analyzed correlates of developmental coordination disorder (DCD) diagnoses among school age children born prematurely (Davis et al., 2007; Goyen & Lui, 2009). Davis and others (2007) reported significantly increased probability of DCD diagnoses in males. In addition, they observed a trend for a relationship between DCD and presence of intraventricular hemorrhage grade III or IV, and between DCD and surfactant exposure. . Goyen and Lui (2009) were unable to show relationships between DCD diagnoses and visual problems, premature rupture of membranes, or retinopathy of prematurity in a sample of 8-year-old children born prematurely. Larson and others (2011) examined soft signs within a group of preterm-born six-year-olds using the Physical and Neurological Examination of Soft Signs

(PANESS). They reported that when the children were separated into two groups based on gestational age at birth (those born < 26 weeks gestation and those born ≥26 weeks), there were no significant group differences in the degree of motor overflow demonstrated across the tasks.

In summary, five of the six studies identified correlates of motor functioning within school-age children born prematurely. Two studies reported associations between gestational age and motor skills (Foulder-Hughes & Cooke, 2003; Larson et al., 2011). One of the studies (Foulder-Hughes & Cooke, 2003) reported a significant association with global motor skills. Both studies (Foulder-Hughes & Cooke, 2003; Larson et al., 2011) reported significant associations with fine motor skills, but one study (Feder et al., 2005) did not find a significant association between fine motor skills and gestational age. Gestational age was reported to be associated with motor speed (Larson et al., 2011) and specific motor skills (Foulder-Hughes & Cooke, 2003), although there was not an association with abnormal motor system development (Samsom et al., 2002). A single study reported associations between birth weight and motor skills (Foulder-Hughes & Cooke, 2003). Foulder-Hughes & Cooke (2003) reported significant associations between birth weight and global motor and specific motor skills. They also reported a significant association with fine motor skills, but another study (Feder et al., 2005) did not observe a significant association. Samsom and others (2002) did not observe a significant association between birth weight and abnormal motor system development. The presence of interventricular hemorrhage was reported to have a trend for a relationship with abnormal motor system development in one study (Davis et al., 2007), but another study did not find an association with fine motor skills (Feder et al., 2005). A single study (Larson et al., 2011) reported significant associations between motor speed and NICU length-of-stay, but failed to find associations of administration of dexamethasone or total number of complications and motor

speed. A male disadvantage on abnormal motor system development was reported by two studies (Samsom et al., 2002; Davis et al., 2007). Also, administration of surfactant demonstrated a trend for a relationship with abnormal motor system development (Davis et al., 2007). However, significant associations between abnormal motor system development and medical severity (Samsom et al., 2002), dysmaturity or appropriateness of birth weight (Samsom et al., 2002), premature rupture of membranes (Goyen & Lui, 2009), abnormal cranial ultrasound (Samsom et al., 2002), or days on ventilation (Samsom et al., 2002) were not reported. Retinopathy of prematurity did not demonstrate an association with fine motor skills (Feder et al., 2005) or abnormal motor system development (Goyen & Lui, 2009). Diagnosed visual problems were not reported to be associated with global motor skills (Goyen & Lui, 2009) or abnormal motor system development (Davis et al., 2007). An association between fine motor skills and diagnosis of bronchopulmonary dysplasia was not observed (Feder et al., 2005).

Older children and adolescents. Only one study (Danks et al., 2012), as seen in Table 1, analyzed the relationships between perinatal risk factors and motor skills in adolescents born prematurely. This group of investigators examined the relationships between scores on motor outcome measures obtained by children born prematurely (N = 48) at four time points: 8-months-old, 2-years-old, 4-years-old, and 11- to 13-years old. They reported that poorer overall motor scores on the NeuroSensory Motor Developmental Assessment (NSMDA; Burns, Ensbey & Norrie, 1989) at 8-months-old was highly predictive of "mild motor impairment" classifications (based on overall Movement Assessment Battery for Children [MABC] score) at 11 to 13 years of age. Furthermore, motor scores at 2- and 4-years-old on the NSMDA significantly predicted motor scores at 11-13 years old. There was a significant effect of gender, with boys exhibiting significantly higher rates of long-term motor impairment (i.e., ongoing motor impairment during

adolescence) than girls. In contrast, variables such as gestational age, multiple birth status, and early growth measures (i.e., birth weight and head circumference) were not found to be significantly related to NSMDA scores. Performances on measures of postural control and sensory motor skills (NSMDA tasks) at 4 years of age were significantly related to motor scores at 11-13, but NSMDA scores of neurological functioning were not significantly related to overall MABC scores at 11 to 13 years of age. In summary, early motor performance during the toddler years was predictive of motor performance during early adolescence. Boys demonstrated higher rates of long-term motor impairment than girls, but perinatal risk factors (gestational age, multiple birth status, early growth measures) were not significant predictors of motor performance.

Meta-analytic study. DeKieviet and others (2009) conducted a quantitative integration of 41 studies that assessed combined fine and gross motor skills (via the Bayley Scales of Infant Development-II [BSID-II], the Movement Assessment Battery for Children [MABC}, or the Bruininks-Oseretsky Test of Motor Proficiency [BOTMP]) in very preterm born children age 6 months to 15 years. A significant effect of age at assessment was found for the BSID-II total scores. Specifically, preterm-born children demonstrated a "catch-up effect," with a significant increase in global motor scores (Psychomotor Developmental Index scores) during early childhood (6 to 36 months of age); however, preterm born children demonstrated a trend for decline in overall scores on the MABC (which assesses more complex motor skills) during elementary school and adolescence. In addition to an effect of age-at-assessment, the authors also documented an effect of perinatal medical status. Children who experienced perinatal complications beyond premature birth obtained significantly lower overall motor scores (Psychomotor Developmental Index scores) than preterm-born children who did not experience

additional perinatal complications. Both birth weight and gestational age were found to be significantly positively related to Psychomotor Developmental Index scores, but neither variable was significantly related to MABC scores. The authors concluded that the increase in BSID-II scores and decrease in MABC scores with increasing age suggests that the BSID-II assesses less complex aspects of motor functioning than the MABC. Thus, the findings indicate that children born prematurely tend to demonstrate a catch-up effect in regard to basic motor skills, but that deficits in complex motor skills persist throughout childhood and early adolescence.

Relationships between Motor Skills and Cognitive Abilities

Of the 18 articles that analyzed motor functioning in children born prematurely, only two studies attempted to understand the relationships between motor skills and cognitive functioning. Both of the studies reported significant relationships between motor functioning and cognitive skills. The details of these studies are displayed in Table 1.

As seen in Table 1, only two studies of preterm-born children assessed the relationships between motor skills and cognitive abilities (Foulder-Hughes & Cooke, 2003; Davis et al., 2007). Foulder-Hughes and Cooke (2003) assessed motor (Movement Assessment Battery for Children [MABC], Clinical Observation of Motor Postural Skills [COMPS], & the Developmental Test of Visual-Motor Integration [VMI]) and cognitive (WISC-III UK) skills in a group of seven-year-olds born prematurely. These investigators reported significant associations between performances on all overall indices (from the MABC, COMPS, & VMI) of motor skills and full scale IQ, verbal IQ, and performance IQ. A second study (Davis et al., 2007) found that among 8- to 9-year-olds born prematurely, children with developmental coordination disorder (DCD) diagnoses obtained significantly lower WISC-III scores (FSIQ, Verbal Comprehension,

Perceptual Organization, Freedom from Distractibility, and Processing Speed Indices) than those without DCD.

Critique of Fifteen Studies Examining Early Correlates of Motor Skills Outcome within Preschool and School-Age Preterm-Born Children

The major methodological shortcomings in studies which examined early correlates of motor development within samples of preterm-born children of preschool or school age are listed below.

Failure to control for neurological conditions.

Six studies were vague about their exclusionary criteria or failed to control for conditions such as cerebral palsy (CP), periventricular hemorrhage (PVL), or intraventricular hemorrhage (IVH) grades III and IV (Leversen et al., 2011; Prins et al., 2010; Foulder-Hughes & Cooke, 2003; Janssen et al., 2008; Davis et al., 2007; Goyen & Lui, 2009). Also, one study (Danks et al., 2012) excluded children with extremely deficient cognitive skills (>2 SD below the mean), which is problematic because the results are not representative of the preterm-born population. It would have probably been more informative to analyze the data with and without the excluded cases.

Failure to consider background perinatal risk-factors in studies examining motor correlates within the preterm population.

Six studies did not statistically adjust for gestational age, medical status of the infant (perinatal complications), intrauterine growth rate (appropriateness of birth weight for gestational age), and/or gender (Prins et al., 2010; Goyen et al., 2006; Davis et al., 2007; Foulder-Hughes & Cooke, 2003; Goyen & Lui, 2009; Larson et al., 2011). Additionally, one

study only looked at arbitrary groupings (i.e., born <26 weeks gestation versus ≥26 weeks) and neglected to examine gestational age as a continuum (e.g., Larson et al., 2011).

Failure to perform proper adjustment for sociodemographic factors.

Several of the 12 studies that examined early correlates of motor functioning in prematurely born children failed to control for socioeconomic status (e.g., Prins et al., 2010; Goyen et al., 2006; Samsom et al., 2002).

Failure to use broad or standardized motor skills measures.

Of the studies examined, the majority used comprehensive standardized batteries of motor functioning (e.g., PDMS, MABC, BSID), although a single study utilized an unstandardized measure of motor skills (Samsom et al., 2002).

Limited generalization due to the use of birth weight cutoff.

Most of the studies used gestational age cutoffs to define who would be included in their preterm groups, but four studies used birth weight cutoffs without examining the effects of appropriateness of birth weight on motor outcome (Larson et al., 2011; Danks et al., 2012; Goyen & Lui, 2009; Davis et al., 2007). The problem with using birth weight as a cut-off is that children who are small for gestational age (SGA) may be overrepresented in the sample. Thus, the sample is biased toward lower performance in the low birth weight group, as children who are small for gestational age have demonstrated poorer outcome than preterm children who are appropriate for gestational age (Leversen et al., 2011).

Hypotheses and Rationale

The literature on motor functioning in children born prematurely is limited, with only 15 studies examining the source of individual differences in motor functioning within the preterm-born group at preschool or school age. Of these 15 studies, only seven explored the source of

motor outcome differences at preschool age, and only two of these studies used early preschool age samples. The current study focused on the early biological factors, or perinatal medical variables, that could influence motor functioning at early preschool age. My goal was to attempt to establish such associations at the earliest possible time beyond infancy or the toddler years, when assessment with psychometric instruments and measures of motor skills often produces more reliable and predictive findings. Identification of motor skills deficits at an early age is essential because interventions tend to be more effective during the early years while the brain is still developing.

1. It was hypothesized that degree of immaturity (operationalized as gestational age at birth) would be significantly related to motor abilities in a nondisabled sample of preterm born children <34 weeks gestation. It was expected that within this sample, children with lower gestational age would perform more poorly on motor outcome measures, even after taking into account the total number of complications, intrauterine growth adequacy, sex, and socioeconomic status. The degree of immaturity has been shown to be directly associated with extent of disruption to cortical development (Kapellou et al., 2006) and has also been shown to be associated with reduced cerebellar volume in preterm-born children during the period following birth (Padilla, Alexandrou, Blennow, & Lagercrantz, 2014). In addition, abnormalities of cerebral white matter (lesions and reduced volume), a brain substrate containing multiple motor tracts, have been shown in preterm-born children relative to controls (Woodward, Anderson, Austin, Howard, & Inder, 2006; Woodward, Clark, Bora, & Inder, 2012). Finally, changes in subcortical grey matter structures known to mediate motor functions, such as the basal ganglia (Grunewaldt et al., 2014), thalamus (Rose et al., 2014), and cerebellum (Allin et al., 2011), have also

been documented in children born prematurely. These changes include reduced volumes (Grunewaldt et al., 2014; Allin et al., 2011), and signal abnormalities on MRI (Rose et al., 2014). Clearly the evidence described above regarding changes in brain structures involved in movement in the preterm born child provide one with the rationale for hypothesizing that the degree of gestational immaturity could be directly related to motor functioning in the preterm born child.

