MABE, BETTY, Ph.D. Neonatal Feeding Skills in Preterm Infants and the Relationship to Speech and Expressive Language Skills at Approximately Ten Years of Age. (2016) Directed by Dr. Virginia Hinton. 135 pp.

This study sought to determine whether neonatal feeding skills in extremely preterm infants (EPT) had an association with scores on speech and expressive language measures at approximately ten years of age. Additionally, neonatal feeding abilities were analyzed to determine if there was an association with sensorimotor and visuomotor test measures at approximately ten years of age. Eighty-four EPT children were categorized based on feeding history at 34 weeks gestational age into two groups: infants who were primarily oral feeding (POF), and infants who were primarily tube feeding (PTF). There was no significant difference in size or sex between the two groups. Independent *t*-tests with a chi-square analysis were used to analyze the composition of the two groups. The majority of infants in the PTF group were characteristically white, had lower birth weights, and a history of bronochopulmonary dysplasia (BPD). Only the variable of race, however, withstood statistical analysis for multiple *t*-tests. One-way ANOVA procedures determined that there was no significant difference between the performance of the two feeding groups on standardized measures of speech or oral expression at 10 years of age. The parent perceptions of the children's speech and oral expression skills also did not differ between the two groups. Additionally, one feeding group did not perform better than the other on measures of sensorimotor or visuomotor skills. While no association was determined in the current study, results remained inconclusive and warrant further investigation with a greater variety of standardized measures of speech, oral expression, and sensorimotor and visuomotor skill.

NEONATAL FEEDING SKILLS IN PRETERM INFANTS AND THE RELATIONSHIP TO SPEECH AND EXPRESSIVE LANGUAGE SKILLS AT APPROXIMATELY TEN YEARS OF AGE

by

Betty Mabe

A Dissertation Submitted to
the Faculty of The Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
2016

Approved by

Virginia Hinton
Committee Chair

To my family

APPROVAL PAGE

This dissertation, written by Betty Mabe, has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

Committee Chair Virginia Hinton

Committee Members Kristine Lundgren

Robert Mayo

Michael O'Shea

March 15, 2016
Date of Acceptance by Committee

March 15, 2016
Date of Final Oral Examination

ACKNOWLEDGMENTS

The investigator gratefully acknowledges Virginia Hinton, Ph.D., Kristine Lundgren, Sc.D., Robert Mayo, Ph.D., T. Michael O'Shea, M.D., MPH., Mary Christiaanse, M.D., Matthew Makel, Ph.D., Victoria Briones Chiongbian, Ph.D., and Richard Allen, B.S. for their guidance and assistance.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

One in every eight babies in the United States is born preterm (CDC, 2013). Prematurity is defined, hierarchically, by several categories relative to gestational age and weight at birth. Infants born between 37 and 32 weeks gestation are defined as *late preterm* (LPT). Infants born before 32-28 weeks gestation are defined as *very preterm* (VPT). Infants born before 28 weeks are defined as *extremely preterm* (EPT). Infants weighing less than 2500 grams (5 lbs. 8 oz.) are categorized as *low birth weight* (LBW). Infants weighing less than 1500 grams (3 lbs. 5 oz.) are diagnosed as *very low birth weight* (VLBW). Short gestation and low birth weight are the second leading cause of infant mortality in the United States accounting for 35% of all infant deaths (Murphy, Xu, & Kochanek, 2013; Sutton & Darmstadt, 2013). For those infants who survive, the lower the gestational age, and/or the lower the birth weight, the greater the risk and severity of adverse neurodevelopmental and functional outcomes (Jobe, 2010; Moore et al., 2012).

Inflammation, infection, microorganisms in the placenta, and bacteremia have been identified as some of the major precipitating factors leading to preterm (PT) labor and delivery (Carlo et al., 2011; Goldenberg, Culhane, Iams, & Romero, 2008; O'Shea et al., 2009). These same factors are also the greatest risk factors for subsequent physiological damage to the immature infant (Lawn et al., 2010; Mathur, Neil, & Inder, 2010; O'Shea et al., 2009). The lower the gestational age and birth weight, the more vulnerable a newborn infant is to infections and harm. Infection and inflammation pass easily through the placenta and amniotic fluid from mother to infant. Underdeveloped organs such as the brain, heart, and lungs, are most vulnerable in infants born prematurely. In addition, neonatal complications such as brain abnormalities, brain hemorrhages, as well as brain and lung infections, are common and can be life threatening. Nearly 25% of PT infants show evidence of intraventricular hemorrhage and as many as 80% show indications of microstructural density differences in white matter (Gozzo et al., 2009).

Significant brain development in a fetus occurs between 22–37 weeks gestation when white matter is most concentrated on building neural connections from the forebrain to the cortex (Volpe, Kinney, Jensen, & Rosenberg, 2011). Molecular and cellular infrastructures in the brain are initiating the processes necessary for healthy neural connectivity between 23 and 27 gestational weeks. Infants born during this period are most vulnerable to the disruption of normal neural connectivity and injuries to the developing sensorimotor system (Anderson et al., 2010; O’Shea et al., 2009).

Birth before the conclusion of the third trimester causes the disruption of delicately balanced chemical and cell infrastructures that orchestrate myelination, initiate proper neural networking, and form the developing motor and sensory systems (Jobe, 2010; Mullen et al., 2011; Panigrahy et al., 2012). Early cerebellar damage before the establishment of the cortical network may not consistently reveal overt indicators of motor damage as evidenced in cerebral palsy, but it can subtly impair cortical connectivity and later synapses affecting functional and behavioral motor development (Bednarek et al., 2008; Dayan & Cohen, 2011; Lubsen et al., 2011).

Impairment of cortical connectivity and neural synapses requires neural reorganization, which results in alterations of brain volume and distribution of white matter, as well as modifications in myelination and development of gray matter (Volpe, 2009). PT infants characteristically have smaller volumes of myelinated white matter and corpus callosal areas with decreased axonal connectivity, and microstructural chemical and cellular development at term than FT infants (Lubsen et al., 2011; Thompson et al., 2012; Volpe, 2009).

Altered brain structure results in altered brain function (Volpe, 2009). PT infants demonstrate later physical and neurodevelopmental complications, as they age, with altered molecular and cellular growth within developing neural networks (Counsell, Rutherford, Cowan, & Edwards, 2003; Inder, Tao, & Neil, 2011; Volpe, 2009). Volpe (2009) refers to this as "the primary destructive and secondary maturational disturbances" (p. 120). PT infants may survive the initial life-threatening injuries related to immature brains, hearts and lungs only to face developmental challenges related to abnormal brain development and altered neural connectivity (Inder et al., 2011; Rees, Harding, & Walker, 2011). In the last 20 years, as mortality rates significantly improved for PT infants, concern has shifted to the neurodevelopmental disorders impacting the quality of life and functional abilities of individuals born prematurely (Allen, Cristofalo, & Kim, 2011; Guillén et al., 2012).

PT infants are more vulnerable to neonatal brain injuries as a consequence of disrupted brain development. At age 16 years, as many as 43% of VPT adolescents continue to show evidence of perinatal brain injury (Abernethy, Palaniappan, & Cooke, 2002). PT infants are born before normal protective neural structures in full-term (FT) infants have occurred. Neuroimaging later in life reveals that brain differences in PT infants persist into adulthood (Luu, Ment, Allan, Schneider, & Vohr, 2011; Nosarti et al., 2008). Luu et al. (2011) observe that VPT infants evidence both delayed and different brain development into adolescence. Underlying neural infrastructures are commensurately less developed and significantly altered in PT infants and adolescents when compared to FT infants (Luu et al., 2011; Ment et al., 2009; Nosarti et al., 2008; Volpe, 2009).

In summary, cellular and molecular disruption to a maturing brain and central nervous system (CNS) in utero, prior to development of critical neural networks, have long term consequences. Recent advances in imaging have provided researchers with greater insights into typical, as well as atypical, brain structures and neural connectivity. Familiarity with normally developing cortical and neuromotor systems in utero has improved our understanding of the short and long term consequences associated with PT birth.

The respiratory and oral-pharyngeal structures for breathing and processing nutrients in utero develop parallel to the brain and CNS system. Respiration and nutrition are essential functions for survival after birth. A normal fetus initiates gross movements of the diaphragm, jaw, lip, tongue, pharyngeal and laryngeal structures, in that order.

Hall (2010) observed early episodes of rhythmic fetal breathing emerging at 8 weeks. Yawning, which involved the diaphragm, the intercostals, the termperomandibular joint, and the perioral muscles, during episodes of inspiration, began at 11 weeks. Consistent rhythmicity of fetal breathing has been observed to be established between 14-17 weeks gestation (Fortin & Thoby-Brisson, 2009; Rajendran, Kessler, & Manning, 2009). The characteristics of frequency and periodicity of breathing vary with gestational age. Rajendran et al. (2009) state that normal regular fetal respiration should be present approximately 40% of the time by 32 weeks gestation. The authors note however, that development of normal anatomy relies on normal function.

A typically developing fetus begins opening the jaw at 8 weeks gestation, with spasmodic movements, while lip tissue is still forming (Green, Moore, & Reilly, 2002; Miller, Sonies, & Macedonia, 2003). Jaw movements are initially poorly controlled, emerging in isolated spasms or clusters. With repetition, the motor system matures and jaw movements become more fluid (Barlow & Estep, 2006; Hall, 2010; Miller, Macedonia, & Sonies, 2006; Miller et al., 2003; Nip, Green, & Marx, 2009; Rajendran et al., 2009). The repetition of movements is an essential component in the development of normal motor and sensory systems (Barlow & Estep, 2006; Hall, 2010; James & Swain, 2011; Miller et al., 2006; Steeve, Moore, Green, Reilly, & McMurtry, 2008). Throughout development in utero, the emergence of controlled movement relies on repetitious movements that facilitate maturation and regulation of the neuronal networks (Barlow & Estep, 2006; Hall, 2010; Greer, Funk, & Ballanyi, 2006; Mantilla & Sieck, 2008). The absence of repetitious facial movements in utero results in predictable craniofacial abnormalities (Hall, 2010). Coordinated jaw openings and closings, as well as clearly defined tongue cupping with midline depression, is observable in a typical fetus by 17 weeks gestation (Miller et al., 2003).

Hall (2010) recorded fetal swallowing, using tongue, pharyngeal, temporalis, and masseter muscles, beginning at 9 weeks. Miller et al. (2003) observed that a normally developing fetus is able to propel amniotic fluid into the nasopharynx using rhythmic jaw opening and closing at 10 weeks. These authors recorded the progression of slow, repetitive pharyngeal contractions comparable to movements in swallowing at 15 weeks gestation. Successful fetal swallowing is essential to the absorption of amniotic fluid that contains nutrients necessary for development in utero (Hall, 2010; Miller et al., 2006, 2003; Rajendran et al., 2009).