As illustrated in Table 1, three studies have reported significant (or nonsignificant trend) associations between gestational age and motor functioning during the preschool and early school ages (Leversen et al., 2011; Foulder-Hughes & Cooke, 2003; and Raz et al., 2010). Two studies were unable to document an effect of gestational age on motor functioning (Samsom et al., 2002; Feder et al., 2005), and one reported significant associations between gestational age and fine motor skills, but inconsistent associations with fine and gross motor speed (Larson et al., 2011). The current study attempted to both replicate and extend the findings of the three studies that reported associations between gestational age and motor functioning. While Raz and others (2010) included only extremely preterm children, I included children born <34 weeks gestation. Leversen and colleagues (2011) examined motor skills within a group of extremely preterm born children, but the current study included a wider gestational age range. While Foulder-Hughes and Cooke (2003) studied motor functioning in 7-year-olds, the current study extended their findings to early preschool-age children. In summary, the sample of preterm birth children I studied were gestationally more mature (<34 weeks), but chronologically younger. The expanded gestational age range and younger age constitute

an extension of the previously documented relationships in the three abovementioned studies.

2. Males disadvantage in recovery from preterm-birth has been attributed to the tendency for boys to develop more slowly and to suffer more serious medical complications at birth (i.e., hypoxic events, infections, and respiratory conditions) than girls (Ingemarsson, 2003). In addition, boys have been shown to demonstrate poorer recovery from perinatal complications than girls (Smith, Alexander, Rosenkrantz, Sadek, & Fitch, 2014). One explanation for this finding is that boys may lack the compensatory and plasticity capabilities that girls exhibit (Smith et al., 2014). For example, boys have significantly lower catecholamine levels than girls, which hinders their ability to recover from hypoxic events (Ingemarsson, 2003). Also, increased testosterone levels have been associated with poorer neonatal health and growth (Cho, Carlo, Su, & McCormick, 2012). Therefore, I hypothesized that boys would perform more poorly than girls on measures of both fine and gross motor functioning. Among full term born children, it has been reported that boys performed better than girls on the PDMS-2 Object Manipulation subscale of the Gross Motor Index (but similarly on the other two subscales: Stationary and Locomotion). In contrast, they performed more poorly on both of the fine motor subscales (Grasping and Visual-Motor Integration; Saraiva, Rodrigues, Cordovil, & Barreiros, 2013). However, this pattern has not been replicated among preterm-born males. As shown in Table 1, three studies reported a significant male disadvantage on measures of gross and fine motor skills (Newman et al., 2011; Leversen et al., 2011; Samsom et al., 2002), and boys have also been shown to demonstrate higher rates of mild motor impairment than girls (Danks et al., 2012). In the current study, I attempted to

replicate and extend the findings of these three studies to a younger, preschool-aged sample. While Leversen and others (2011) used a sample of extremely preterm-born children, the current study included a wider gestational age range, as noted above. This investigation also utilized a standardized battery of motor functioning rather than unstandardized clinical evaluation (see Samsom et al., 2002), and included younger children with a more extended gestational age range than those children studied by Newman and others (2011).

3. It was hypothesized that significant relationships would exist between motor skills, and functioning in other neuropsychological domains, specifically, cognitive and language functioning.

    a. It was hypothesized that performance on both fine and gross motor tasks would be directly associated with verbal and visuospatial cognitive performance (i.e., VIQ and PIQ) in a sample of preterm born children at early preschool age. The rationale for this hypothesis was firstly, that structures known to be susceptible to the various insults associated with prematurity (e.g., the cerebellum; Allin et al., 2000) are involved in both cognitive, as well as gross and fine motor skills. For instance, Diamond (2000) hypothesized that the cerebellum, which is known for its role in motor function, is also involved in cognitive functioning. Specifically, the cerebellum is believed to be involved in learning, or the acquisition of cognitive skills (Diamond, 2000). Thus, damage to the cerebellum may affect both motor and cognitive performance. As shown in Table 1, both of the studies that examined the relationships between cognitive and motor performances in preschool and school age children reported significant associations (Foulder-

Hughes and Cooke, 2003; Davis et al., 2007). Motor skills deficits may be apparent at a younger age than cognitive impairments, so if there is a relationship between motor and cognitive abilities, identification of motor deficits may indicate the necessity for cognitive assessment. Thus, the current study attempted to replicate the associations between cognitive and motor performances reported among groups of 7-year-old children, and extended the findings downward to early preschool-age children.

b. It was hypothesized that within a sample of preterm born children, performance on motor tasks would be directly associated with performance on expressive language measures. Specifically, based on associations reported in previous studies, it was expected that only fine motor skills, but not gross motor skills, would be associated with expressive language skills. Imaging studies have identified abnormalities in cortical and subcortical white matter among children with specific language impairments (e.g., ventricular enlargement, central volume loss, white matter hyperintensity, periventricular encephalomalacia; Trauner, Wulfeck, Tallal & Hesselink, 2007), while ventricular enlargement (Melhem et al., 2000) and white matter lesions (Chau, 2013), in turn, are common in children with motor impairments. Similar brain abnormalities are also common in children born prematurely (e.g., Lax et al., 2013; Woodward, Anderson, Austin, Howard, & Inder, 2006). Clearly, speech requires extensive oral muscle coordination or control. Thus it is possible that deficient motor skills will result in difficulties with expressive language, specifically with articulation and fluency tasks. The association between fine motor, but not gross motor, skills and expressive

language skills has been documented in children with conditions such as autism (LeBarton & Iverson, 2013) and specific language impairment (SLI; Hill, 2010). Therefore, the current study attempted to examine the associations between performance on fine motor tasks and expressive language tasks in a sample of preterm born preschoolers. This association between fine motor and expressive language abilities has never been studied, especially within this unique population.

CHAPTER 2: METHOD

Participants

One hundred and nine (109) subjects were recruited for the current study. The children were recruited as a part of a larger investigation titled Neuropsychological Outcome in Preschool and School Aged Children with Perinatal Complications and with Various Degrees of Exposure to Prenatal Steroids, approved by both William Beaumont Hospital (WBH) and Wayne State University (WSU) internal review boards. The parents of children born at or before 33 weeks gestation, who were born and treated in the NICU at William Beaumont Hospital (Royal Oak, Michigan) between 2007 and 2010, were contacted to determine interest in participating.

Inclusion Criteria. Participants for this segment of the study were recruited from a cohort of preterm born infants (less than 34 weeks of completed gestation) who were born and treated in the Neonatal Intensive Care Unit (NICU) at William Beaumont Hospital in Royal Oak, Michigan. Participants were born between 2007 and 2010 and were between the ages of 3 and 4 years (adjusted for prematurity) at the time of recruitment. Of the 614 eligible children, 20% were tested, 1.7% did not show to their scheduled appointments, 18% were not interested in participating, and 60% were not contactable (i.e., we did not have their correct phone numbers or addresses, or the families did not return our messages).

General Exclusion Criteria. Infants were excluded from this segment of the Steroid Study under the following circumstances: death, gestational age >33 weeks, presence of major congenital anomalies (e.g., spina bifida, cleft palate, etc.) or chromosomal disorders, children with perinatal neonatal meningitis, and children who required mechanical ventilation at discharge from the NICU. Infants were also excluded if they were transported to Beaumont from a different hospital (i.e., "outborn"). It is thought that during transport from one hospital to

another, infants may receive insufficient respiratory support (Lee et al., 2003). Additionally, children whose parents had reported on the Background Questionnaire that the child had a seizure disorder that required antiepileptic medication (in contrast to neonatal seizures), history of severe head trauma with loss of consciousness, severe cerebral palsy, or uncorrected sensory deficits (e.g., blindness, deafness) were excluded.

Additional exclusion criteria for the Prematurity Motor Skills Study. Infants were excluded from the Prematurity Motor Skills Study under the same circumstances as those listed above for the Steroid Study and also in the case of maternal alcohol/drug abuse during pregnancy (as indicated in the labor & delivery records), although cases where the mothers admitted to occasional alcohol use were included. In addition, children were excluded from the Prematurity Motor Skills Study if they sustained a severe intracranial hemorrhage (grades 3 or 4), a hemorrhage that originated outside the Germinal Matrix, or have been diagnosed with periventricular leukomalacia (PVL).

Sample characteristics. Altogether, 109 participants were recruited for the study; however, five children were excluded from the study who were untestable due to low functioning and/or who were uncooperative with most of the assessment. Thus, 104 children were included in this study. One child with cerebral palsy (spastic diplegia) and two children with moderate-to-severe intracranial hemorrhage were included in the current study; however, the statistical analyses were run first with, and then without, these three "neurological" cases. The participants were divided into two groups based on gestational age at birth. The lower gestational age group consists of children born at 30 weeks gestation or earlier (M = 28.25, SD = 1.92) and the higher gestational age group consists of children born after 30 weeks gestation (M = 32.39, SD = 0.82). The demographic and socio-familial characteristics of each group are presented in Table 3. No

significant group differences were observed in race, gender, adjusted age at testing, proportion of multiple gestation, maternal and paternal education, maternal VIQ, and SES (Hollingshead, 1975).

The antenatal, perinatal, and neonatal complications by gestational age group are depicted in Table 4. In regard to antenatal complications, the lower gestational age group exhibited higher rates of chorioamnionitis and demonstrated significantly poorer intrauterine growth rates, indexed by the intrauterine growth *z*-score, than the higher gestational age group. The intrauterine growth z-score was calculated according to norms published by Kramer and colleagues (2001), which requires calculating the deviation of an infant's birth weight from the mean weight of his or her normative group, as defined by both gestational age at birth and sex. The groups did not differ significantly in frequency of placental abruption, maternal diabetes, HELLP syndrome, hypertension in pregnancy, IUGR diagnosis, prolonged rupture of membranes (>12 hours), oligohydramnios, smoking during pregnancy, or vaginal bleeding. Additionally, the groups did not differ on maternal age at delivery, maternal height, or parity.

With respect to perinatal risk factors, as expected, the lower gestational age group had significantly lower birth weight, shorter birth length, and smaller head circumference at birth, than the higher gestational age group (see Table 4). The groups also significantly differed on 1-minute and 5-minute Apgar scores, with the younger gestational age group demonstrating poorer scores than the older gestational age group. The groups did not differ significantly on the relative frequency of abnormal presentation, caesarean section, use of forceps, general anesthesia, nuchal cord, or fetal tachycardia.

Concerning neonatal risk factors, Table 4 illustrates that the lower gestational age group exhibited significantly more cases of apnea, bronchopulmonary dysplasia, hyaline membrane

disease, patent ductus arteriosus, retinopathy of prematurity, sepsis, and greater number of days in the NICU. Conversely, in comparison to the lower gestational age group, the higher gestational age group exhibited a greater frequency of hyperbilirubinemia and greater peak bilirubin levels. The groups did not differ significantly in the relative frequencies of anemia, hypermagnesemia, hypotension, intracranial hemorrhage, meconium aspiration, necrotizing enterocolitis, persistent pulmonary stenosis, pneumothorax, or thrombocytopenia.