By 18 weeks, Bingham (2009) observed that a normal fetus could clear a bolus using tongue movement and palatal elevation. Miller et al. (2003) reported that at 28 weeks, a fetus demonstrated anterior-to-posterior lingual movement patterns propelling amniotic fluid into the oral cavity, cupped by the tongue as a bolus, and propelled to the posterior dorsum, then swallowed. Functional development of swallowing in utero is necessary for subsequent emergence of normal pharyngeal movement (Miller et al., 2006). Slow or inadequate fetal swallowing patterns may result in inadequate oral-pharyngeal growth (Bingham, 2009; Miller et al., 2003; Ranjendran et al., 2009). A typically developing fetus manages an intake of 700 mL of amniotic fluid per day for adequate growth and the progression of ingestive and oropharyngeal motor patterns necessary for sustenance at birth (Bingham, 2009; Hall, 2010). Infants born at or before

28 weeks may experience a disruption to the normal process for establishing the movements of respiration and oromotor coordination. As a result, feeding disorders are common in PT infants. Immature neurological, metabolic, and physiologic systems are challenged to accomplish basic functions such as regulating body temperature, management of bilirubin levels (jaundice), and infection (sepsis), further complicated by poor feeding/nutritional intake (Samra, McGrath, & Wehbe, 2011).

Oromotor impairment is initially one of the more apparent disorders in neonates. Subsumed under motor impairments, a feeding disorder can pose one of the earliest barriers to the PT infant's survival in the neonatal intensive care unit (NICU). Ninety per cent of infants born at or before 28 weeks exhibit feeding dysfunction and/or intolerance (Kempley et al., 2014; Lau, 2006). Immature respiratory, oral, pharyngeal, and digestive systems contribute to the PT infant's feeding disorders. Lung infections, intubation, and ventilation may further interfere with developing normal respiration essential for rhythmic sucking, swallowing, and breathing (Stumm et al., 2008). Medical interventions necessary to sustain life in the PT infant can cause aversive sensory and behavioral responses for many years (Jonsson, van Doorn, & van den Berg, 2013). Oral and intestinal processes necessary for normal ingestion, motility, and nutritional sustenance are not fully functional in EPT infants. Reduced nutritional intake, slower growth, and smaller stature even at corrected ages are common in the first two years of a PT infant's life. At 3 months, 29% of VPT infants exhibit oromotor dysfunction and 33% exhibit avoidant feeding behaviors (DeMauro, Patel, Medoff-Cooper, Posencheg, & Abbasi, 2011). Oral dysfunction and avoidance behaviors often persist beyond infancy. Forty percent of patients in feeding clinics are former PT infants (Barlow, 2009). At school-age, VPT children exhibit two to five times greater risk of feeding problems then FT peers (Samara, Johnson, Lamberts, Marlow, & Wolke, 2009). EPT children show increased oral hypersensitivity, food refusal, and have more difficulty managing chewy textured foods (Samara et al., 2009). Clinicians attribute most neonatal feeding problems as secondary to poor coordination of respiration and disorganization of oral motor skills. Mizuno and Ueda (2005) report that early feeding assessments within the first year of life were better predictors of impaired neuro-developmental outcomes at 18 months than early ultrasound analyses.

While feeding behaviors may improve in most PT children over time, some researchers report that impaired oral motor abilities continue to impact speech and phonological development in a negative manner through adolescence (Northam et al., 2012; Wolke, Samara, Bracewell, & Marlow, 2008). Underlying subtle impairments in gross and fine motor skills, which subsume oral motor skills, can remain an influential factor through adolescence in EPT children (Wolke et al., 2008). Wolke et al. (2008) conclude that speech impairments "may be significantly affected by specific motor problems" such as early oral motor disorders of feeding (p. 261). A number of researchers hypothesize that early motor-speech behaviors emerge from shared or overlapping neural networks (Barlow & Estep, 2006, Lund & Kolta, 2006; Steeve & Moore, 2009). Nip, Green, and Marx (2011), as well as Barlow and Estep (2006), postulate that the foundational skills for speech develop from a hierarchy of oral motor skill maturation related to early vegetative functions. Barlow (2009) suggests that delayed development and/or impairment of critical oral motor brainstem pattern generators needed for early suckling contribute to subsequent delays in related oromotor skills such as babbling and speech development. He hypothesizes that poorly coordinated breathing and swallowing in PT infants may be predictive of poorer neurodevelopmental outcomes. However, the relationship between early feeding and later speech development has yet to be conclusively resolved (Barlow, 2009; Bunton, 2008; Green et al., 2002; Nip et al., 2009, 2011; Steeve et al., 2008; Wilson, Green, & Weismer, 2012).

Early feeding problems may be one of many developmental disorders over the lifetime of a PT individual. Improved survival rates for PT children result in a larger population of individuals with functional and learning challenges. These individuals exhibit generally poorer neurodevelopmental outcomes as a result of early brain injuries and altered neural pathways (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009; Allen et al., 2011; Samra et al., 2011). Motor, vision, hearing, speech and language, voice, attentional, behavioral and social-emotional impairments are twice as likely to occur in PT children as FT children (French et al., 2013; Orchinik et al., 2011; Volpe, 2009; Wolke et al., 2008). In addition, cognitive deficits are 3 to 6 times higher in PT children than those who are full term (Orchinik et al., 2011; Wolke et al., 2008). Therefore, children born prematurely exhibit between 2% to 6% higher incidence of severe bilateral hearing impairments and 10% have significantly impaired visual acuity (Woythaler, McCormick, & Smith, 2011). Twice as many children born between 32-36 weeks gestation exhibit learning disabilities requiring special education classes in comparison to FT controls (Wolke et al., 2008; Woythaler et al., 2011). At school age, attentional problems, mathematics, and reading skills are moderately to severely below those of FT peers even when controlling for IQ (Aarnoudse-Moens et al., 2009; Wolke et al., 2008).

Ten to fifteen percent of infants born before 30 weeks are diagnosed with cerebral palsy by 24 months adjusted age (Mathur et al., 2010). The absence of a diagnosis of cerebral palsy, however, is not assurance that a PT infant has completely escaped any motor impairment. Early cerebellar damage prior to the establishment of an intact cortical network can subtly impair cortical connectivity and synapses affecting functional and behavioral motor development (Bednarek et al., 2008; Dayan & Cohen, 2011; Lubsen et al., 2011). Much of motor learning relies on normal movement patterns to establish and reinforce normal synaptic circuits (Barnhart, Davenport, Epps, & Nordquist, 2003; Hall, 2010). Subtle motor impairments may not be apparent in newborns but may become evident later in development as the outcome of altered cortical networks. More than 8% of PT children between 6 and 12 years of age are diagnosed with developmental coordination disorders in the absence of cognitive and obvious tone disorders (Barnhart et al., 2003). Visuomotor integrative skills, executive function, working memory, rapid naming, phonologic, and speech impairments are reportedly 2-3 times more common in PT children and adolescents than FT controls (Aylward, 2005; van Noort-van der Spek, Franken, & Weisglas-Kuperus, 2012; Wolke et al., 2008).

Speech impairments are 2.6 times more likely in VPT children at school-age than in full-term peers, even when adjusting for general cognitive impairments (van Noort-van der Spek et al., 2012; Wolke et al., 2008). These speech disorders affect intelligibility, articulation, and phonological development in preterm infants are common and often persist into adolescence (Northam et al., 2012; Orchinik et al., 2011). It is understandable that speech disorders are more common in PT infants who have greater gross and fine motor delays and impairments. Northam et al. (2012) attributes a higher rate of speech impairment in PT infants to subtle general motor impairments. These researchers report that early left hemisphere injuries to the corticospinal tract (CST) and speech-motor corticobulbar tract (CBT) in PT infants are significant predictors of adverse speech and oromotor outcomes, in typically developing individuals, speech production and articulation rely primarily on the function of the left hemisphere for innervation of face, tongue, and laryngeal motor control. Therefore, damage to left hemisphere CST and CBT fibers likely results in motor impairment of facial/oromotor function. Northam's research team documents that 31% of PT individuals at 16 years of age exhibit deficits in oromotor and motor-speech control. These authors note that specific weaknesses in coordination of lips, jaw, face, and tongue are evident in PT adolescents even when controlling for CP and significant neurological findings (Northam et al., 2012).

In addition, van Noort-van der Spek et al. (2012) hypothesize that the delayed maturation of oral and articulatory structures in young VLBW children impedes the development of early canonical babbling, even when excluding children with diagnoses of neuromotor impairments. Van Noort-van der Spek and her colleagues conclude that analysis of a child's early spontaneous speech productions is predictive of later phonological abilities foundational for language and reading. These authors note that early disturbances in phonological development impair developing components of expressive language. In van Noort-van der Spek's analyses, fifty percent (50%) of 2-year-old VLBW children's spontaneous speech demonstrates below average phonological skills, fewer consonant productions, and lower mean lengths of utterance than FT children.

Twenty to forty percent of VLBW children are diagnosed with language impairments within the first 7 years of life when not controlling for cognitive ability (Singer et al., 2001). Early preterm (EPT) children demonstrate significantly poorer language abilities than full-term peers as infants and toddlers (Ortiz-Mantilla, Choudhury, Leevers, & Benasich, 2008). Throughout early childhood, children who were preterm score lower on simple and complex language measurements than FT controls even in the absence of severe disabilities, independent of socio-economic factors (van Noort-van der Spek et al., 2012). More specifically, VLBW children demonstrate poorer abilities in receptive and expressive semantics (Barre, Morgan, Doyle, & Anderson, 2010). A study of VLBW infants' ability to discriminate word stress and speech rhythm, reveals poorer differentiation of prosodic stress patterns than FT/NBW peers (Herold, Höhle, Walch, Weber, & Obladen, 2008). In addition, PT toddlers evince delayed discrimination of prosodic stress patterns and word segmentation, which some researchers hypothesize contribute to a higher incidence of language delays at school-age (Newman, Ratner, Jusczyk, Jusczyk, & Dow, 2006). Wocadlo and Rieger (2007) report a significant correlation between expressive vocabulary and phonological naming at school-age.

Study conclusions vary considerably even when controlling for cognitive deficits. Wolke et al. (2008) found that when controlling for cognitive impairment, school-age PT children did not show significant delays in either phonetic awareness or receptive language. The children did, however, evidence deficits in speech and general academic achievement despite adjustments for lower cognitive scores. Lee, Yeatman, Luna, and Feldman (2011), as well as Luu et al. (2011) disagree, stating that both receptive and expressive language skills, syntactic comprehension, language processing, verbal memory, and reading comprehension deficits persist in PT born adolescents even when adjusting for IQ. Luu et al. summarize their findings stating that adolescents born prematurely exhibit deficits "across all measures of executive function and memory" (p. e644).