Psychological Assessment

General Considerations. Each child was evaluated over 1 to 3 sessions depending upon the examiner's assessment of his/her attention and concentration. Prior to evaluation, the parents signed an informed consent form verifying that they understood the nature of the assessment and agreed to the outlined terms. During the evaluation, the parents completed a background questionnaire designed to obtain information about their child's medical and developmental history as well as current behavioral functioning. Approximately two weeks after the initial child assessment, the mothers (or fathers) were contacted by phone, during which an evaluation of their verbal intellectual ability was obtained, and verbal feedback was provided regarding the results of their child's assessment. After feedback was completed, each parent was mailed a typed copy of a report that outlined the results of his or her child's evaluation, including recommendations for further testing as needed.

Motor Skills. Gross and fine motor functioning were evaluated using the Peabody Developmental Motor Scales—Second Edition (PDMS-2; Folio & Fewell, 2000). Reliability and validity properties can be found in Table 2. The Gross Motor Quotient is comprised of three subtests: Stationary, Locomotion, and Object Manipulation. The Stationary subtest assesses the child's ability to maintain his or her balance (e.g., standing on one foot, standing on toes, etc.).

The Locomotion subtest examines a child's ability to move around the room (e.g., running, skipping, etc.). The Object Manipulation subtest includes throwing, catching, and kicking balls. The Fine Motor Quotient is comprised of the Grasping and Visual-Motor Integration subtests. The Grasping subtest assesses the ability to grasp objects and control finger movements. The Visual-Motor Integration subtest evaluates hand-eye coordination. The Total Motor Quotient is a composite of all five gross and fine motor subtest scores, representing overall motor performance.

Four subtests from the NEPSY- Second Edition: *A Developmental Neuropsychological Assessment* (NEPSY-II; Korkman, Kirk, & Kemp, 1997) were used: Design Copying, Imitating Hand Positions, Manual Motor Sequences, and Visuomotor Precision. Design Copying is a visuospatial reproduction task in which the child is asked to copy shapes that gradually become more complex. For Imitating Hand Positions, the child is asked to imitate a hand position demonstrated by the examiner. For Manual Motor Sequences, the examiner demonstrates a series of hand movements and the child is asked to imitate the movements several times. The Visuomotor Precision subtest requires the child to quickly draw a line between two printed lines on a page that become narrower with each trial.

Intellectual Ability. Intellectual functioning was evaluated using the Wechsler Preschool and Primary Scale of Intelligence-Third/-Fourth Edition (WPPSI-III: Wechsler, 2002; WPPSI-IV: Wechsler, 2012). One subtest from the verbal subscale (Information) and one subtest from the performance subscale (Block Design) were administered to each child to obtain an estimate of verbal ability (VIQ) and visual-spatial ability (PIQ). These two subtests were selected because they have the highest correlations with PIQ and VIQ respectively. Reliability and validity properties can be found in Table 2.

Language skills. Expressive (i.e., the ability to produce meaningful speech) language skills were assessed using the Clinical Evaluation of Language Fundamentals—Preschool, Second Edition (CELF-P2; Wiig, Secord & Semel, 2004). For three to four year olds, the CELF-P2 provides five index scores: Core Language Score, Receptive Language Index, Expressive Language Index, Language Content Index, and Language Structure Index. Reliability and validity properties can be found in Table 2.

General Statistical Considerations

Simultaneous multiple regression analyses were used to analyze the data. The variables of interest were gestational age and gender. The neuropsychological outcomes of interest were various motor performance scores. Relationships between motor, cognitive, and language outcomes were also analyzed to help understand the relationship between motor functioning and other neuropsychological abilities. A separate multiple regression analysis was conducted for each outcome measure, and included a set of predictors determined to be appropriate for that particular performance measure.

Several procedures were used in order to identify demographic and perinatal variables that may contribute significant variance to the measured outcomes and subsequently, to determine additional predictors, i.e., "covariates" to include in the analyses. Group differences according to gestational age (<30 weeks versus ≥30 weeks) were examined on a variety of socio-demographic variables and medical complications to determine appropriate "covariates" to include in the analyses. As Table 3 shows, the two gestational age groups did not vary significantly on any of the socio-demographic variables. As Table 4 shows, in regard to medical complications, significant group differences were identified for several variables, including intrauterine growth rate (*z*-score), birth weight, birth length, birth head circumference, 1- and 5-

minute Apgar scores, apnea, bronchopulmonary dysplasia, days in the neonatal intensive care unit, hyaline membrane disease, hyperbilirubinemia, patent ductus arteriosus, peak bilirubin, retinopathy of prematurity, and sepsis. Correlations between various socio-demographic/medical variables and outcome variables were also computed in order to identify potential confounding variables. To reduce multicollinearity, only SES, intrauterine growth rate (*z*-score), adjusted age, and total number of complications were entered as "covariates." SES was chosen because it represents a combination of parental education and occupation factors, and because it is often found to predict outcome (Raz et al., 2010). Adjusted age at testing was significantly correlated with motor outcome (highest $r = -.424$, $p < .01$), so it was included as a covariate. Total complications and days on supplemental oxygen were significantly correlated ($r = .545$, $p < .01$), so only total complications was included. Because birth weight was significantly correlated with gestational age ($r = .818$, $p < .01$), a predictor of interest, it was not included. These covariates, along with the predictors of gestational age and sex, were entered simultaneously in all multiple regression analyses. Visual inspection of predictor variables revealed a significant proportion of missing data for a single NEPSY subtest, Manual Motor Sequences. However, children who did not complete this task did not differ significantly from those who completed the task on fine motor skills (PDMS-2 Fine Motor Quotient), $t(98) = 1.589$, $p = .115$, or on cognitive abilities (WPPSI-III/IV prorated FSIQ), $t(101) = 1.903$, $p = .060$. Hence, no steps were taken to replace missing values.

CHAPTER 3: RESULTS

Statistical Analyses

Table 6 presents the results of the multiple regression analyses for each outcome measure. For each model, a single neuropsychological outcome measure served as the predicted variable. The predictors were identical in all models, and included two variables of interest, two covariates reflecting early medical risk, and two covariates reflecting sociodemographic risk. The variables of interest were gestational age and sex, in accord with Hypothesis 1 and Hypothesis 2, respectively. Medical covariates included intrauterine growth rate (a *z*-score reflecting birthweight adjusted for gestational age) and total complications score (a summary score reflecting the total number of ante-, peri- and neonatal complications, as presented in Table 4). Sociodemographic covariates included SES and adjusted age, or chronological age adjusted for prematurity. The presence of interactions between sex, the only dichotomous variable, and all other predictors in the model was examined. Because no significant interactions were found for multiple models, the reduced model was used. However, significant two-way interactions were entered into the regression models for two outcome variables, including Imitating Hand Positions (sex x intrauterine growth rate) and Visuomotor Precision (sex x adjusted age). It should be noted that performance indices were adjusted for prematurity for all outcome measures. Two children with severe Intracranial Hemorrhage (ICH) and a single child with cerebral palsy (spastic diplegia) were included in the analyses. However, all statistical tests were also repeated after exclusion of these three "neurological" cases. Both Table 6 and the narrative summary below provide information regarding differences, when present, between analyses with the full sample, and analyses after exclusion of neurological cases.

Results of Regression Analyses

As was predicted (see Hypothesis 1), gestational age was directly associated with motor outcome, with improved motor performance observed in children born at more advanced gestational ages. The relationships occurred in the expected direction for each of the following associations. As Table 6 illustrates, gestational age was significantly associated only with the PDMS-2 Object Manipulation subtest score [sr^2 = .038, F(1,96) = 4.26, p < .05]. There was a nonsignificant trend for a relationship between gestational age and the Fine Motor Quotient of the PDMS-2 [sr^2 = .020, F(1,98) = 2.12, p < .15]. When the three neurological cases were excluded, the association between gestational age and the Visual Motor Integration subtest became significant [sr^2 = .046, F(1,95) = 4.58, p < .05] and a nonsignificant trend for a relationship between gestational age and the Total Motor Quotient (PDMS-2) was present [sr^2 = .031, F(1,91) = 3.09, p < .10]. Otherwise, the results were not altered significantly.

As predicted (see Hypothesis 2), sex was significantly associated with motor outcome, with girls consistently outperforming boys (see Table 6). A significant female advantage was present for the Total Motor [sr^2 = .045, F(1,94) = 4.71, p < .05] and one of its two constituting components, the Fine Motor Quotient [sr^2 = .065, F(1,98) = 6.96, p < .01] of the PDMS-2. There was a significant female advantage for the Grasping [sr^2 = .091, F(1,98) = 9.64, p < .01] and Locomotion [sr^2 = .063, F(1,97) = 6.62, p < .05] subtests of the PDMS-2; the former being one of two components of the FMQ while the latter being one of the three components of the GMQ. A significant female advantage was also observed for performance on the four NEPSY subtests used in the current investigation [Design Copying: sr^2 = .088, F(1,94) = 8.86, p < .01; Imitating Hand Positions: sr^2 = .062, F(1,99) = 7.08, p < .01; Manual Motor Sequences: sr^2 = .070, F(1,88) = 6.76, p < .05; and Visuomotor Precision: sr^2 = .040, F(1,93) = 5.22, p < .05]. There were nonsignificant trends for relationships between sex and two outcome variables: the Gross Motor

Quotient [sr^2 = .024, F(1,96) = 2.88, p < .10] and the Stationary subtest [sr^2 = .019, F(1,97) = 2.28, p < .15] of the PDMS-2, with females obtaining higher scores than males. Because the "sex x intrauterine growth rate" and "sex x adjusted age" interactions had been added to the models for Imitating Hand Positions [F(1,99) = 5.09, p < .05] and Visuomotor Precision [F(1,93) = 6.30, p < .05] respectively, the main effects observed in Table 6 cannot be straightforwardly interpreted. The results were not significantly altered when the three neurological cases were excluded.

Amongst medical risk covariates, the intrauterine growth rate (z-score) was directly associated with two of nine subtests of motor skills. In each instance, higher z-scores were related to more developed motor skills. Hence, improved intrauterine growth rate was associated with better performance on Object Manipulation [PDMS-2; sr^2 = .043, F(1,96) = 4.75, p < .05] and Imitating Hand Positions [NEPSY; sr^2 = .040, F(1,99) = 4.57, p < .05]. There were nonsignificant trends for relationships between intrauterine growth rate and the following three PDMS-2 motor outcomes in the expected direction: Total Motor Quotient [sr^2 = .025, F(1,95) = 2.61, p < .15], Gross Motor Quotient [sr^2 = .026, F(1,96) = 3.08, p < .10], and Visual Motor Integration [sr^2 = .028, F(1,98) = 2.99, p < .10]. When the three neurological cases were excluded from the analyses, the association with the Gross Motor Quotient became significant [sr^2 = .040, F(1,93) = 4.59, p < .05], and a nonsignificant trend for a relationship with Locomotion was present [sr^2 = .028, F(1,95) = 2.88, p < .10] in the expected direction. In regard to the total complications score, there was a nonsignificant trend for a relationship between the score and Imitating Hand Positions [NEPSY; sr^2 = .019, F(1,99) = 2.16, p < .15], with a greater number of complications being related to poorer motor skills. However, the total complications

score was not significantly associated with any other motor outcomes, and exclusion of the three neurological cases did not significantly affect the results.

As illustrated in Table 6, amongst sociodemographic covariates, adjusted age was significantly associated with the greatest number of motor outcomes (two out of three indices and five out of nine subtests). For each outcome, older children, according to their adjusted age at the time of testing, obtained poorer motor scores than younger children. Indices that were significantly associated with adjusted age included the Total Motor [sr^2 = .067, F(1,94) = 6.97, p < .01] and Gross Motor Quotients [sr^2 = .201, F(1,96) = 24.03, p < .01] of the PDMS-2. Motor subtests associated with adjusted age included the Stationary [sr^2 = .210, F(1,97) = 25.26, p < .01], Locomotion [sr^2 = .044, F(1,97) = 4.63, p < .05], and Object Manipulation [sr^2 = .117, F(1,96) = 12.95, p < .01] subtests of the PDMS-2, and the Manual Motor Sequences [sr^2 = .080, F(1,88) = 7.64, p < .01] and Visomotor Precision [sr^2 = .042, F(1,93) = 4.43, p < .05] subtests from the NEPSY. There was a nonsignificant trend for a relationship between adjusted age and Design Copying [NEPSY; sr^2 = .028, F(1,94) = 2.83, p < .10]. When the three neurological cases were excluded from the analyses, the relationship between adjusted age and the Locomotion subtest was reduced to a nonsignificant trend [sr^2 = .028, F(1,95) = 2.88, p < .10], but the other results did not change substantially. Socioeconomic status was significantly associated with one of three motor indices and one of nine motor subtests. Higher SES scores were related to more developed motor performance for both outcome measures. There were nonsignificant trends for relationships between SES and the Fine Motor Quotient [sr^2 = .034, F(1,98) = 3.66, p < .10] and the Grasping subtest [sr^2 = .029, F(1,98) = 3.10, p < .10] of the PDMS-2. Socioeconomic status was not significantly associated with any other motor outcomes, and the results were not significantly altered when the three neurological cases were excluded.

Relationships Between Outcomes

Regression models were used to study the relationships between motor performance and neuropsychological outcome in the cognitive and language domains. The variables of interest were the two major performance indices of the Peabody Developmental Motor Scales-2, the Gross Motor Quotient and the Fine Motor Quotient. The cognitive outcome measures of interest were the two subtests representing the WPPSI-III/IV Verbal and Performance Intelligence Quotients (Information and Block Design, respectively). The language outcome measure of interest was the Expressive Language Index of the Clinical Evaluation of Language Fundamentals-Preschool (CELF-P2). This specific index was selected because previous studies have reported associations between fine motor skills and expressive language skills in other populations (e.g., LeBarton & Iverson, 2013; Hill, 2010), and it was hypothesized in the current study that poor motor skills would interfere with language expression among children born prematurely. The same six predictors used in testing Hypotheses 1 and 2 were used in these analyses as well. Hence, the variables entered as covariates were adjusted age, sex, SES, intrauterine growth (*z*-score), total complications, and gestational age. The three neurological cases were excluded from the analyses.

As predicted (see Hypothesis 3a), motor outcome was directly associated with verbal and nonverbal IQ. Specifically, improved Gross Motor Quotient [sr^2 = .080, F(1,92) = 8.09 , p < .01] and Fine Motor Quotient [sr^2 = .118, F(1,93) = 12.73, p = .001] performances were linked to better performance on Block Design, a single subtest from the performance IQ index of the WPPSI-III/–IV. Similarly, improved Gross Motor Quotient [sr^2 = .075, F(1,93) = 11.41, p < .01] and Fine Motor Quotient [sr^2 = .128, F(1,94) = 19.00, p < .001] performances were associated

with higher scores on Information, a single subtest from the verbal IQ index of the WPPSI-III/–IV.

As predicted (see Hypothesis 3b), fine motor performance was directly associated with expressive language performance. Specifically, performance on the Fine Motor Quotient of the PDMS-2 was directly associated with the Expressive Language Index of the CELF-P2 [sr^2 = .090, $F(1,88) = 12.09$, $p < .01$]. Thus, more developed fine motor skills were associated with more developed expressive language skills. However, unexpectedly, performance on the Gross motor Quotient was also directly associated with Expressive Language Index scores [sr^2 = .037, $F(1,87) = 4.48$, $p < .05$] , which was not predicted. Specifically, more developed gross motor skills were associated with more developed expressive language skills.

CHAPTER 4: DISCUSSION

In this study, I examined the associations between early risk factors and motor outcome, and the association between motor outcome and intellectual and language outcomes, in a sample of 104 preschoolers, who were on average 44.35 months of age (*SD* = 3.44), and primarily from middle class strata. My goals were 1. to examine the associations of gestational age and sex with motor performance, and 2. to examine whether preschool motor abilities were associated with cognitive and language abilities, after statistical adjustment for socioeconomic status (SES) and early medical risk (gestational age, age at testing, intrauterine growth rate, total complications). I reasoned that the level of motor performance in preschoolers may represent residual perinatal risk that is associated with adverse brain changes and may not be possible to capture by the above listed perinatal covariates.

In contrast with Hypothesis 1, no significant associations were found between gestational age and global motor indices (TMQ, FMQ, and GMQ). Notably, there was a nonsignificant trend ($p < .15$) for a relationship between gestational age and the Fine Motor Quotient (PDMS-2). A similar trend was observed between gestational age and the Total Motor Quotient (PDMS-2) after removal of the 3 neurological cases. In contrast to the absence of associations between gestational age and global motor indices, my examination of the relationships between gestational age and discrete motor skills yielded different results. There was a significant association between gestational age and a single gross motor task (Object Manipulation, PDMS-2), with gestational age accounting for 3.8% of the variance in this measure, a small effect size. Following the removal of the three neurological cases, the association between gestational age and a single fine motor subtest (Visual-Motor Integration, NEPSY) became significant, with gestational age accounting for 4.6% of the variance in this measure, a small effect size. The

emergence of significant associations following the removal of the three neurological cases suggests that gestational immaturity is linked to motor system development, but that the association is strongest amongst infants who do not experience significant neurological damage. Gestational age was found to have significant associations with select motor skills, particularly those that require the manipulation of objects and hand-eye coordination (i.e., throwing a ball, drawing with markers, fastening buttons). However, performance on one such subtest, Visuomotor Precision (NEPSY), did not exhibit a significant association with gestational age. This task is timed and requires the child to utilize a pencil, and thus is a more challenging task than Object Manipulation and Visual-Motor Integration. Visuomotor Precision requires speed in addition to accuracy along with mastery of pencil skills, which requires more developed fine motor skills than using a marker or throwing and kicking a ball. Perhaps the effects of perinatal risk are masked during the completion of complex motor tasks as a result of the increased presence of extraneous factors, such as fatigue or inattention, which occur less frequently during the completion of more simple tasks. This significant association between degree of gestational immaturity and motor performance is consistent with earlier research showing that preterm children born at lower gestational ages demonstrate poorer performance on global indices of motor skills (Leversen et al., 2011; Raz et al., 2010; Foulder-Hughes & Cooke, 2003), and fine motor skills (Foulder-Hughes & Cooke, 2003). Thus, the current study replicated the findings from these investigations. However, our study also extends the findings from the earlier investigations. While two of these studies (Raz et al., 2010; Leversen et al., 2011) examined motor skills among samples of children born prior to 28 weeks gestation only, the current study included a sample of children born at a broader gestational age range (prior to 34 weeks).

Additionally, Leversen and colleagues (2011) examined motor abilities among children at age 7 years, while the current study evaluated children at early preschool age.

There are few mechanisms through which being born too early may affect later motor system development. Linear relationships between gestational age and degree of brain damage in motor regions have been documented. Increased prematurity is associated with greater disruption to cortical development (Kapellou et al., 2006) and reductions in cerebellar volume (Padilla et al., 2014). These structures are associated with motor control, and such damage may lead to impaired motor functioning early in life.

Hypothesis 2, that sex would be associated with gross and fine motor skills, was supported in the current study. Girls consistently demonstrated stronger motor skills than boys as explained below. A significant female advantage was observed for the Total Motor Quotient (PDMS-2), with sex accounting for 4.5% of the variance, which approximates a medium effect size. There was also a female advantage on the Fine Motor Quotient (PDMS-2), with sex accounting for 6.5% of the variance in outcome, a medium effect size. My examination of discrete motor tasks indicated that girls outperformed boys on five out of six fine motor subtests. In detail, sex accounted for 9.1% of the variance (a medium-to-large effect size) on Grasping (PDMS-2), 8.8% of the variance (a medium-to-large effect size) on Design Copying (NEPSY), 6.2% of variance (a medium effect size) on Imitating Hand Positions (NEPSY), 7.0% of the variance (a medium effect size) on Manual Motor Sequences (NEPSY), and 4.0% of the variance (a small effect size) on Visuomotor Precision (NEPSY). Additionally, girls outperformed boys on Locomotion (PDMS-2), one of the three gross motor subtests, with sex accounting for 6.3% of the variance, a medium effect size. The results were similar following exclusion of the three neurological cases.

The female advantage was present for select tasks within the fine and gross motor domains, and it was more prevalent for fine motor tasks than for gross motor tasks. These findings are comparable with previous studies which found that females outperformed males on both fine and gross motor skills in samples of children age three to six years old (Newman et al., 2011), five years old (Leversen et al., 2011) and seven years old (Samsom et al., 2002). The current study extended the findings from Leversen and colleagues (2011) and Samsom and others (2002) to a younger sample of preschool-age children, and replicated the findings reported by Newman and others (2011). Additionally, two studies (Newman et al., 2011; Leversen et al., 2011) included samples of extremely preterm born children, but the current study extended the findings from these studies to children born at a broader range of gestational ages (<34 weeks).

While the findings in the current study are comparable to the literature on motor skills amongst children born prematurely as discussed above, they contrast motor skills amongst children born full term. Because this study did not include a control group of typically developing children, we searched the literature for PDMS-II performance in healthy children, by age and sex. Since an American study comparing the sexes on motor skills could not be found, the results of the current study were compared to the results of a Portuguese study by Saraiva and others (2013). The researchers examined motor skills among typically developing (assumed full-term) preschoolers born using the PDMS-2. Although they found differences in performance between their sample and the American PDMS-2 standardization sample, the performance pattern they found was similar to that found in other studies of motor skills in full-term born preschoolers. Particularly, as documented by Saraiva and colleagues (2013), several studies have reported a male advantage on ball skills (e.g., Livesey, Coleman, & Piek, 2007; Giagazoglou et al., 2011) and a female advantage on fine motor skills (e.g., Chow, Henderson, & Barnett, 2001;

Livesey et al., 2007) among typically developing children. Regarding their study, the researchers reported that girls significantly outperformed boys on both fine motor tasks, Grasping (4 year-old norms: Males *M* = 50.5, *SD* = 1.7; Females *M* = 51.3, *SD* = 1.0; *d* = 0.57) and Visual-Motor Integration (4 year-old norms: Males *M* = 135.1, *SD* = 5.7; Females *M* = 137.0, *SD* = 5.2; *d* = 0.35). Consistent with Saraiva et al.'s findings, the current study also found a female advantage on the Grasping subtest (Males: Adj. *M* = 9.7, *SE* = .353; Females: Adj. *M* = 10.9, *SE* = .288; *d* = 0.41). However, while Saraiva and colleagues reported a significant *male* advantage on one out of three gross motor tasks (Object Manipulation, 4 year-old norms: Males *M* = 36.6, *SD* = 6.2; Females *M* = 32.9, *SD* = 5.4; *d* = 0.62), the findings from the current study did not support male advantage on any gross motor tasks in our preterm-born sample. In fact, the current study found that girls outperformed boys on a single gross motor subtest (Locomotion: Males Adj. *M* = 9.84, *SD* = 2.10; Females Adj. *M* = 10.83, *SD* = 2.30; *d* = 0.45), but no significant sex differences were present on the other two gross motor subtests. Thus, whereas preterm-born girls demonstrate a similar advantage in fine motor abilities as girls born full-term, preterm-born boys do not exhibit the advantage in gross motor abilities that full-term boys demonstrate, based on the Portuguese study.