In summary, research conclusions differ regarding the specific impairments of speech and expressive language skills exhibited by PT individuals at various ages. Some differences may be explained by (a) the diverse types and degrees of early brain injuries, (b) category of prematurity, (c) birth weight, (d) and age at testing. Analysis of early vegetative oral motor function and later speech and expressive language skills could contribute significantly to our knowledge base of PT children. Such research may provide the bases for more timely and appropriate therapeutic intervention.

The present study analyzes the relationship between the primary method of feeding for EPT infants at 34 weeks gestational age and their speech, and expressive language abilities at approximately 10 years of age. Further study of early feeding and its relationship to later speech and expressive language development is needed to understand better whether an association exists (Barlow, 2009; Green et al., 2002; Nip et al., 2009, 2011). This study may contribute toward better understanding the influence of early feeding on speech and expressive language outcomes. Early feeding and later sensorimotor and visuomotor perceptual performance were also analyzed to determine if an association exists between these skills (Aylward, 2005; van Noort-van der Spek, Franken, & Weisglas-Kuperus, 2012).

CHAPTER II

LITERATURE REVIEW

Population of Children Who Are Born Prematurely

A total of 3,952,841 live births were recorded in the United States in 2012. Thirteen percent or 513,869 of those infants were born prematurely, and 8% or 316,227, were low birth weight (CDC, 2013). With advances in medical technology, the population of infants surviving preterm birth also increases (Volpe, 2009). The population of preterm (PT) infants multiplied annually, represents a significant number of children in need of services by teams of healthcare providers and special educators. Familiarity with the epidemiology, common characteristics, and neurodevelopmental outcomes of these children across the life-span can improve early identification and effectiveness of services.

Risk Factors for Preterm Delivery

The most common factors leading to PT labor and delivery are infection, inflammation, microorganisms in the placenta, bacteremia, and uterine stress in the mother (Carlo et al., 2011; Goldenberg et al., 2008; O'Shea et al., 2009). These same factors, also pose the greatest risk for physiological damage and poorer long-term neurodevelopmental outcomes in infants who are born prematurely (Lawn et al., 2010; Mathur et al., 2010; O'Shea et al., 2009; Rees et al., 2011; Volpe, 2009). Infection and inflammation are easily transmitted from the mother to the fetus as amniotic fluid is swallowed or absorbed through the lungs and mucous membranes of the fetus (Jobe, 2010). Additionally, the immature organs of the PT infant, weakened by the stress of birth, often have to continue fending off the same infection and inflammation that precipitated the preterm birth. Organs such as the brain, heart, and lungs remain on an altered developmental trajectory as a result of continued infection and inflammation during maturation in the early postnatal period. This altered developmental trajectory, in many instances, is a life-long hallmark of pre-term birth.

Brain Differences in Preterm Infants

Brain imaging studies indicate that there are both short-term and long-term in the neural structures of PT infants, when compared to full term (FT) peers. Differences in molecular and cellular structure, as well as volume, size, and function, are well documented in the literature of embryology, neonatology, and pediatric radiology. These structural differences are evident in PT infants, even in the absence of obvious focal injuries, and may continue to be observable into adolescence (Inder et al., 2011; Volpe et al., 2011). Specifically, MRI studies show that the regions typically associated with motor-speech and language abilities are functionally different in preterm infants (Bracewell & Marlow, 2002; Thompson et al., 2007).

Volume and Size

Normal cerebral growth progresses in a stepwise pattern from 24 to 40 weeks gestation. As the cortex develops, it forms an elaborate system of folds (sulci) that appear between 24 and 26 weeks (Jobe, 2010; Volpe, 2009) and serve to protect the brain by surrounding developing neural networks. The sulci also allow a normal brain to develop more surface area by folding over multiple times within a small space. In contrast to a normally developing fetus, at 36 weeks gestation, whose brain has intricate sulci and weighs 260 grams, the brain of a PT infant born at 24 weeks has a relatively smooth surface and weighs only 100 grams (Counsell et al., 2003; Jobe, 2010). In addition, at 34 weeks gestation, brain weight in PT infants is 65% of normal term brain weight (Samra et al., 2011).

White matter, cortical gray matter, and corpus collosum volumes in PT infants are reduced relative to FT at birth in comparison to typical gestational age infants in utero. The lower the gestational age at birth, the greater the reduction in the white and gray matter volume of the PT infant (Jobe, 2010; Lubsen et al., 2011; Thompson et al., 2012). Further imaging of infant brain volumes at 40 weeks gestation indicates that white and gray matter content in PT infants remains smaller than that of typically developing infants born at term (Jobe, 2010; Limperopoulos, Chilingaryan, Guizard, Robertson, & Du Plessis, 2010; Lubsen et al., 2011). In addition, PT infants at 24 months adjusted age continue to have smaller frontal, parietal, and transverse cerebellar diameters bilaterally than FT infants at the same age (Tich et al., 2011). Longitudinal studies on brain volume changes indicate that white matter volume increases by 26% in FT children between 8 and 12 years of age, compared with only a 10% increase in PT children of the same age (Ment et al., 2009). Thus, not only are the brains of premature infants smaller at birth, they remain significantly smaller through adolescence (Tich et al., 2011).

Cellular and Molecular Structures

Significant refined development in the brain occurs between 22-37 weeks gestation. During this period, major organizational events occur in the development of neurons and glia at the cellular and molecular level (Anderson, Spencer-Smith, & Wood, 2011; Jobe, 2010; Volpe, 2009). Researchers have identified pre-oligodendrocytes (pre-OLs) as the cells most often damaged in preterm infants (Volpe et al., 2011). Pre-OLs are the most prolific cells in the white matter of infants at this gestational age and are the cells most vulnerable to disruptions. When damaged, pre-OLs impede the protective and maturational process of myelination and neural development (Volpe et al., 2011). This, in turn, reduces the protection myelin provides to the developing neural network, as well as alters the process of typical connectivity.

As a normal brain matures, neurons are generated and migrate to predetermined areas of connectivity (Anderson et al., 2011). These areas of connectivity create the neural networks that form the infrastructure for the nervous system and are necessary for information processing. PT birth disrupts the normal neural organizational process, altering cellular growth within developing neural networks (Counsell et al., 2003; Inder et al., 2011). The degree of alteration to the developing neurological system depends on the type of injury, the extent of brain areas affected, and the gestational age at the time of the injury (Rees et al., 2011). The lower the gestational age and birth weight of a PT infant, the more immature and vulnerable their brain and developing neural infrastructure are to disruption and damage.

Rees et al. (2011) describe the brain reorganization in PT infants as a “cascade of damaging effects” (p. 556). After delivery, the PT infant experiences physiological threats that may result in injury to the immature brain, as well as subsequent abnormal brain development (Inder et al., 2011; Rees et al., 2011). Due to the smaller brain volume and altered neural connectivity that occurs as a consequence of PT birth, the altered neural pathways do not always function successfully (Anderson et al., 2011). Specifically, the altered pathways noted in PT infants do not perform the same as typically developed neural networks in FT infants (Dudink, Kerr, Paterson, & Counsell, 2008; Lubsen et al., 2011; Volpe et al., 2011). In addition, reorganized neural pathways can be maladaptive and contribute to further brain injury, thereby having a negative impact on subsequent brain development (Jobe, 2010; Volpe et al., 2011).

White Matter

White matter is composed of bundles of myelinated neural tissue that are connected to gray matter. Myelin insulates nerve axons, protecting and enhancing neural connectivity, which therefore, is often impaired or damaged in PT infants. The smaller volume of myelinated white matter in PT infants is secondary to early birth and the disruption of the gestational myelination process (Inder et al., 2011). Oligodendrocytes, more prolific in white matter, are responsible for initiating the myelination process. Thus, white matter alterations in PT infants impact the on-going myelination process occurring early in fetal development and continuing into early adulthood (Inder et al., 2011; Mullen et al., 2011). Reduced or damaged white matter may result in permanently under-myelinated or over-myelinated nerve cells (Mathur et al., 2010; Volpe, 2009).

Insufficient myelination results in slower and/or deficient development of motor functions, while excessive myelination results in hypotonia, respiratory difficulties, and sensory-motor deficits (Inder et al., 2011; Jobe, 2010; Panigrahy et al., 2012).

White matter damage is a common form of brain injury in PT infants. Up to 75% of PT infants show evidence of white matter abnormalities on imaging (Mathur et al., 2010). As many as 80% of PT individuals show microstructural density differences in white matter on imaging in adolescence (Dudink et al., 2008; Gozzo et al., 2009; Inder et al., 2011). White matter injuries in children who are born PT most often consist of diffuse microscopic points of damage (punctate lesions). Typically, these are dead cells within the white matter that usually occur secondary to inflammation or infection. These punctate lesions disable and disrupt developing brain cells and neural pathways in the early stages of formation (Rees et al., 2011; Volpe, 2009). Damaged white matter emits what Volpe et al. (2011) refer to as “danger signals” (p. 575). These signals cause the brain to react defensively, producing excessive proteins and molecular responders which, in excess, are toxic and may amplify the injury. Injuries to white matter negatively affect subsequent cerebral growth as well as motor development (Inder et al., 2011).

Gray Matter

Gray matter contains most of the brain’s neuronal cell bodies and is found in the brain and spinal cord. Gray matter serves as the central processing unit for the central nervous system (CNS) and spinal cord. Reduced or damaged gray matter thus affects muscle control, neuronal synapses, and sensory perception throughout the spinal cord and central nervous system. Gray matter damage, between 25 to 29 weeks gestation, may result in degeneration of the corticospinal motor system which carries motor fibers responsible for motor control (Volpe, 2009; Volpe et al., 2011). The younger the gestational age of the PT infant, the lower the gray matter volume and the slower it develops, particularly during the first year of life (Rees et al., 2011). For this reason, many very preterm (VPT) infants present with movement disorders that may resolve by the adjusted age of 24 months as gray matter develops. The smaller volumes of gray matter exhibited by VPT infants throughout childhood and into late adolescence are thought to underlie poorer cognitive, gross and fine motor abilities (de Kieviet, Pick, Aamoudse-Moens, & Oosterlaan, 2009; Inder et al., 2011; Jobe, 2010). In addition, in gray matter, the pre-OLs discussed earlier, mature into oligodendrocytes, which serve as connectors to neurons. Therefore, damaged oligodendrocytes in gray matter result in impaired neuronal connectivity that affects cognitive and motor development, as well as function.