The lack of expected male advantage on gross motor performance observed in the current study is thought to be caused by the increased number of medical complications that males suffer at the time of birth in comparison to females (Ingemarsson, 2003) in addition to the poorer recovery from such perinatal complications (Smith et al., 2014). Because boys did not exhibit a greater number of medical complications than girls in the current study, the latter explanation concerning poor recovery in males acts as a more adequate clarification of my findings. Poor recovery in males has been hypothesized to be caused by insufficient compensatory mechanisms

(Smith et al., 2014), low catecholamine levels that interfere with the recovery from hypoxic events (Ingemarsson, 2003), and adverse effects of increased testosterone levels on neonatal health and growth (Cho et al., 2012).

Hypothesis 3, that motor outcome would be significantly associated with language and cognitive outcomes, after adjustment for sociodemographic and medical risk, was supported in the current study. As predicted (Hypothesis 3a), improved gross motor abilities (GMQ, PDMS-2) were significantly related to higher Verbal IQ (Information, WPPSI-III/-IV), with GMQ accounting for 9.4% of the variance in verbal IQ, a medium effect size. Also, improved performance on the GMQ (PDMS-2) was associated with Performance IQ (Block Design, WPPSI-III/-IV), with GMQ accounting for 8.0% of the variance in performance IQ outcome, a medium effect size. Similarly, improved fine motor abilities (FMQ, PDMS-2) were also significantly related to higher Verbal and Performance IQ (Information & Block Design, WPPSI-III/-IV), with FMQ accounting for 15.4% (a large effect size) and 11.8% (a medium effect size) of the variance in Verbal and Performance IQ, respectively.

Hypothesis 3b, that more developed fine motor skills (FMQ, PDMS-2) would be associated with stronger expressive language abilities (Expressive Language Index, CELF-P2) was supported in the current study. FMQ performance accounted for 11.6% of the variance in expressive language outcome, a medium effect size. However, gross motor skills (GMQ, PDMS-2) were also directly associated with expressive language abilities (Expressive Language Index, CELF-P2), a finding that I did not anticipate. GMQ performance accounted for 5.2% of the variance in expressive language outcome, a small effect size. Because motor skills contributed to explained variance in cognitive and language outcome, above and beyond the variance accounted for by perinatal sociodemographic and medical risk factors, motor abilities may reflect an

important aspect of perinatal medical status that is not easily quantifiable. Specifically, brain integrity around the time of birth may not be properly accounted for by the inclusion of variables such as days on supplemental oxygen, gestational age, or birth complications summary scores.

The motor system is highly pervasive in the brain, which may explain the prevalence of motor deficiencies among children born prematurely. Motor skills are represented in many regions of the brain, which may explain why perinatal risk may be higher for motor skills than other neuropsychological skills that are more localized. For example, reduced volumes in several brain regions associated with motor control have been demonstrated in children born prematurely, including the basal ganglia (Walsh, Doyle, Anderson, Lee, & Cheong, 2014), subcortical white matter (Lax et al., 2013 and Duerden, Card, Lax, Donner, & Taylor, 2013), and the cerebellum (Allin et al., 2000; Walsh et al., 2014). Additionally, reduced connectivity between hemispheres and between cortical regions, which has been associated with deficient motor abilities, has been found to be more prevalent in the preterm born population (Pannek, Hatzigeorgiou, Colditz, & Rose, 2013; Melbourne et al., 2014; Pitcher et al., 2011). Because injury to any one of these areas can cause damage to the motor system, children born prematurely are especially vulnerable to experiencing motor deficits during the early years, possibly more than other types of neuropsychological deficits that are not so pervasive within the brain.

An interesting finding, unrelated to my hypotheses, was a significant relationship between adjusted age and motor outcome (see Table 6). In comparison to younger children, older children demonstrated poorer motor abilities on a comprehensive motor index (TMQ, PDMS-2), and on select gross motor (PDMS-2: GMQ, Stationary, Locomotion, Object Manipulation) and fine motor tasks (NEPSY: Manual Motor Sequences and Visuomotor Precision). Adjusted age

accounted for 6.7% of the variance in outcome on TMQ, a medium effect size. Regarding gross motor tasks, GMQ, Stationary, Locomotion, and Object Manipulation, adjusted age accounted for 20.1% (large effect size), 21.0% (large effect size), 4.4% (small effect size) and 11.7% (medium effect size) of the variance in outcome, respectively. Among fine motor tasks, adjusted age accounted for 8.0% (medium effect size) of the variance in outcome on Manual Motor Sequences, and 4.2% (small effect size) of the variance in outcome on Visuomotor Precision. The adjusted ages of the children ranged from 38.6 to 53.1 months old (range: 14.5 months). One explanation for the relationship between age and motor performance could be a significant instrument/test effect, in that the design of the test lends to decreased performance as the child ages; however, the age effect was present for performances on the PDMS-2 as well as the NEPSY. A design flaw is highly unlikely to have afflicted both tests of motor performances administered in the current study. Another hypothesis is that there is a significant "year of birth" effect, indicating possible improvements in medical care in the NICU during the period in which the children in our sample were born. There was a small, yet significant, correlation between year of birth and adjusted age at testing [$r(104) = -.206$, $p = .039$], illustrating that children who were older at the time of testing tended to be born earlier. This indicates that there may have been significant medical improvements during the period of time our subjects were born, which contributed to the improved performance of children born later. Another possible explanation for the significant effect of age at testing is that as they age, children born prematurely are not able to meet increasing performance demands. It has been suggested that the detrimental developmental effects of premature birth may not be readily apparent during the early years, and that as environmental demands increase, deficits begin to become apparent. However, this study

was cross-sectional, so a longitudinal study must be carried out in order to test this time-dependent account of the relationship between age at testing and motor abilities.

Limitations and Future Directions

There were limitations of the current study that should be used to inform future studies in this area of research. First, the study was cross-sectional, making it difficult to examine causal relationships between perinatal risk factors and early motor development. A longitudinal design could address this issue in subsequent studies. Secondly, the current study excluded children who had diagnoses of CP, who were low-functioning, or who were uncooperative. This may have resulted in a restriction of range of skills within our sample by excluding children with the weakest motor abilities. Future studies may wish to include these children, and to use measures of motor functioning that are more appropriate for a wider range of motor skills at the preschool age. The young age of the children in the study is another limitation. At the preschool age, behavioral issues (e.g., refusals, hyperactivity, and inattention) are common and may contribute to "noise" in the data. Lastly, many of the children in our middle class sample have already attended school, speech and language therapy, and OT or PT. These services, that are less likely to be available to lower SES families, may have affected the results of the study, and this reduces the generalizability of our findings to the general preemie population.

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Table 1
Methodological Characteristics and Findings of Prior Research on Correlates of Motor Functioning within Preterm-Born Children

PRESCHOOL								
Authors & Year	**GA (weeks)**	**BW (g)**	**N (PT:FT)**	**Age at testing**	**Comparison Group**	**Exclusions**	**Outcome Measures**	**Results**
Goyen et al., 2006	<29	<1,000 *Met either the GA or BW cutoff	N=45, divided into 3 groups based on stage of ROP	3 years	Norms	Infants with Stage 4 or 5 ROP, SGA, congenital abnormalities, sensorineural impairment (i.e., CP, severe visual impairment, and deafness requiring hearing aids)	Griffiths Mental Development Scales, PDMS, ophthalmic assessments	Motor: **Gross:** Sig. group differences on Locomotor and Gross Motor scales, with the Stage 3 group exhibiting poorer scores than the other 2 groups
Janssen et al., 2008	≤32 (25-32)	1213.7 ± 331.7; 468 - 2350	437	2-3 yrs corrected (M=29 mos ± 3.3)	Norms	Known chromosomal disorders, neuromuscular diseases, CP, unable to complete testing	Motor: BSID-II PDI	Motor: **Global:** Boys sig. worse classification than girls; those who were 29-31 mos at age of testing performed better than other age groups (~higher age at testing -> better scores); neonatal convulsions, chronic lung disease, male sex & low maternal education all sig. related to delayed motor performance

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
Leversen et al., 2011	22-27	<1,000 (500-999) *Met either the GA or BW cutoff	306	M=5 yrs 10 mos	Norms	1 child with Down's syndrome excluded (included sensory deficits, CP& autism)	WPPSI-R, MABC, clinical vision and hearing exams; for kids with CP only--Gross Motor Function Classification for Cerebral Palsy	Motor: **Global:** higher proportion of moderate neurodevelopmental disabilities in children born at 25 weeks or less, compared to those born between 26 and 27 weeks. For children born <28 weeks without CP, blindness, or deafness—MABC score positively associated with GA and prenatal steroids, and negatively associated with male gender, SGA status, and ROP. **Gross:** Boys performed sig. poorer than girls on balance **Fine:** Boys performed sig. poorer than girls on hand function Sig. Cerebral ultrasound findings were NOT predictive of MABC scores, or disabilities, when CP, blindness & deafness excluded

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
Newman et al., 2011	<32 (28.1 ± 2.5; 23-31)	1,178 ± 413; 365-2,179	156	3-6 yrs (4.87 ± 0.81 yrs)	None	CP, ICH grade ≥2	Motor: PDMS-2	Motor: **Global:** All groups (severe BPD, mild/moderate BPD, no BPD) performed similarly on global motor score; When days on ventilation entered as continuous variable instead of bpd group designation, days on vent was not associated with global motor performance; but total number of days on oxygen (instead of vent) was sig. inversely related to global motor outcome; PDA associated with global motor score; number of total nonrespiratory complications, SES, and male sex all associated with global motor performance **Gross:** univariate analyses revealed NO association between oxygen days and GMQ; but sig association between PDA and GMQ **Fine:** univariate analyses revealed sig. association between oxygen days and FMQ; FMQ subtests—sig. association between oxygen days and Grasping, but not visual-motor integration; NO sig association between PDA and FMQ

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
Prins et al., 2010	32 - 34	Not reported	70	3 mos, 6 mos, 9 mos, 4 years (corrected)	Norms	Those who failed to complete at least 2 time points (4 year time point required for inclusion)	AIMS (at 3, 6, & 9 months) & MABC (at 4 yrs)	*6 mo. data not reported due to sig. amount of missing data Motor: **Abn Development:** At 3 mos, 8/66 (12%) showed abnormal motor development, but only 1 had abnormal development at 4 years. At 9 mos, 20/62 scored abnormal, and 20% of these also scored abnormal at 4 years. 68% of children at 9 mos and 83% at 4 years scored in the normal range. No sig. correlation between motor development at 3 mos or 9 mos and 4 years. (aka impairment resolved)
Raz et al., 2012	23-34 (28.65 ± 2.65)	365-1495 (1075 ± 282)	143	3-6 years	None	CP, ICH >2, porencephaly, hydrocephalus	Motor:PDMS-2 Cognitive: WPPSI-R Language: PLS-3	Motor: *Intrauterine growth treated as binary & continuous **Global:** IUGR group obtained sig lower mean scores than appropriate intrauterine growth group on Total Motor scores; intrauterine growth z-score sig. associated with TM **Gross:** Intrauterine growth z-score sig. associated with GM **Fine:** intrauterine growth z-score sig. associated with FM

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
Raz et al., 2010	Group 1: 23-24 (24.23 ± .59); Group 2: 25-26 (26.12 ± .60)	Group 1: 628.40 ± 111.08 ; Group 2: 855.85 ± 152.71	40	3-6 years	Norms	Congenital anomalies, discharged from NICU on ventilator; no subjects had severe sensory, perceptual, or motor handicap	Motor: PDMS-2 Cognitive: WPPSI-R	Motor: **Global:** Sig. group differences on Total Motor (remained sig. after covariates entered); Earlier PT group had higher rates of low scores on TM; SES & postnatal steroids weresig. predictors of TM, but nonrespiratory complications was not **Gross:** Non sig. trend for relationships between group and GM index; Earlier PT group had higher rates of low scores on GM; SES, nonrespiratory complications, and postnatal steroids were sig. predictors of GM **Fine:** Non sig. trend for relationships between group and FM index; Earlier PT group had higher rates of low scores on FM; SES, nonrespiratory complications, and postnatal steroids were NOT sig. predictors of FM

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
SCHOOL AGE								
Davis et al., 2007	<28	<1,000 *Met either GA or BW cutoff	255:208	8-9 yrs	FT, matched on DOB, sex, mother' s country of birth, and hospital insurance status	For DCD analyses only, exclusions = CP or IQ 2 SD below mean	Motor: MABC Cog: WISC-III Academics: WRAT Bx: BASC	Motor: **DCD:** male sex & postnatal corticosteroids associated with sig. increased risk of developing DCD in PT group (but only male sex remained sig. after adjusting for other perinatal variables); nonsig. trend between surfactant and Grade III/IV IVH and DCD Motor & Cognitive: PT with DCD had sig. lower FSIQ than PT without DCD; DCD group scored sig. lower on all WISC-III indices
Feder et al., 2005	<34 (27.8 ± 2; 24-34)	<1,250 (997.3 g ± 174.8g ; 470-1235) *Met *both* the GA and BW cutoffs	48: 69	6-7 yrs (6 yr 7 mos ± 3.9 mos)	School- and sex-matched FT classmates	CP, cognitive impairment, chromosomal abnormalities, genetic syndromes, major auditory impairment, visual impairment, IVH Grade III	Fine Motor: BOTMP, In-hand Manipulation Skill Test Handwriting: ETCH-M ADHD: Connors ASQ	Motor: **Fine:** Handwriting legibility: boys sig. poorer than girls; Handwriting speed: no sig. sex differences; no sig. relationships btwn handwriting legibility or speed and gestational age or birth weight; no sig. relationships between presence of IVH (1-2), BPD (1-3) or ROP (1-3) and handwriting legibility or speed

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
Foulder-Hughes & Cooke, 2003	<32 (M = 29.8; 23-32)	1467 ± 424; 512-2860	280:210	M= 89.8 mos, Range= 82-101	Classmates who were same sex & had birthdates closest to the PT child's	None (included those with hemorrhage, PVL, etc.)	Motor: MABC, COMPS, VMI Cognitive: WISC-III (UK version) Behavior: Connors' Teach Rating Scale for ADHD	Motor: **Global:** Sig. negative correlation between GA and BW and total MABC score, COMPS total weighted score **Fine:** Sig. negative correlation between GA, BW & VMI standard score Motor & Cognitive: --scores from all 3 motor tests were correlated with Total IQ, VIQ, and PIQ
Goyen & Lui, 2009	<29 (27.9 ± 1.7)	<1,000 (997 ± 194) *Met either the GA or BW cutoff	50:50	8 yrs (8.8 ± 0.3)	FT classmates, matched for age and gender	Outside Sydney, not in mainstream classes, disability at 5-yr visit (i.e., FSIQ ≤84, neurological abnormality, visual or hearing impairment requiring hearing aids (included IVH 3-4, PVL, ROP stage 3)	Motor: MABC [DCD defined as -1SD below the mean on total MABC score]	Motor: **Global:** No sig difference between those with and without visual probs on median total MABC scores **DCD:** no sig differences in dx's between those with and without visual problems; PROM & ROP sig. associated with DCD dx but became insig. when Apgar ≤5 entered in; PDMS scores (fine & gross) at 3 yrs. are good at predicting DCD dx at 8 yrs & 5-yr scores were even more precise

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
Samsom et al., 2002	<32 (29.86 ± 1.6; 25.57-31.86)	<1,500 (1,409 ± 385; 750-2130) *Met either the GA or BW cutoff	63	7 years (7.5 ± 0.29)	None	Admitted to hospital >24 hours after birth, chromosomal aberrations, or congenital malformations; Neonatal Medical Index < III (only included at-risk children)	Medical: Neonatal Medical Index (I= few medical problems, to V= most serious complications); neurological exam, observed hand preference / lateralization	Motor: **Neurological Score:** total outcome sig. poorer in boys; Total outcome sig. different between Groups III & V, and IV & V.; Hand Function: Hand fx sig. related to all other subcategories & with lateralization; nonsig. trend with education below age level; Hand fx differed sig. between III & IV, and III & V. Quality of Walking: Sig. related to all other subcategories, lateralization, and education below age level; Sig. poorer in boys; Sig. differed between III & IV. Postural Control: Sig. related to all subcategories, lateralization, and education below age level; sig. poorer in boys; sig. different between III & V, and IV & V Passive Muscle Tone: Sig. related to all other subcategories except diado., lateralization, & education below age level; nonsig. trend for male disadvantage; Sig. differences between III & V. Coordination: Sig. related to all other subcategories, lateralization, & education below age level; sig. more boys exhibited poor

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
Samsom et al., 2002 (cont.)								coordination; Sig. differences between III & IV, and III & V. Diadochokinesia: Sig. related to other subcategories (except for muscle tone), and education below age level (not lat.); Sig. differences between IV & V, with nonsig. trend between III & V. **Motor & Perinatal Factors:** Total outcome, hand fx, quality of walking, postural control, passive muscle tone, coordination, & diado. NOT related to birth weight, GA, dysmaturity, or brain ultrasonography classification; Only NMI classification & gender sig. related to total outcome and all categories except for diado. (not related: birthweight, GA, dysmaturity, brain ultrasonography, days on ventilator). **Associated Movements:** No sig. relationships between associated movements or asymmetry & other subcategories, gender, NMI categories, birth weight, GA, dysmaturity, or brain ultrasonography; only nonsig. trend between asymmetry & groups III and V.

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
Larson et al., 2011	<35 (26.32 ± 2.37; 23-34)	<1,000 (773.26 ± 138.89; 440-1000) *BW used as cutoff	66:23	M= 6.7 years, SD = 0.75	Full-term, hospital-matched	Genetic disorder, severe sensorineural loss, brain tumor, non-English speaking, and failure to complete testing; There were no cases of severe IVH at NICU discharge or severe motor impairment at time of testing	Neuromotor: VMI, Purdue Pegboard Test of Manual Dexterity Neurological: PANESS Cognitive: DAS Attention: Sky Search subtest (TEA-Ch)	Motor: PT groups (<26 wks vs. ≥26 wks) didn't differ from one another on motor overflow (PANESS); <26 weeks group performed more poorly (sig.) than the ≥26 group on Purdue-dominant hand only; PT groups did not sig. differ on SFA scores (PANESS); <26 weeks group performed sig. worse than ≥26 group on right foot taps; earlier PT group performed sig. worse than later PT group on left heel-to-toe taps; hand pronate/supinate—earlier PT group performed sig. worse than later PT group for the right side; Sig. model emerged: DAS spelling, handedness, enrollment in OT sig. contributing to SFA performance, but model wasn't significant for total Motor Overflow; sig. positive correlation between SFA & NICU length-of-stay, but no other sig. correlations between PANESS variables and medical variables found

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
ADOLESCENTS								
Danks et al., 2012	26.8± 2.0	<1,000 (791 ± 214)	48	11-13 (prior assessments at 8 mos, 2 yrs, & 4 yrs)	None	Disabilities: diagnosed neurological disability at 2 yrs old, >2 SD below the mean on a General Cognitive Index at 4 yrs, uncorrected visual or auditory impairment, or physical impairment	NSMDA (8 mos., 2 & 4 yrs) & MABC (11-13 yrs.)	Motor: Scores from 8 mos evaluation "had strong sensitivity for identifying mild motor impairment that was demonstrated to be persistent in long-term follow-up." NSMDA scores at 2 & 4 years sig. predicted motor outcome at 11-13 yrs, above and beyond the effects of birthweight, gestational age, multiple birth status, head circumference, and gender; males exhibited increased risk of long-term motor impairment; degree of prematurity, multiple birth status, and early growth measures did not predict motor outcome; postural control & sensory motor scores at 4 yrs associated with long-term motor outcomes at 11-13, but neurological score was not (NSMDA scales)

Authors & Year	GA (weeks)	BW (g)	N (PT:FT)	Age at testing	Comparison Group	Exclusions	Outcome Measures	Results
META-ANALYSIS								
De Kieviet, Piek, Aarnoudse-Moens, & Oosterlaan, 2009	≤32 weeks (28.2 ± 1.5)	≤1,500 g (1060 ± 207) *met GA and/or BW cutoff	41 articles N= 9,653	6 mos – 15 yrs	FT	Congenital anomalies & additional perinatal complications	Motor: BSID-II, MABC, or BOTMP	Motor: **Global:** VPT &: VLBW with perinatal complications exhibited sig. lower PDI than those without complications; Age at assessment-- Scores on BSID-II PDI showed a catch-up effect in the first years of development, while the MABC showed (nonsig.) reduction in scores with increasing age; Birth weight and gestational age sig. positively related to PDI scores, but not related to MABC

Note: GA=Gestational Age, BW=Birth weight, PT=Preterm, FT=Full term, ROP=retinopathy of prematurity, CP=cerebral palsy, PDMS=Peabody Developmental Motor Scales, BSID/II=Bayley Scales of Infant Devleopment, PDI=Psychomotor Development Index, WPPSI/R=Wechsler Preschool and Primary Scale of Intelligence, MABC=Movement Assessment Battery for Children, SGA=small for gestational age, AIMS=Alberta Infant Motor Scales, NICU=neonatal intensive care unit, PLS-3=Preschool Language Scales-3, DOB=date of birth, DCD=developmental coordination disorder, WISC/III=Wechsler Intelligence Scale for Children, WRAT=Wide Range Achievement Test, BASC=Behavior Assessment System for Children, IVH=intraventricular hemorrhage, BOTMP=Bruininks-Oseretsky Test of Motor Proficiency, VMI=Visual-Motor Integration, SIPT=Sensory Integration and Praxis Tests, ETCH-M=Evaluation Tool of Children's Handwriting-Manuscript, TVPS=Test of Visual-Perceptual Skills, ASQ=Abbreviated Symptom Questionnaire, BPD=bronchopulmonary dysplasia, COMPS=Clinical Observations of Motor and Postural Skills, PANESS=Physical and Neurological Examination of Subtle Signs, DAS=Differential Ability Scale, TEA-Ch=Test of Everyday Attention for Children, SFA=Slow-for-age, OT=occupational therapy, NSMDA=NeuroSensory Motor Developmental Assessment