Ventricles

Most infants who are born PT exhibit larger than average ventricles in the brain and greater than normal amounts of cerebrospinal fluid when compared to their FT peers (Inder et al., 2011). Ventricular enlargement and increased CS fluid volume occurs secondary to injured brain tissue swelling and associated blood vessels rupturing and bleeding into the surrounding tissue. In response to the decreased circulation, blood oxygen levels decrease and may result in brain cell and tissue death. Brain cell and tissue death further slow the normal circulation of CS fluid, thereby slowing the distribution of CS fluid throughout the brain and spinal cord. CS fluid not properly circulated may collect in the brain ventricles. The excess CS fluid requires greater than normal space, enlarging the ventricles (ventriculomegaly) and slowing normal development of the brain. Nearly 25% of all PT infants show some evidence of intraventricular brain hemorrhage on neonatal cranial imaging (Gozzo et al., 2009). In most cases, slightly excess CS fluid is absorbed as it circulates and ventriculomegaly resolves over time without causing measurable permanent impairment. In severe cases, however, progressive accumulation of excessive CS fluid and subsequent ventricular enlargement can result in hydrocephalus. Hydrocephalus increases intracranial pressure within the skull and may permanently enlarge the head. In severe cases of ventriculomegaly, inflammation and infection may develop. Excessive dead brain cells and tissue may collect and form cysts which can cause perventricular leucomalacia (PVL). The cysts prevent flow of blood oxygen and CS fluid, severely damaging the brain. PVL damages adjacent white matter causing severe damage to the motor system.

Brain Injury in Preterm Infants

The preterm infant as an organism lacks the advantage of maturation afforded by the final full trimester of pregnancy. Blood vessels in the brains of PT infants are more fragile and rupture easily with any changes in blood oxygen levels. Excess oxygen (hyperoxic) as well as too little oxygen (hypoxic) can rupture the delicate blood vessels supporting organs in PT infants. Immature lungs are often not able to deliver adequate oxygen to the brain, even with the mechanical assistance of a ventilator. Decreased oxygen levels cause cell death in newly forming brain tissue. Not only is the newly developed brain tissue injured, but brain tissue under construction and neural connectivity that occurs with normal growth and future development is damaged and altered at the cellular level.

Neonatal arterial ischemic stroke (AIS) is another common cause of perinatal brain injury (Härtel, Schilling, Sperner, & Thyen, 2004). AIS damages white matter in PT infants, because the cortex, most commonly damaged by adult stroke, is not yet developed (Volpe et al., 2011). Inadequate blood flow to the brain during AIS results in oxygen deprivation and cell death to developing white matter. AIS is associated with many motor and neurodevelopmental disorders in children. Hemiplegic cerebral palsy (CP) is a common outcome in PT infants who have experienced unilateral AIS. If damage is bilateral, quadriplegic CP may result. CP affects not only limbs but also oral and facial muscle tone and coordination. Infants diagnosed with AIS experience greater challenges in every aspect of motor development including the oral motor function of feeding as neonates (Barkat-Masih, Saha, Hamby, Ofner, & Golomb, 2010).

Intraventricular hemorrhages (IVH) are common in infants who are born PT. These hemorrhages are thought to be the results of hypoxic episodes. The lack of oxygen degrades cell structures in the germinal matrix (Inder et al., 2011). Swelling then occurs in the germinal matrix and ruptures adjacent blood vessels. The amount of bleeding varies depending on the severity and extent of damage sustained. The more extensive the intraventricular bleeding, the greater the impact to surrounding gray and white matter brain tissue.

Neonatal injury to white matter, gray matter, brain ventricles, and neural circuitry that have not yet been adequately established, is more likely to result in permanent damage due to the limited neural plasticity at this very young age (Anderson et al., 2011; Kolb & Teskey, 2010).

Neural Plasticity

Neural plasticity is defined as the brain's ability successfully to repair, recruit, and reorganize healthy cells in response to injury. The brain of a PT infant has reduced resources for repairs when simultaneously coping with inflammation or infection and under-developed, already damaged cells (preOLs) shortly after birth.

Injured neural networks in children seek homologous neural pathways for recruitment (Anderson et al., 2011). The PT brain has reduced resources from which to recruit alternative neural pathways secondary to infected and inflamed brain tissue as well as diminished volume (Kolk, Ennok, Laugesaar, Kaldoja, & Talvik, 2011; Limperopoulos et al., 2010; Ment et al., 2009). Specifically, healthy white matter, as well as robust neural infrastructures, is necessary for successful recruitment (Max, Bruce, Keatley, & Delis, 2010; Mosch, Max, & Tranel, 2005).

From delivery, the PT brain is already organizing itself differently due to the disruption of normal development. A different means of neural organization is necessary due to the functional demands on under-developed organs and neural pathways in the early stages of construction (Anderson et al., 2011; Inder et al., 2011). Cerebral structures in the early state of new construction are more fragile and less reliable than established neural architectures (Inder et al., 2011; Jobe, 2010; Volpe, 2009, Tich et al., 2011). In addition, reorganized neural pathways in the PT neonate brain can be maladaptive and inadequate. Reorganized pathways may fail to adequately connect with healthy pathways or adequately accommodate the necessary functions. Dysfunctional neural pathways may result in permanent cognitive, motor, or sensory impairment, or disordered cognitive functions. Coordination of respiration and sensory-motor functions such as oral-motor skills for feeding, and later motor-speech may be impaired.

Neural plasticity is a process, not an isolated event. This process attempts to unbind degenerating cells and divert pathways to establish new functional connectivity. While younger brains are considered to have greater capability for neural restoration through regrowth and reorganization, the period of neural plasticity appears optimal in FT, typically developing children over the age of two years (Anderson et al., 2010; Inder et al., 2011, Volpe, 2009). Healthy older FT children benefit most from intact, robust plasticity (Kolb & Teskey, 2010; Mosch et al., 2005). Cerebral structures in the early stages of new construction are more fragile than established architectures. The protective mechanisms of a very young brain, even in FT infants, can cause more extensive damage than the initial focal injury by overcompensating or hyperfunctioning in multiple adjacent areas (Kolk et al., 2011; Mathur et al., 2010). Damage to primary areas of the fetal brain prior to 40 weeks gestation is more likely to be severe and permanent (Kleim & Jones, 2008; Kolb & Teskey, 2010).

Researcher supports the premise that neural plasticity relies on mature, established, and stable neural networks as well as learning experiences. Furthermore, recovery of established cognitive and motor skills is typically more successful than development of new skills after brain injury (Anderson et al., 2010; Inder et al., 2011). Neural circuitry not activated during functional task performance degrades over time.

This pruning of inactive or nonactivated circuitry directly impacts the cognitive and motor learning of PT infants with brain injuries. Current research supports the motor learning theory that dual influences of task-specific practice and cortical stimulation are essential for development of functional cognitive and motor outcomes (Kleim & Jones, 2008; Kolb & Teskey, 2010). This means that not only is it important that the neural circuitry be in place and functioning, but that infants need the motor experiences of movement and sensory feedback to continue to develop a normal motor system. Infants who are born PT have an altered trajectory of early motor experiences from FT infants. PT infants typically spend many weeks in the NICU, swaddled to help their bodies maintain adequate thermal regulation, which restricts movement. They experience the aversive sensory feedback from naso-gastric tubes threaded through their nose into their stomach for feedings over an extended period of time, palpable every time they swallow or constrict their pharynx. EPT neonates experience much higher levels of environmental noise (e.g., beeping of medical monitors), bright lights, and reduced maternal sensory interaction. Opportunities for typical motor-sensory learning are reduced and delayed in the NICU environment. Even a relatively uneventful few days in the NICU alters the normal progression of mother-child bonding, motor opportunities, and positive brain-nurturing experiences, even without observable damage to the PT brain on imaging.

Before 28 weeks gestation, unilateral hemisphere damage causes impaired growth and development in the uninjured contralateral hemisphere as well (Limperopoulos et al., 2010). Research reveals that PT children with left-sided focal brain injuries develop increasing reliance on right-sided activations for cognitive and language functions

(Mullen et al., 2011; Myers et al., 2010; Thiel et al., 2006). Right hemisphere auxiliary function for cognitive-linguistic abilities, later in life, often results in measurable deficits in the expressive language functions of discourse skills and verbal fluency (Myers et al., 2010).

Oral Motor Development in Utero

Speech is a complex, highly refined motor skill that involves multiple sensory, motor, and cognitive systems (Kent, 2004; Visscher et al., 2010). Specifically, successful speech production involves coordination of input and feedback from multiple sensory and motor signals, and more than 70 muscles in the head, neck, and thorax (Cheng, Murdoch, Goozée, & Scott, 2007; Nip et al., 2011). Maturation and coordination of these systems develops throughout childhood and is dependent on an intact nervous system. It is important for speech-language pathologists to be familiar with literature regarding normal development of oral structures and typical progression of oral motor development. Familiarity with typical oral and motor-speech milestones is essential for early identification of atypical and disordered oral and motor-speech functions.

Studies on emergent structures and initiation of function vary with the gestational age of the participants, the focus, and the professional background of the researcher. Embryologic and obstetric studies provide much-needed information regarding development oral-facial structures and initiation of functions in utero. A typically developing fetus initiates early diaphragm, jaw, lip, tongue, pharyngeal, and laryngeal movements in gross motions in that order.

Respiration

Hall (2010) used three dimensional ultrasound imaging to document fetal craniofacial development following fertilization. She recorded early fetal development of the diaphragm and oral-pharyngeal structures and function. Early episodes of intermittent rhythmic fetal breathing were observed to emerge at 8 weeks. Yawning, involving the diaphragm, intercostals, temporomandibular joint, and perioral muscles, during episodes of inspiration began at 11 weeks. Fetal breathing establishes rhythmicity between 14-17 weeks gestation (Rajendran, Kessler, & Manning, 2009; Fortin & Thoby-Brisson, 2009). The CNS is coordinating rhythmic breathing movements by 29 weeks (Delaney & Arvedson, 2008). The characteristics of frequency and periodicity of respiration change with gestational age. Rajendran et al. (2009) state that normal, regular fetal respiration, involving diaphragmatic excursions combined with intercostal movements, should be present approximately 40% of the time by 32 weeks gestation. These authors note that "normal anatomical development depends on normal physiological expression" (p. 713). Continued normal development of oral and respiratory structures relies upon normal function of those structures.

Jaw, Tongue, and Lips

During the fifth week of fetal development the facial structures begin to emerge (Jiang, Bush, & Lidral, 2006). Jaw movements emerge in isolation or clusters of spasms. With repetition, these spasms become more fluid as motor systems mature (Barlow & Estep, 2006; Hall, 2010; Miller et al., 2006, 2003; Nip et al., 2009; Rajendran et al., 2009). While lip tissue is still forming at 8 weeks gestation, the fetus begins opening the jaw in poorly controlled movements (Miller et al., 2003; Green et al., 2002).