Table 2
Psychometric Properties of Measures Used

	Internal Consistency		Test-Retest Reliability	
	3 years Old	4 years old	3 years old	4 years old
MOTOR:				
PDMS-2				
Stationary	.71	.77	NA	NA
Locomotion	.95	.96	NA	NA
Object Manipulation	.90	.92	NA	NA
Grasping	.74	.96	NA	NA
Visual-Motor Integration	.94	.96	NA	NA
Gross Motor Index	.93	.94	NA	NA
Fine Motor Index	.91	.98	NA	NA
Total Motor Index	.95	.97	NA	NA
NEPSY-II				
Design Copying (DCP Total)	.82	.92	.80	.80
Imitating Hand Positions (Total Score)	.90	.88	.66	.66
Manual Motor Sequences	NA	NA	NA	NA
Visuomotor Precision (Combined ss)	.89	.89	NA	NA
COGNITIVE:				
WPPSI-III				
Block Design	.84 (all ages)		.9 (2:6- 3:11)	.5 (4:0- 5:5)
Information	.88 (all ages)		.3 (2:6-3:11)	.9 (4:0-5:5)
FSIQ (prorated)	.713	NA	.919	NA
LANGUAGE:				
CELF-P2				
Core Language	3:0-3:5: .91 3:6-3:11: .91	4:0-4:5: .93 4:6-4:11: .93	.92	.89
Receptive Language	3:0-3:5: .91 3:6-3:11: .92	4:0-4:5: .94 4:6-4:11: .91	.92	.95
Expressive Language	3:0-3:5: .93 3:6-3:11: .92	4:0-4:5: .94 4:6-4:11: .94	.95	.92

Note: NA = Not Available

Table 3
Group Comparison of Socio-demographic and Sociofamilial Characteristics

Characteristics	Gestational Age ≤ 30 weeks n = 50	Gestational Age >30 weeks n = 54
Adjusted age (mos.)[a]	43.942 ± 3.096	44.5019 ± 3.733
Gender (M:F)[b]	21:29	20:34
Multiples	18	20
Race (W : O)[c]	35:15	39:15
SES[d]	46.380 ± 11.409	48.778 ± 8.387
Maternal VIQ[e]	99.068 ± 9.549 (44)	103.023 ± 10.222 (44)
Mother's education (yrs.)	15.689 ± 1.940 (45)	16.051 ± 1.378 (49)
Father's education (yrs.)	14.911 ± 2.009 (45)	15.143 ± 2.227 (49)

Note. All differences n.s.
Frequencies are reported for discrete data, means and standard deviations for continuous data. Group differences examined via *t* test (continuous data) or 2 X 2 χ^2 with Yates correction (discrete data). In the case of missing data, number of subjects used in calculating group means and SD's is provided in parentheses.
[a] Adjusted age at first testing session
[b] M=male, F=female
[c] W=White, O = Other
[d] Hollingshead's (1975) Four Factor Index of Social Status.
[e] Prorated parental IQ based on three subtests (Vocabulary, Similarities, and Information) of the Wechsler Adult Intelligence Scale-IV (Wechsler, 2008); Testing was completed on the biological mothers in 86 out of the 88 cases.

Table 4
Antenatal Perinatal and Neonatal Factors by Group[a]

Characteristics	Gestational Age ≤30 Weeks n = 50	Gestational Age > 30 Weeks n = 54
Antenatal Factors		
Abruption of the placenta	8 (50)	6 (54)
Chorioamnionitis (histological)*	18 (42)	9 (47)
Diabetes[b]	3 (47)	5 (50)
HELLP syndrome[c]	5	5
Hypertension in pregnancy	17	21
Intrauterine growth (*z*-score)[d]*	-0.180 ± 0.679	-0.482 ± 0.799
IUGR diagnosis	9	15
Membranes ruptured >12 hrs[e]	13	12
Mother's age at delivery (years)	31.776 ± 4.506 (49)	32.654 ± 4.781 (52)
Mother's height (inch)	63.857 ± 9.657 (49)	65.378 ± 3.083 (49)
Oligohydramnios	3 (41)	1 (48)
Parity	0.540 ± 0.885	0.547 ± 0.748 (53)
Smoking during pregnancy[f]	1	4
Vaginal bleeding (abnormal)	7 (45)	6 (49)
Total antenatal complications[g]	1.460 ± 0.788	1.426 ± 1.057
Perinatal Factors		
Abnormal presentation[h]	19 (49)	21 (53)
Birth weight (g)***	1100.740 ± 309.078	1677.04 ± 312.469
Birth length (cm)***	36.810 ± 4.259	42.301 ± 3.184
Birth head circumference (cm)***	24.999 ± 5.735	28.845 ± 4.220
Cesarean section	37	43 (53)
Forceps	0 (49)	0 (53)
General anesthesia	3 (49)	6 (53)
Gestational age (weeks)[i]***	28.252 ± 1.919	32.389 ± 0.820
Nuchal Cord	9 (47)	12 (51)
Fetal Tachycardia	1 (49)	3 (52)
1 minute Apgar**	6.140 ± 1.714	7.300 ± 1.787

5 minute Apgar***	7.840 ± 1.184	8.590 ± 0.714
Total perinatal complications[j]	1.360 ± 0.851	1.519 ± 0.926
Neonatal Factors		
Anemia at birth[k]	1	1 (52)
Apnea***	42	23
Bronchopulmonary dysplasia**	8	0
Days in Neonatal Intensive Care***	58.620 ± 28.331	21.570 ± 8.852
Hyaline membrane disease[l]***	46	27
Hyperbilirubinemia[m]***	1 (49)	15
Hypermagnesemia	4	2
Hypotension[n]	1	0
Intracranial hemorrhage[o]	7	4
Meconium aspiration	2	2 (53)
Necrotizing enterocolitis[p]	3	0
Patent ductus arteriosus[q]***	20	2
Peak bilirubin (mg/dl)***	7.931 ± 1.640	10.593 ± 1.967
Persistent pulmonary stenosis	1	0
Pneumothorax	0	0
Retinopathy of prematurity***	16	2
Sepsis (initial or acquired)[r]*	7	1
Thrombocytopenia	4	2
Total neonatal complications[s]***	3.380 ± 1.589	1.593 ± 1.141
*Total complications****	6.200 ± 2.222	4.537 ± 1.551

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Note. Frequencies are reported for discrete data, means and standard deviations for continuous data. Group differences examined via *t* test (continuous data), 2 X 2 χ^2 with Yates correction (discrete data), or Fisher exact probability test (less than five cases per cell). In the case of missing data, number of subjects used in calculating group means and SD's is provided in parentheses.

[a]All comparisons between ≤30 weeks and >30 weeks Gestational Age groups.
[b] Includes both gestational diabetes and diabetes mellitus.
[c] Hemolysis, elevated liver enzymes and low platelets.
[d] A *z*-score expressing the deviation of an infant's birth weight from the mean weight of his/her gestational age group, at delivery, according to norms published by Kramer et al. (2001).

[e] Time from spontaneous or artificial rupture of membranes to delivery.
[f] Smoking behavior: >30 Weeks Group: 1 case < 5 cigarettes per day, 3 cases no information. ≤30 Weeks Group: 21 cases no smoking reported, 4 cases no information.
[g] Total antepartum complications includes placental abruption, chorioamnionitis, maternal diabetes, HELLP syndrome, maternal hypertension, IUGR, membranes ruptured >12 hours, smoking during pregnancy.
[h] Includes various atypical presentations such as breech or transverse lie.
[i] As determined by obstetrician; > 95% of cases were corroborated by antenatal ultrasound.
[j] Total perinatal complications include abnormal presentation, C- section, forceps, general anesthesia, nuchal cord, and fetal tachycardia.
[k] Hematocrit < 40 %.
[l] Based on a chest roentgenogram and clinical evaluation.
[m] Peak bilirubin ≥ 12 mg/dl
[n] Requiring treatment
[o] Documented on the basis of cranial ultrasound
[p] Documented by radiographic changes, positive stool guiacs and abdominal distention.
[q] Diagnosed by clinical manifestations and echocardiographic information.
[r] Established by positive blood culture.
s Total neonatal complications includes anemia, apnea, hyaline membrane disease, bronchopulmonary dysplasia, hyperbilirubinemia, hypermagnesemia, hypotension, intracranial hemorrhage, meconium aspiration, necrotizing enterocolitis, patent ductus arteriosus, persistent pulmonary stenosis, pneumothorax, retinopathy of prematurity, sepsis, and thrombocytopenia.

Table 5
Antenatal and Neonatal Diagnostic and Intervention Procedures by Group[a]

	Gestational Age	
Diagnostic and intervention procedures	≤ 30 Weeks n = 50	> 30 Weeks n = 54
Antenatal magnesium sulfate [b]	37	30 (53)
Antenatal steroids [c]	46	50
Antenatal steroid doses	1.460 ± 0.646	1.593 ± 0.630
Hypertension medications (m)	12 (45)	16 (49)
Neonatal cranial ultrasound [***]	50	33 (52)
Surfactant administration	47	50
Days respiratory support [d] [***]	38.000 ± 41.819	2.588 ± 8.507 (51)
Days ventilation [**]	7.204 ± 17.220 (49)	0.327 ± 0.985 (52)
Highest percentage O_2 [***]	53.630 ± 28.642 (32)	31.130 ± 19.681 (39)
Home on O_2 [**]	11	1

[*] $p < .05$, [**] $p < .01$, [***] $p < .001$

Note. Frequencies are reported for discrete data, means and standard deviations for continuous data. t-tests were used to test continuous data; 2x2 chi-square with Yates correction were used for discrete data, and Fisher's exact probability test were used for discrete data with less than five cases per cell.
In the case of missing data, number of subjects used in calculating group means and SD's is provided in parentheses.
[a] All comparisons between the ≤30 weeks and >30 weeks Gestational Age groups.
[b] Magnesium sulfate, administered to inhibit preterm labor and/or control seizures in preeclampsia
[c] Betamethasone, to promote fetal lung maturation
[d] Including mechanical ventilation, continuous positive airway pressure (CPAP), nasal cannula and oxyhood

Table 6
Summary of Simultaneous Multiple Regression Analyses

Index	Source	F	*df*	*p*	sr^{2b}
PDMS-2					
TMQ[c]	Gestational Age	1.93	1, 94	.168[o]	.018
	Growth rate (*z*-score)	2.61	1,94	.110	.025
	Socioeconomic Status	.29	1,94	.591	
	Sex	4.71	1,94	.033[a]	.045
	Total Complications	.33	1,94	.567	
	Age at Testing (adjusted)	6.97	1,94	.010[A]	.067
GMQ[d]	Gestational Age	1.23	1,96	.271	
	Growth rate (z-score)	3.08	1,96	.083[p]	.026
	Socioeconomic Status	.621	1,96	.433	
	Sex	2.88	1,96	.093	.024
	Total Complications	.395	1,96	.532	
	Age at Testing (adjusted)	24.03	1,96	.000[A]	.201
FMQ[e]	Gestational Age	2.12	1,98	.149	.020
	Growth rate (*z*-score)	1.61	1,98	.207	.015
	Socioeconomic Status	3.66	1,98	.059	.034
	Sex	6.96	1,98	.010[A]	.065
	Total Complications	.03	1,98	.875	
	Age at Testing (adjusted)	.04	1,98	.842	
Stationary[f]	Gestational Age	.21	1,97	.650	
	Growth rate (*z*-score)	.01	1,97	.922	
	Socioeconomic Status	1.06	1,97	.305	
	Sex	2.28	1,97	.134	.019
	Total Complications	1.34	1,97	.251	.011
	Age at Testing (adjusted)	25.26	1,97	.000[A]	.210
Locomotion[g]	Gestational Age	.41	1,97	.523	
	Growth rate (*z*-score)	2.04	1,97	.157[q]	.019
	Socioeconomic Status	.00	1,97	.957	

Table 6 cont.

Index	Source	F	df	*p*	sr^2
	Sex	6.62	1,97	.012[a]	.063
	Total Complications	1.58	1,97	.213	.015
	Age at Testing (adjusted)	4.63	1,97	.034[ar]	.044
Object Manipulat-ion[h]	Gestational Age	4.26	1,96	.042[a]	.038
	Growth rate (z-score)	4.75	1,96	.032[a]	.043
	Socioeconomic Status	.38	1,96	.539	
	Sex	.42	1,96	.520	
	Total Complications	1.18	1,96	.281	.011
	Age at Testing (adjusted)	12.95	1,96	.001[A]	.117
Grasping[i]	Gestational Age	.61	1,98	.437	
	Growth rate (z-score)	.26	1,98	.613	
	Socioeconomic Status	3.10	1,98	.082	.029
	Sex	9.64	1,98	.003[A]	.091
	Total Complications	.07	1,98	.791	
	Age at Testing (adjusted)	.79	1,98	.378	
Visual-Motor Integration[j]	Gestational Age	2.97	1,98	.088[s]	.029
	Growth rate (z-score)	2.88	1,98	.093	.028
	Socioeconomic Status	2.05	1,98	.156	.020
	Sex	1.46	1,98	.230	.014
	Total Complications	.34	1,98	.561	
	Age at Testing (adjusted)	.41	1,98	.522	
NEPSY-II					
Design Copying[k]	Gestational Age	.75	1,94	.390	
	Growth rate (z-score)	1.23	1,94	.270	.012
	Socioeconomic Status	1.73	1,94	.192	.017
	Sex	8.86	1,94	.004[A]	.088
	Total Complications	.28	1,94	.596	
	Age at Testing (adjusted)	2.83	1,94	.096	.028

Table 6 cont.

Index	Source	F	*df*	*p*	sr^2
Imitating Hand Positions[l]	Gestational Age	.79	1,99	.377	
	Growth rate (z-score)	4.57	1,99	.035	.040
	Socioeconomic Status	.57	1,99	.454	
	Sex	7.08	1,99	.009[A]	.062
	Total Complications	2.16	1,99	.146	.019
	Age at Testing (adjusted)	1.24	1,99	.269	
	Kramer z * Sex interaction term	5.09	1,99	.027	.045
Manual Motor Sequences[m]	Gestational Age	.01	1,88	.912	
	Growth rate (z-score)	.29	1,88	.593	
	Socioeconomic Status	.14	1,88	.710	
	Sex	6.76	1,88	.011[A]	.070
	Total Complications	.47	1,88	.494	
	Age at Testing (adjusted)	7.64	1,88	.007[A]	.080
Visuomotor Precision[n]	Gestational Age	.034	1,93	.854	
	Growth rate (z-score)	.51	1,93	.478	
	Socioeconomic Status	1.29	1,93	.259	.012
	Sex	5.22	1,93	.025[a]	.040
	Total Complications	.89	1,93	.349	
	Age at Testing (adjusted)	4.43	1,93	.038[a]	.042
	Sex * Age at testing interaction term	6.30	1,93	.014	.060

[a] significant at the .05 level or [A] significant at the .01 level, when growth rate, SES, sex, total complications, and adjusted age are used as covariates in a multiple regression analysis.
[b] sr^2,the squared semipartial correlation, reflects the increase in R^2 of the GLM when that specific predictor was added to the analysis
[c] Outcome data missing for 8 subjects: 3 incomplete evaluations, 1 CP, 3 uncooperative, 1 low functioning/ uncooperative
[d] Outcome data missing for 6 subjects: 1 incomplete evaluation, 1 CP, 3 uncooperative, 1 low functioning/ uncooperative
[e] Outcome data missing for 4 subjects: 3 incomplete evaluations, 1 low functioning/ uncooperative
[f] Outcome data missing for 3 subjects: 1 incomplete evaluation, 1 CP, 1 uncooperative
[g] Outcome data missing for 5 subjects: 1 incomplete evaluation, 1 CP, 2 uncooperative, 1 low functioning/uncooperative,
[h] Outcome data missing for 6 subjects: 1 incomplete evaluation, 1 CP, 3 uncooperative, 1 low functioning/uncooperative
[i] Outcome data missing for 4 subjects: 3 uncooperative, 1 low functioning/uncooperative
[j] Outcome data missing for 4 subjects: 3 uncooperative, 1 low functioning/uncooperative
[k] Outcome data missing for 8 subjects: 1 incomplete evaluation, 2 uncooperative, 4 didn't understand task, 1 ASD/refused

[l] Outcome data missing for 3 subjects: 1 incomplete evaluation, 2 uncooperative
[m] Outcome data missing for 15 subjects: 2 incomplete evaluations, 12 uncooperative, 1 ASD/refused
[n] Outcome data missing for 9 subjects: 2 incomplete evaluations, 4 uncooperative, 2 didn't understand task, 1 low functioning/didn't understand task
[o] when three neurological cases excluded, this became a nonsignificant trend [sr^2 = .031, F(1,91) = 3.09, $p < .10$]
[p] when three neurological cases excluded, this became significant [sr^2 = .040, F(1,93) = 4.59, $p < .05$]
[q] when three neurological cases excluded, this became a nonsignificant trend [sr^2 = .028, F(1,95) = 2.88, $p < .10$]
[r] when three neurological cases excluded, this became a nonsignificant trend [sr^2 = .028, F(1,95) = 2.88, $p < .10$]
[s] when three neurological cases excluded, this became significant [sr^2 = .046, F(1,95) = 4.58, p < .05]

Table 7
Relationships between Motor and Other Neuropsychological Outcome Measures

Index	Source	F	*df*	*p*	sr^2
CELF-P2 Receptive Language Index	GMQ	10.57	1,91	.002[A]	.088
	Gestational Age	0.00	1,91	.976	
	Growth Rate (*z*-score)	0.44	1,91	.510	
	Socioeconomic Status	20.81	1,91	.000[A]	.174
	Sex	0.06	1,91	.809	
	Total Complications	0.17	1,91	.683	
	Age at Testing (adjusted)	0.48	1,91	.490	
	FMQ	26.89	1,93	.000[A]	.191
	Gestational Age	0.10	1,93	.758	
	Growth Rate (z-score)	0.38	1,93	.540	
	Socioeconomic Status	11.85	1,93	.001[A]	.084
	Sex	0.47	1,93	.495	
	Total Complications	0.29	1,93	.292	
	Age at Testing (adjusted)	1.30	1,93	.257	
Expressive Language Index	GMQ	4.48	1,87	.038[a]	.037
	Gestational Age	.01	1,87	.940	
	Growth Rate (*z*-score)	0.36	1,87	.550	
	Socioeconomic Status	12.95	1,87	.001[A]	.106
	Sex	8.56	1,87	.004[A]	.070
	Total Complications	2.57	1,87	.113	.021
	Age at Testing (adjusted)	9.177	1,87	.003[A]	.076
	Sex*Adjusted Age	9.05	1,87	.004[A]	.075
	FMQ	12.09	1,88	.001[A]	.090
	Gestational Age	0.10	1,88	.756	
	Growth Rate (z-score)	0.28	1,88	.601	
	Socioeconomic Status	7.30	1,88	.008[A]	.054
	Sex	8.15	1,88	.005[A]	.061
	Total Complications	4.40	1,88	.039[a]	.033
	Age at Testing (adjusted)	11.29	1,88	.001[A]	.084

Table 7 cont.

Index	Source	F	*df*	*p*	sr^2
	Sex*Adjusted Age	8.37	1,88	.005	.063
WPPSI-III/-IV	GMQ	11.41	1,93	.003[A]	.075
	Gestational Age	0.93	1,93	.339	
Information	Growth Rate (z-score)	1.59	1,93	.211	
	Socioeconomic Status	16.07	1,93	.000[A]	.126
	Sex	4.54	1,93	.036[a]	.035
	Total Complications	3.02	1,93	.086	.024
	Age at Testing (adjusted)	3.15	1,93	.079	.025
	Sex*Adjusted Age	5.03	1,93	.028[a]	.039
	FMQ	19.00	1,94	.000[A]	.128
	Gestational Age	2.98	1,94	.088	.020
	Growth Rate (z-score)	2.26	1,94	.136	.015
	Socioeconomic Status	9.62	1,94	.003[A]	.065
	Sex	4.66	1,94	.034[a]	.031
	Total Complications	10.15	1,94	.002[A]	.069
	Age at Testing (adjusted)	5.67	1,94	.019[a]	.038
	Sex*Adjusted Age	4.97	1,94	.028[a]	.033
Block Design	GMQ	8.09	1,92	.006[A]	.080
	Gestational Age	0.14	1,92	.710	
	Growth Rate (z-score)	0.12	1,92	.726	
	Socioeconomic Status	3.70	1,92	.058	.037
	Sex	2.46	1,92	.121	.024
	Total Complications	0.87	1,92	.354	
	Age at Testing (adjusted)	0.00	1,92	.993	
	FMQ	12.73	1,93	.001[A]	.118
	Gestational Age	0.00	1,93	.982	
	Growth Rate (z-score)	0.13	1,93	.717	
	Socioeconomic Status	1.15	1,93	.286	
	Sex	4.04	1,93	.048[a]	.038

Table 7 cont.

Index	Source	F	*df*	*p*	sr^2
	Total Complications	0.12	1,93	.726	
	Age at Testing (adjusted)	2.96	1,93	.089	.028

[a] significant at the .05 level or [A] significant at the .01 level, when gestational age, growth rate, SES, sex, total complications, and adjusted age are used as covariates in a multiple regression analysis.

Note: All analyses excluded the 3 "neurological" cases

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ABSTRACT

MOTOR SKILLS AMONG PRESCHOOL-AGED CHILDREN BORN PREMATURELY

by

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Advisor: Dr. Sarah Raz

Major: Psychology (Clinical)

Degree: Doctor of Philosophy

It has been documented that children who are born prematurely are at risk of experiencing motor skills deficits early in life; however, little is known about the relationships between early perinatal risk factors and later motor abilities. The current investigation attempted to gain better understanding regarding the influence of gestational age and sex on early motor development among a cohort of preschool-aged children born prior to 34 weeks gestation (N = 104). Additionally, relationships between motor performance and other abilities, namely cognitive and language, were examined. As hypothesized, degree of gestational immaturity was significantly associated with poorer performance on specific motor tasks. Additionally, a female advantage was found on select fine and gross motor tasks. Examination of associations between performances in different neuropsychological domains revealed that motor performance contributed to explained variance in cognitive and language outcome, above and beyond the variance accounted for by perinatal sociodemographic and medical risk factors. The implications of these findings are discussed.

AUTOBIOGRAPHICAL STATEMENT

Brittany was raised in Fenton, Michigan. She moved to Chicago following high school to attend college at Loyola University Chicago. She initially intended to major in biology, but ended up developing an interest in psychology, and in particular, brain-behavior relationships (neuropsychology). She was involved with various faculty-led research projects while at LUC, and also conducted an independent project on the visual processing of words. She graduated from Loyola in May 2010, with a Bachelor of Science in Psychology and double minors in Biology and Neuroscience.

Brittany returned to Michigan in August of 2010 and enrolled at Wayne State University to earn her doctoral degree in Clinical Psychology with a specific interest in Pediatric Neuropsychology. She has worked with Dr. Sarah Raz for the past five years, conducting research aimed at gaining a better understanding of the effects of premature birth on early development. In regard to clinical work, she has conducted assessments and psychotherapy at the WSU Psychology Clinic, neuropsychological assessments at the Children's Hospital of Michigan, and child and adolescent therapy at a private practice as well as at the General Pediatric and Adolescent Medicine Clinic at the Children's Hospital of Michigan. She is currently a pre-doctoral intern at the Children's Hospital of Michigan in Detroit, MI. Brittany will officially complete her doctoral degree upon the completion of her internship.