Hall (2010) observed that basic tongue, pharyngeal, laryngeal, and diaphragm structures, in addition to rudimentary musculature for function of the temporalis masseter, buccal muscles, and perioral muscles, could be distinguished as early as 9 weeks. She noted rhythmic jaw opening and closing began at 10 weeks.

Miller et al. (2003) used four-plane sonographic imaging of fetuses between 15-38 weeks gestation and reported measured temporal and spatial data from a communication sciences perspective. They observed clusters of small jaw movements with open lips at 16 weeks gestation. By 17 weeks gestation, non-repetitive, coordinated jaw openings and closings were established in healthy controls. Miller et al. (2003) observed anterior protrusion of the tongue beyond the lip lines with immediate lingual posterior retraction at 18 weeks gestational age. This tongue movement was noted as being similar to the suckle pattern used by infants at birth. These authors reported measurable tongue cupping movements with midline depression emerging in some subjects as early as 16 weeks gestation. In their study, tongue cupping with midline depression was mastered by all typically developing fetuses by 28 weeks. Normal fetuses responded to oral-facial stimuli by exhibiting consistent suckle-pattern tongue movements at 28 weeks.

The mandibular prominences merge around 9 weeks gestation to begin formation of the lower lip. The lips are formed by multiple layers of muscle and an even greater network of supporting neural pathways. In utero lip movement follows jaw movement (Miller et al., 2003).

Swallowing

Hall (2010) observed that fetal swallowing using tongue, pharyngeal, temporalis, and masseter muscles begins at 9 weeks. Fetal swallowing is critical to the absorption of amniotic fluid containing nutrients essential for development in utero (Hall, 2010; Miller et al., 2006, 2003; Rajendran et al., 2009).

Fetal studies by Miller et al. (2003) observed that initially, the nasopharynx fills with fluid propelled by the tongue at 10 weeks gestation. Rhythmic lingual movements with slow pharyngeal contractions for non-nutritive sucking and swallowing were recorded for most subjects at 15 weeks gestation. Rhythmic tongue movements paired with jaw opening, progressed to an established pattern of forward tongue thrusting in most fetuses by 17 weeks gestation. By 18 weeks, glottal closure emerges and a bolus is cleared by a full pharyngeal contraction with associated dorsal tongue and soft palate elevation. Pharyngeal contractions paired with lingual protrusion and cupping emerging emerges around 28 weeks. At 28 weeks, the anterior-to-posterior lingual movement pattern propels amniotic fluid into the oral cavity, which is cupped by the tongue as a bolus, propelled to the posterior dorsum, and swallowed.

Pharyngeal growth is concomitant with pharyngeal movement associated with swallowing (Miller et al., 2003). Rhythmic pharyngeal and laryngeal movements were recorded by Miller et al. throughout the second and third trimesters in utero. Miller et al. as well as other researchers have noted that fetuses demonstrating slow or minimal swallowing patterns also exhibit smaller, underdeveloped pharyngeal growth (Bingham, 2009; Miller et al., 2003; Ranjendran et al., 2009). Most researchers agree that by 37 weeks gestation a normally developing fetus should be managing an intake of 700 mL of amniotic fluid per day to promote adequate growth and the advancement of ingestive and oropharyngeal motor patterns necessary for oral feeding at birth (Bingham, 2009; Hall, 2010).

Importance of Movement in Utero

In the third trimester and perinatal period, the normal fetus and neonate rely on a system of rhythmic movements to mature and regulate the sensory-motor system. In normal motor development, repetitive movements facilitate maturation and regulation of neural networks that are necessary to develop controlled movements used for later speech production (Hall, 2010; Kleim & Jones, 2008). Task specific movement stimulates standard motor neuron connectivity (Chakrabarty, Shullman, & Martin, 2009; Limperopoulos et al., 2010).

Opportunities for task-specific movement are limited for PT infants in the neonatal intensive care unit (NICU). Movement is constrained by swaddling for thermal regulation, intravenous lines for medications and feeding, tubes for oxygen, and later naso-gastric feeding tubes. The limited early motor experiences of the PT infant can further impair normal development of neural pathways and typical motor experiences, even in the absence of brain injury. Disruption in the development of early movement patterns in PT infants alters the normal progression of foundational skills for motor-learning (Bracewell & Marlow, 2002; Barlow & Estep, 2006).

Sex Differences in Fetal Development

While males and females in utero exhibit nearly parallel patterns of physical growth, females demonstrate more advanced pharyngeal airway skills (Miller et al., 2006). Miller et al. (2006) observe that, in the second trimester, females demonstrate more episodes of rhythmic mouthing, lip pursing, yawning, and more complete pharyngeal constrictions in utero than males. The average female masters complete pharyngeal constriction in the third trimester with 100% consistency, whereas the average male demonstrates 66% consistency. The authors hypothesize that this early disparity in functional development suggests a "sex-specific trajectory" (p. 469) or normal sex-based difference in motor development. The authors theorize that the difference in emerging oral motor skills in utero may explain why male preterm infants present with less mature feeding behaviors than same-gestational age females at birth, why healthy term males develop speech-motor skills later than females, and why males present with a greater incidence of speech impairments in early childhood (Miller et al., 2006).

Oral-Motor Development Following Birth

Neural control of the diaphragm, jaw, tongue, lips, pharyngeal, and laryngeal structures and musculature is vital to survival at birth. Following birth, infants must continuously advance and strengthen their motor skills under gradations of stress if they are to thrive. During the perinatal period, as in utero, normal motor experiences and movement are necessary for continued normal development of corticospinal maturation and function (Martin, Choy, Pullman, & Meng, 2004). Oral motor development in infants follows a similar systematic progression as the oral motor development in utero, beginning with coordination of respiration and, later, the addition of specific oral movements.

Respiration

Respiratory control for ventilation in newborns is coordinated by the maturing CNS. Central processing generators (CPGs) establish rhythmicity of inspiration and expiration in utero and continue to develop after birth. The CPGs adapt further to coordination of respiration during crying, at rest, and oral feeding (Fortin & Thoby-Brisson, 2009; Owens, Metz, & Farinella, 2010). During rest-breathing the chest wall is coupled to the rib cage and abdomen in newborns (Owens et al., 2010). Synchronous movement of the rib cage and abdomen characterize rest-breathing in infants (Owens et al., 2010; Reilly & Moore, 2009).

Rest breathing and speech-related breathing mature simultaneously in infants (Connaghan, Moore, & Higashakawa, 2004; Reilly & Moore, 2009). Respiration for vocalization requires increased volume of air intake and increased coordination to prolong exhalation with voicing. Reilly and Moore (2009) note that the influence of the chest wall on rib cage and abdominal movement decreases significantly between 7 and 11 months. These authors observe that as the chest wall develops, it accommodates greater excursions of the rib cage and abdomen. This greater freedom of movement allows oppositional movements of the rib cage and abdomen to occur. Paradoxing, or oppositional movements of the rib cage and abdomen, characterizes breathing for vocalization. Reilly and Moore (2009) note that canonical babbling emerges during the time the chest wall is expanding to accommodate increased oppositional movements of the rib cage and abdomen. These authors hypothesize that the function of respiration for life support and habitual horizontal positioning in infants constrains the involvement of the respiratory neuromuscular system for prolonged vocalization. In addition, positional and gravitational changes in infants appear to be factors that assist with the development of chest wall, rib cage, and abdominal musculature changes in coordination of respiration (Connaghan et al., 2004; Iverson, 2010; Locke, 2004; Owens et al., 2010).

Connaghan et al. (2004) observed that after 9 months of age lung capacity increases and respiratory rates decrease as biomechanical systems and anatomical structures mature. Fewer breaths are required as lung intake capacity increases. The authors noted that children use larger rib cage excursions and require a greater lung volume during speech breathing than adults. They observed that increased lung capacity occurs concurrently with thoracic lengthening (growth) and rib cage stiffening (calcification). Connaghan et al. note that greater lung volume exchange increasingly relies on coordination of rib cage and chest wall movement rather than the formerly predominating abdominal movements. These researchers document that the respiratory patterns for rest-breathing and speech-related breathing gradually diverge between 9 and 48 months of age. Between 9 and 12 months the chest wall stiffens, the hyoid bone and larynx descend, and the epiglottis inclines away from the soft palate, providing improved resonating cavities for voicing (Owens et al., 2010).

Positional changes from prone to standing parallel the maturation of the respiratory system, and are important motor experiences associated with developmental and physiological lung capacity changes. Infants, who do not experience the typical progression of gross motor positional changes from handling by caregivers or by being in prone and supine positions on their own, characteristically are at greater risk for developing respiratory disorders. EPT infants who are delivered at or more than 10 weeks before term lack the lung development and surfactant production to expand the lungs for adequate respiratory support, and easily develop bronchopulmonary dysplasia (BPD). Surfactant is the liquid lining which coats the inside of the lungs that assists in expansion for inhalation. PT infants with a history of BPD are at greater risk than the general population of PT infants for poorer outcomes (Thompson et al., 2007). Lewis et al. (2002) hypothesize that BPD may have localized effects on brain areas responsible for motor skills, visual-motor integration, and visual-spatial skills.

Treatments for respiratory disorders, such as corticosteroids and oxygen, additionally are recognized as exacerbating elements in differentiating adverse outcomes from disease versus problems related to the unintended consequences of treatment (Deuber & Terhaar, 2011; O'Shea et al., 2012; Rajendran et al., 2009). PT infants who develop respiratory disorders are at greater risk for long-term respiratory problems as well as feeding and speech disorders. Researchers attribute this association between early respiratory problems and later feeding and speech problems to the combination of inflammation and extended period of time these infants are exposed to interventions such as therapeutic surfactant and supplemental oxygen. (Singer et al., 2001; Spittle et al., 2009; Slattery, Morgan, & Douglas, 2012). Not only are the lungs of PT infants immature, but the interventions used to improve lung function feeding (i.e., tubes, ventilators, and side-lying in incubators) are physically restricting and may impair development of respiratory control for speech and feeding. Lewis et al. (2002) observed that infants with a history of BPD demonstrate poorer articulation and gross and fine motor skills later in life than either VLBW or FT infants.

In summary, adequate respiratory support is necessary for the health and growth of all infants. Lower oxygen saturation rates, as well as bronchial and pulmonary complications secondary to PT birth, put these infants at greater risk for survival early in life. These complications may also impair coordination of respiration during oral-motor skill exploration involving the jaw, tongue, and lips.

Jaw, Tongue, and Lips

Normally developing neonates learn to coordinate oral activity relative to the demand for survival (Steeve & Moore, 2009). Specifically, sensori-motor coordination of an alternating rhythmic pattern of jaw pressure (for expression) and suction (for extraction), timed between respiratory inspiration and expiration, is necessary for the infant to breathe and feed (Barlow, 2009; Mizuno & Ueda, 2005). Jaw stability significantly precedes lip stability in coordinating jaw opening and closing, also essential for feeding (Green et al., 2002). Neonates must quickly develop rudimentary jaw stabilization and respiratory control to organize movements essential for breathing and feeding. Nine month-old infants exhibit mandibular movement patterns similar to those of adults for both feeding and speech, but with less coordination and effectiveness (Steeve & Moore, 2009).

One of the primary functions of the jaw in early development is to alter the shape of the vocal tract by manipulating tongue height and pharyngeal positioning (Cheng et al., 2007). Pharyngeal, laryngeal, and vocal tract changes in size and shape occur with degrees of jaw opening and closing movements (Grigos, 2009; Green et al., 2002). The jaw is acknowledged to be the most fundamental structure to influence control of the oral-motor infrastructure necessary for articulation (Ho & Wilmut, 2010; Terband, Maassen, van Lieshout, & Nijland, 2010). Tongue movements are initially associated with jaw movement but later demonstrate increasing independence from the jaw (Cheng et al., 2007; Green et al., 2002; Wohlert & Smith, 2002).

Infants learn to integrate emerging control of lip movement into well-established jaw movement patterns (Green et al., 2002). Lower lip movements in unison with jaw motion are stabilized before tongue tip extension is paired with graded jaw openings (Green et al., 2002; Nip et al., 2011; Terband et al., 2010). Until 12 months of age, lower lip and jaw movements are predominantly synchronous, which accounts for the emergence of vowels as first sounds (Green et al., 2002). Lips have much greater degrees of freedom and multidirectional movement than the other articulators. Upper and lower lip coordination matures at different ages (Green et al., 2002; Grigos & Kolenda, 2010). Independence of lower lip movements begins emerging around 9 months and increases markedly between 9 and 12 months when children are using first words and bilabial sounds (Nip et al., 2009). Coordinated range of movement for the lower lip during speech improves correspondingly with age (Nip et al., 2009, 2011). Upper lip mobility has greater responsibility for refined grading of lip aperture (Green et al., 2002; Smith & Zelaznik, 2004). Green et al. (2002) hypothesize that the lower lip constrains upper lip development and delays the emergence of labiodentals fricatives until after 2 years of age.

At 19 months upper and lower lip stability improves to resemble more closely "adult-like patterns" of speech" (Grigos, 2009). Researchers hypothesize that the systematic progression of oral function may be a natural result of structures with greater degrees of freedom in movement, requiring more learned constraint for refined control from the nervous system (Green et al., 2002, Nip et al., 2011). Only after gross motor control of the jaw, lips, and tongue has been well established can the fine motor coordination of oral musculature meet the precision demands of purposeful speech.

Relationship between Early Feeding and Speech

The considerable controversy relating to the relationship of early feeding and speech has yet to be conclusively resolved (Barlow, 2009; Bunton, 2008; Green et al., 2002; Nip et al., 2009; Steeve et al., 2008; Wilson et al., 2012). Both feeding and speech are products of multiple sensory and motor pathways, but the specific parameters of their intersecting functions remain unclear (Finan & Smith, 2005; Steeve & Moore, 2009; Wilson et al., 2012). However, an integrated sensorimotor system is the foundation for the motor acts of breathing, sucking, swallowing, and speech (Barlow & Estep, 2006; Delaney & Arvedson, 2008).

Barlow and Estep (2006) posit that vocalizations and speech may evolve from a shared rudimentary "pattern-generating circuitry for respiration, suck, and mastication" (p. 375). They draw upon an amalgam of motor learning theories, hypothesizing that one motor act may drive another (dynamic systems theory) such that neural circuitry for speech evolves from "recombination and neuromodulatory effects" (p. 375) on more primitive motor patterns originally generated for breathing and feeding (schema theory). Barlow and Estep's theory supports the concept of Steeve and Moore (2009) that "early non-speech behaviors rely on coordinative mechanisms that are later exploited for production of early speech vocalizations" (p. 1530). Lund and Kolta (2006), as well as McFarland and Tremblay (2006), postulate that the CPG for mastication, which lies in the pons and medulla, is responsible for both mastication and "control of orofacial movements during speech" (Lund & Kolta, 2006, p. 388). These investigators cite the high incidence co-morbidity of swallowing and voice/speech impairments as further evidence of the inter-relationship of the oromotor and speech systems.

Conversely, Steeve et al. (2008) conclude that the underlying motor infrastructure for speech is task-specific, directed by "distinct non-overlapping task demands" (p. 1390). They observe "weak coupling" (p. 1390) of mandibular muscle groups during sucking, chewing, and babbling in EMG studies. Steeve et al. purport that "feeding skills emerge from distinct cortical networks" (p. 1402). They hypothesize that the differences in motor control for speech arises not as a "serendipitous consequence of jaw movement" (p. 1402) but as a result of neural maturation. The authors note that the distinctly different musculature for feeding and speech are the result of differently developing neural pathways based on functional movements. Steeve et al. cite that the masseter and temporalis muscles feature predominantly in chewing whereas the medial pterygoid and anterior belly of the digastric are the major muscles controlling jaw aperture for speech. Speech emerges only after more sophisticated motor experiences, such as coordinated jaw movement and random sound play, have provided separate neural pathways specifically for a linguistic system.

Yet another group of investigators acknowledge the research on task-specific motor learning but cite the parallels of gross motor learning as prerequisites facilitating oral motor physiology advancement for speech (Iverson, 2010; Oller, 2010; Smith, 2006). These authors propose that sitting, crawling, and walking provide language and motor experiences essential to sound play, babbling, and syllable production emergence. They cite this as evidence that all motor skills have an impact on one another. These researchers advocate further investigation of the associations between motor achievements and language milestones. Oller (2010) and Iverson (2010) assign particular significance to the associations between repetitive limb movements and emergence of repetitive vocalizations exhibited in sound play. They note that mouthing of toys and objects is critical experience for infants to produce more varied vowel and consonant sounds.

Maas et al. (2008) assert that although the motor behaviors underlying non-speech and speech tasks may be distinct, information pertaining to the function and infrastructure of intact motor systems may reveal much about the development and relationship between the two. These authors question whether an impaired early motor system adheres to the same network learning trajectory as an intact motor system. These researchers postulate that damage to the developing motor system likely affects the foundational motor functions of both feeding and early speech.

Based on the inconclusive information regarding the relationship between speech and feeding, addition investigation is needed (Alcock, 2006; Nip et al., 2009; Smith, 2006; Steeve & Moore, 2009; Steeve et al., 2008). Wilson et al. (2012) recommend longitudinal studies of masticatory skills from infancy through childhood to establish norms in typical developmental progression. This developmental timeline could then provide valuable information for age appropriate chewing performance and "developmentally-appropriate therapeutic interventions" (p.636) in early oral motor skills.

Feeding Skills of Preterm Infants

Brain injury in the prenatal or perinatal period has an adverse effect on motor development and, consequently, the oral-motor skills required for the vegetative function of oral feedings (Barlow, 2009; Lau, Geddes, Mizuno, & Schaal, 2012; Slattery et al., 2012). As discussed earlier, a healthy fetus exhibits pharyngeal contractions paired with tongue protrusion and lingual cupping at 28 weeks (Hall, 2010). Coordination of jaw opening and closing, lip rounding and the strength necessary to maintain a reasonable seal around a nipple, as well as tongue protrusion, lingual cupping to propel the bolus, pharyngeal contractions to swallow the bolus, and adequate muscle tone of the upper and lower esophageal sphincters, are all essential motor functions for successful oral feeding. Infants, who are born prematurely, typically rely on intravenous tube feedings until medically stable. Healthy PT infants are transitioned to naso-gastric (NG) tube feedings around 30 weeks gestational age. Healthy PT infants, who remain medically stable after transition to NG tube feedings, are introduced to oral feedings, usually consisting of bottle or breast feedings, at approximately 32 weeks.

PT infants with obvious brain or other organ inflammation or damage are transitioned to NG feedings when they are able to maintain adequate oxygen saturation rates and remain overall healthy with this change. The transition to oral feedings is postponed until adequate respiration and oxygenation is maintained during positional changes, as well as a consistently safe suck-swallow reflex is established without aspiration during feedings. For most PT infants with any medical complications, the transition to oral feeding is a protracted process. Pulmonary immaturity and insufficiency during respiratory changes involved with any movement is a major concern during early oral feedings. Hypoxic episodes during early attempts of bottle feedings are common and a primary concern for the overall health of the infant. Many PT infants at 32 weeks lack the necessary coordination of respiration and oral-pharyngeal motor components required for successful oral feeding. Most often, a basic suck-swallow reflex is absent or is not adequately developed. (Delaney & Arvedson, 2008; Lau, 2006; Mantilla & Sieck, 2008). Some researchers contend that the absence of the suck-swallow reflex itself is an indicator of CNS dysfunction and brain injury, even in PT infants where no damage is observable on radiologic imaging (Bingham, 2009; Poore & Barlow, 2009; Slattery et al., 2012; Tsai, Chen, & Lin, 2010).

Eliciting a suck-swallow response to oral-facial stimuli may require repeated trials and extensive experience over time. Until the suck-swallow reflex is established with adequate respiratory coordination for management of liquids presented orally, no infant is ready for nutrition to rely completely on oral feedings. Through this period, a combination of NG tube feedings and oral feeding trials is common. Infant feeding specialists acknowledge that the presence of an NG tube alone, however, alters normal oral-pharyngeal proprioception and swallowing (Delaney & Arvedson, 2008; Lau et al., 2012; Törölä, Lehtihalmes, Yliherva, & Olsén, 2012).

Healthy PT infants who progress without problems to oral feedings only, between 32 and 34 weeks gestational age, are usually discharged from the NICU and join their families at home. PT infants who are unable to manage oral feedings at 34 weeks usually have additional medical concerns and will continue to be hospitalized and receive NG tube feedings or have a gastrostomy tube placed between 32 and 34 weeks. Gastrostomy tubes (G-tube), gastrojejunal (G-J tube), and jejunal tubes (J-tube) are placed when the gastroenterologist determines that the oral-pharyngeal functions of an infant are not progressing over time toward completely oral feedings. Placement of a G-tube itself may reduce an infant's proprioceptive, sensory, motor, and oral-pharyngeal experiences such that coordination of respiration and oral-peripheral functions supporting oral feeding continue to be absent or dysfunctional for this vegetative function (Delaney & Arvedson, 2008; Slattery et al., 2012). Therefore, a therapeutic protocol of facial and oral-motor stimulation with trials of very small amounts of formula or breast milk is often recommended to facilitate successful experiences toward the goal of oral feeding (Lau et al., 2012; Poore, Zimmerman, Barlow, Wang, & Gu, 2008; Reissland, Mason, Schaal, & Lincoln, 2012).

Because some PT infants are frequently discharged from the NICU after 34 weeks if they are completely feeding orally without problems, the proposed study will gather NICU records on all infants at 34 weeks gestational age. Healthy PT infants are often followed only by a family practitioner or pediatrician after discharge from the NICU. Although some infants continue to be entirely tube-dependent for feeding beyond 40 weeks gestational age, most are discharged from the NICU whenever they are medically stable at or beyond 36 weeks. Forty percent of patients followed by outpatient feeding clinics are PT infants and children (Delaney & Arvedson, 2008; Lau et al., 2012). Children who were born PT often continue to demonstrate failure to progress with textures, food aversions, and food volume issues, which become associated with nutrition and growth concerns for many years (DeMauro et al., 2011; Samara et al., 2009). EPT children show greater oral hypersensitivity and food refusal, and have greater difficulty managing chewy textures in comparison to later gestational age PT children and FT peers. For these reasons, EPT children at school-age exhibit two to five times increased risk of feeding issues (Samara et al., 2009).

Clinicians attribute most persistent feeding problems as being secondary to poor coordination of respiration and/or poor organization and coordination of oral-motor skills. Ongoing subtle impairments of gross and fine motor skills remain continue to have a negative impact on overall oral-motor development (Bauer, Prade, Keske-Soares, Haëffner, & Weinmann, 2008; Northam et al., 2012; Samara et al., 2009). Some researchers hypothesize that persistent feeding problems in infancy predict poorer neurodevelopmental outcomes later in life for PT children (Adams-Chapman, Bann, Vaucher, & Stoll, 2013; Mizuno & Ueda, 2005; Samara et al., 2009; Slattery et al., 2012).

Association of Early Feeding Skills to Adverse Neurodevelopmental Outcomes

To date, three studies conclude that there may be an association between early feeding performance and the severity of later neurodevelopmental outcomes (Adams-Chapman et al., 2013; Mizuno & Ueda, 2005; Slattery et al., 2012). Mizuno and Ueda (2005) observed a significant correlation between feeding assessments conducted on infants born after 35 weeks gestation and performance on the Bayley Scales of Infant Development, 2nd Ed. (BSID-II) administered at 18 months of age. The authors excluded children with brain abnormalities on imaging or severe tone disorders, genetic syndromes, or craniofacial deformities. These researchers reported that the severity of impaired feeding behaviors at one month after birth, correlated with the classification of delays on the BSID-II.

Slattery et al. (2012) conducted a systematic review of research articles which reported early measures of early sucking and swallowing in PT infants, who were diagnosed with neonatal brain injuries, and measurement of later neurodevelopmental outcomes. These authors concluded that early sucking and swallowing problems were present in the majority of PT children studied who later evidenced poorer performance on standardized tests.

Adams-Chapman et al. (2013) assessed the relationship between abnormal feeding behaviors in EPT infants and neurodevelopmental evaluations at 18-22 months corrected age. These researchers concluded that EPT infants with an early diagnosis of a feeding disorder were significantly more likely to exhibit severely delayed language skills on the Bayley Scale of Infant Development 3rd Ed. (BSID-III) than EPT infants with normal early feeding behaviors More than 50% of the infants in this study with feeding problems had no evidence of other motor impairments, which led these authors to question whether general gross motor skills are being adequately assessed in infants with obvious oral motor dysfunction.

Normal Motor-Speech Development in Children

Basic motor speech praxis in full-term, typically developing children, follows a sequential learning curve of emergence, refinement, and proficiency that, with familiarity, can be assessed in the same way as general childhood motor milestones (Iverson 2010; Iverson & Fagan, 2004; Smith, 2006). Speech and language proficiency follow the acquisition of normal motor-speech skills in typically developing children (Alcock, 2006; Iverson, 2010; Locke, 2004; Nip et al., 2009). The motor cortex animates the muscles of the diaphragm, jaw, tongue, lips, pharynx, and larynx responsible for respiration, phonation, resonation, and articulation (Nip et al., 2011; Oller, 2010; Smith, 2006). Injury or impairment to the motor cortex directly impacts function and normal development of diaphragm, jaw, tongue, lip, pharyngeal, and laryngeal function (Green et al., 2002; Jiang et al., 2006; Kempley et al., 2014). Therefore, children who are born PT, are at greater risk for later speech and articulation disorders (Samara et al., 2009).

Respiration

With maturation, the chest wall loses much of its flexibility and stiffens to protect the expanding lungs (Owens et al., 2010). Up to age four, lung capacity continues to increase and respiratory rates decrease as biomechanical systems and anatomical structures mature (Connaghan et al., 2004). By 4 years of age, most children exhibit respiratory patterns similar to adults. Adult-like respiration is characterized by synchronous rib cage and abdominal movements during rest and oppositional rib cage and abdominal movements during speech (Connaghan et al., 2004; Wohlert & Smith, 2002). Respiratory movements are easily coordinated by typically developing children for vocalization on exhalation. Normal children also automatically suspend both inhalation and exhalation during the intake of food. At-rest respiration resumes as a bolus is transferred safely past the upper and lower esophageal sphincters, into the stomach (Miller et al., 2003).

Jaw

Jaw coordination is generally acknowledged as the primary catalyst in oral motor-development (Cheng et al., 2007; Green et al., 2002; Green & Nip, 2010; Grigos, 2009; Nip et al., 2009). Mastery of jaw movement is necessary before control of smaller articulators can be attempted (Smith, 2006; Steeve & Moore, 2009; Steeve et al., 2008). An infant’s limited ability to control jaw movement constrains his or her ability to produce a wide variety of phonetic sounds until the tongue and lips establish independent movements, resulting in predictable speech sound errors and distortions (Green et al., 2002). As the child grows and gains control of jaw grading skills, a larger repertoire of vowel sounds is possible.

Jaw stability precedes lip stability. For this reason, infants first learn to produce a variety of vowel sounds by improving control of jaw grading (Smith, 2006; Steeve &

Moore, 2009; Steeve et al., 2008). Jaw and lip excursions in 1 year olds during speech become significantly more coordinated by 2 years of age (Green & Nip, 2010; Green et al., 2002). Motor disorders, muscle tone or coordination disorders, such as hypotonia, hypertonia, cerebral palsy or even milder discoordination disorders, alter the normal trajectory of jaw coordination for both feeding and speech.

Lund and Kolta (2006) conclude that the same CPG circuitry responsible for early reflexive jaw openings and closings adapts with sensory input to control speech. These authors hypothesize that early jaw movements for mastication are characterized by repetitive oscillations evolving a motor stereotypy that entrains a more coordinated jaw movement pattern for early babbling (Lund & Kolta, 2006). They assert that rhythmic grading of jaw opening and closing primes the CPGs for chewing to develop similar but more controlled movement patterns, for speech. This supports the hypothesis that jaw control for speech emerges as a product of entrainment. Entrainment involves the motor activity of one system assuming the properties of another. Lund and Kolta (2006) assert that jaw control for speech emerges relies on well-established opening and closing patterns for feeding.

Steeve and Moore (2009) present a differing view, citing that coordinating muscle groups are responsible for mandibular control for speech. They assert that jaw movement for chewing is a separate and distinct function. Researchers agree, however, that stable and predictable jaw movements for speech are established in typically developing infants by 9 months of age (Lund & Kolta, 2006; Steeve et al., 2008).

Tongue

The base of the tongue follows jaw movement in infants and toddlers (Green & Nip, 2010). Most oral motor studies on infants under 6 months have focused exclusively on tongue movement patterns for feeding (Arvedson, 2006; Alcock, 2006; Barlow, 2009). Motor control for tongue movement, separate from jaw movement, emerges later than separate lip and jaw movements (Cheng et al., 2007; Wohlert & Smith, 2002). Initially, the body of the tongue moves in tandem with the mandible. Tongue-tip disassociation from jaw movements occurs later. Lingual movements during babbling emerge between 6 and 8 months of age but are limited by pressure from the palate and bilateral buccal pads. At rest, tongue placement is in a low cupped position responding to pressure from the lower, somewhat flatter infant palate (Maassen & Ziegler, 2004). Around 21 months of age, the frontal aspect of the tongue changes its habitual resting position closer to the alveolar ridge, while the lips remain closed. The tongue develops greater freedom of movement and increasing strength as the palate responds by becoming higher and more arched. Through 7 years of age, children demonstrate greater variability and range of tongue movements than adults. They explore tongue positioning options between consonant and vowel productions (Cheng et al., 2007; Maassen & Ziegler, 2004; Wohlert & Smith, 2002). After 7 years of age, this wide variation of tongue placement is replaced by more refined movements which quickly and efficiently produce target speech sounds (Cheng et al., 2007).

Maturation for the rate of tongue movement is highly individualized but may be the predominant factor in the generalized timeline of developmental phonological processes. Children incorporate new movements and sounds as they master articulatory patterns. Nearly all consonants are mastered between 7 and 8 years of age (Cheng et al., 2007; Owens et al., 2010; Smith, 2006). Tongue-jaw de-coupling, allowing for more stable, independent movement of the coronal aspect (tongue body), dorsum (tongue blade), and tongue tip, is evidenced by 8 years of age (Cheng et al., 2007). Subtle refinement of lingual tip control continues into adulthood (Cheng et al., 2007; Owens et al., 2010).

Lips

By age three, typically developing children have mastered separation of lower lip movement from associated jaw motion to produce voiced /b/ and voiceless /p/ consonants (Grigos, 2009). Speed and range of lower lip movement are refined into adulthood (Green et al., 2002). Because greater jaw, tongue, upper lip, and lower lip coordination is necessary to produce /f/, this sound is observed less in early sound play and not consistently mastered before 4 years of age (Green et al., 2002).

The upper lip becomes increasingly dissociated from the lower lip beginning at 24 months (Grigos, Saxman, & Gordon, 2005). Green et al. (2002) hypothesize that the reliance of the lower lip on jaw movement constrains upper lip development (Green et al., 2002). Upper lip control during voiced and voiceless consonants emerges in typically developing children by 3 years of age, after jaw and lower lip stability and coordination have been established (Grigos, 2009).

Motor-Speech Development in PT Children

There appears to be no literature available on the motor-speech development of PT infants. Studies providing information as to whether PT infants follow a slower or altered learning curve for mastery of jaw, lip, and tongue coordination would be of great value. Clinicians characteristically question if young children exhibiting delayed and disordered oral-motor skills for feeding and motor-speech were preterm or experienced any early injuries or illnesses which might affect normal development. Theoretically, speech-language pathologists know that any alteration to the developing CNS and brain increases a young child's risk for motor-speech disorders (American Speech-Language-Hearing Association [ASHA], 2007; Iverson, 2010; Oller, 2010).

Refinement of Motor-Speech Praxis

As normal children grow and gain increased control of their respiration during a variety of activities, they incorporate greater coordination of the jaw, lips and tongue as well. Physiology and regulatory changes in typically developing children occur simultaneously with age and maturation.

Physiology and Regulatory Changes with Age

Younger children demonstrate greater variability of articulator movements in sound productions than older children (Smith, 2006; Smith & Zelaznik, 2004; Zharkova, Hewlett, & Hardcastle, 2011). This variability is generally attributed to children learning to achieve target jaw, tongue, and lip and laryngeal-pharyngeal coordination for specific target sounds. Four year-olds may produce a target sound correctly on every trial but show considerable differences in use of jaw, upper, and lower lip movements for each trial (Smith & Zelaznik, 2004). By the age of 4 years, children shift their motor organizational strategy from more simple motor-driven goals to more sophisticated motor-speech commands directed by phonetic goals, phrase goals, and sentence level goals (Smith, 2006).

Between 4 and 5 years, children master coordination of finely graded lip aperture with girls showing greater mastery than boys of the same age (Smith & Zelaznik, 2004). Smith and Zelaznik (2004) note that this difference between the sexes at this age cannot be attributed to differences in growth rates because craniofacial growth rates for girls and boys do not diverge until 12 years.

By 6 years of age, the jaw, upper lip, and lower lip coordinate during movement sequences and are able to perform at increased speed (Green & Nip, 2010; Smith & Zelaznik, 2004). Between 7 and 10 years, the vocal tract and lower face experience significant growth in length (Green et al., 2002; Zharkova et al., 2011). By 12 years, children show more consistency and less variability in consecutive target productions than young children, but their motor patterns are not yet as consistent as adults (Smith & Zelaznik, 2004). Jaw, upper lip, and lower lip mobility measurements for variance, timing and velocity follow corresponding growth curves through adolescence into adulthood (Smith & Zelaznik, 2004).

After children establish typical gross movement patterns of the articulators, they progress toward smaller, more refined movements. They then develop a greater repertoire of target phonemes and words (Grigos et al., 2005). Children advance from relatively wide excursions of movement with greater variability, to faster, more precise and less variable movements of the articulators (Barlow & Estep, 2006; Dodd & McIntosh, 2010; Grigos, et al., 2005; Smith & Zelaznik, 2004; Nip et al., 2011). While no significant changes in tongue-base to jaw coupling have been observed between children and adults, tongue-tip to jaw coupling is a later maturing synergy required for increased speed of articulation and speech (Cheng et al., 2007). Adult-like motor-speech control is established by 8 years of age although speed and precision and continue to improve into early adulthood (Cheng et al., 2007; Nip et al., 2011).

Summary of Oral-Motor Development Overview

Coordination of respiration, with sucking and swallowing for successful feeding, is normally established by a fetus at 34 weeks gestation in utero. EPT infants, whose in utero development is disrupted, often exhibit motor and sensorimotor dysfunction. Many EPT infants are unable to coordinate the oral-motor acts necessary for coordinating sucking and swallowing with respiration for successful oral feeding, even at the corrected age of 34 weeks in the NICU.

Typically developing children have acquired most of the sounds of their primary language by the age of 4 and mastered these sounds by the age of 7. There is a strong correlation between the first sounds used during babbling and beginning sounds in first words. This indicates that phonological development follows motor-speech development. Increased speech rate and reduced variability in the production of same target sounds-in-sequence are the main areas where motor-speech proficiency continues to develop through adulthood.

The emergence of age-appropriate speech and language skills is dependent on adequate motor-speech coordination. Very young children with disordered motor development often later exhibit impaired speech development (Iverson, 2010; Northam et al., 2012; Oller, 2010). There is developmental interdependence between the motor and speech systems. The combined influences of refined motor-speech praxis with sensory and cognitive experiences result in the acquisition of normal speech and language skills. Motor-speech disorders impact sensorimotor learning which, in turn, affects normal development of speech-sounds, phonological processes, and higher level language processing abilities (Nip et al., 2011; Ortiz-Mantilla et al., 2008; Zharkova et al., 2011).

Neurodevelopmental Outcomes for Preterm Children

In reviewing the literature, outcome results can vary widely when only birth weight or only gestational age are the inclusion factors for the study sample (Aylward, 2005; Samara et al., 2009; Samra et al., 2011). All researchers agree, however, that in comparison to the general population, twice as many preterm children present with adverse neurodevelopmental outcomes (Woythaler et al., 2011). Sixteen percent (16%) of ELBW infants at 18 months appear unimpaired, twenty-two percent (22%) exhibit mild impairments, and twenty-two percent (22%) present with moderate-severe neurodevelopmental impairments (Allen et al., 2011).

One clear conclusion from research to date is that neurodevelopmental outcomes in PT individuals do not specifically correlate with isolated sites of brain injury (Inder et al., 2011; Leviton et al., 2010). Instead, clusters of disorders seem to result from diffuse damage to generalized areas of the brain. The timing of an injury, medications/treatments used, and associated secondary injuries are greater predictors of neurodevelopmental outcomes (Mathur et al., 2010; Moore et al., 2012).

One of the most confounding issues in studying outcomes in premature infants is recognizing how primary injuries impact subsequent CNS, organ, and brain development. Initial brain trauma such as a cerebellar injury is often further complicated by vascular injuries which result in even greater damage. Hypoxia, stress, inflammation and drug therapies all contribute to decreased neurodevelopmental outcomes in preterm infants (Thompson et al., 2007). As more prognostic indicators are identified, earlier diagnosis and interventions may provide improved outcomes (Allen et al., 2011; Leviton et al., 2010).

Cognitive

Cognitive deficits are the most prevalent adverse outcome among low birth weight, low gestational-age preterm infants (Volpe, 2009). Cognitive deficits are 3 to 6 times higher in preterm infants than those who are full term (Orchinik et al., 2011; Wolke et al., 2008). Specifically, preterm infants perform significantly below average on tasks of language, visual matching, motor and perceptual-motor skills and spatial and non-verbal reasoning when compared to children who were born at term. Investigators report that as many as 40% of EPT children have cognitive deficits (Wolke et al., 2008).

Intelligence tests are based on an individual’s ability to process, follow directions, and provide verbal responses. Intelligence tests are standardized on children who were term infants presenting with similar cognitive processes, logic, and problem-solving abilities. Preterm infants process and problem-solve differently (Lubsen et al., 2011;

Mathur et al., 2010). Given that children born prematurely have a higher incidence of language disorders, it follows that they may not do as well as the average FT child on measures of intelligence (Ortiz-Mantilla et al., 2008; Myers et al., 2010).

Overall cognitive ability is not restricted to any specific area of the brain, but more a result of successful combinations of areas working together to provide underlying neuro infrastructure for cerebral function. Cognitive delay is a significant problem for most children who were EPT/LBW infants. Late preterm infants born between 36 to 39 weeks show 52% more cognitive delays than term infants when measured at 24 months (Woythaler et al., 2011). PT children experience four times more educational problems than same-age FT, normal birth weight peers (Wolke et al., 2008).

Imaging scans conducted on VLBW preterm children with cognitive impairments revealed that, unlike NB peers, they employed alternate patterns of brain activity during language comprehension tasks. These children used neural pathways for language processing that normal children use to process meaningless phonologic sounds (Peterson et al., 2002). The researchers concluded that one reason for the lower cognitive and language abilities in this group was most likely associated with deficient and/or defective neural processing. Most researchers attribute problems with delays in processing and learning disabilities to less effective alternative neural pathway development (Myers et al., 2010).

Longitudinal research on cognitive outcomes in EPT/ELBW children at 6 years of age through high school consistently identifies deficits in visuospatial skills, sensorimotor abilities, attention, and executive function (EF), even when controlling for global cognitive ability (Orchinik et al., 2011). Learning disabilities frequently go unrecognized in PT children for several years after school entry until patterns of under-performance become consistent (Aylward, 2005; Wolke et al., 2008).

Motor

One of the earliest indicators of CNS dysfunction is neuromotor abnormality (Allen et al., 2011). Asymmetries, tone disorders, and absence or prolongation of primitive reflexes can be observed within the first few months of life. Cerebral palsy (CP) is typically the earliest observable motor outcome. As many as 10% of preterm infants develop spastic motor dysfunctions such as cerebral palsy by 24 months of age (Inder et al., 2011; O'Shea et al., 2012).

CP follows a hierarchy of severity correlating with the extent of brain injury. Motor impairment ranges from severe quadriplegia to milder impairments such as developmental coordination disorder (DCD) or mild neuromotor abnormalities. More research is available about CP and severe motor disorders than is available about milder impairments. Severe brain damage is more clearly evident in resonance imaging, unlike milder brain injuries that may not be as discernable.

Previously, children who were described as "clumsy" but without a diagnosis of CP were considered to exhibit 'slow' motor skills. More recently these children are being diagnosed with developmental coordination disorder (DCD). DCD is a much less disabling motor condition than CP, yet it greatly affects motor and cognitive development. DCD is diagnosed between 5-6% in typically developing children. Its prevalence in EPT/VLBW children is estimated to be between 9.5% to 51% (Ferrari et al., 2012; Holsti, Grunau, & Whitfield, 2002).

A number of PT children are identified as having transient idiopathic dystonia within the first two years of life. This typically resolves in at least 25% of children by age two (Calado, Monteiro, & Fonseca, 2011; Ferrari et al., 2012). More recent research indicates that children previously diagnosed with transient idiopathic dystonia may continue to have subtle motor dysfunction. This subtle motor dysfunction may go undetected until greater physical motor demands are placed on the child such as running, climbing, or bicycle riding. By definition, DCD impairs motor performance in daily life and academic skills. The basic criterion for defining DCD is that an individual's motor performance in routine skills is significantly below their chronological age and measured intelligence. Some, but not all children, with DCD show neurological dysfunction on imaging (Calado et al., 2011).

Hearing and Vision

EPT children have the highest rates (2% to 6%) of severe bilateral hearing impairments. As many as 9–10% of EPT children have significantly impaired visual acuity, contrast sensitivity, stereopsis, and strabismus (Allen et al., 2011). Subtle learning disabilities are associated with deficits in auditory processing and visual-spatial skill proficiency.

Speech and Language

The majority of speech-language findings in all preterm infants have been analyzed and reported by psychologists. While the fields of psychology and speech-language pathology have much in common, it is a different perspective from those specifically trained in identifying speech and language disorders. The available literature frequently uses the term “language” interchangeably with “speech,” further confusing neonatal professionals about specific research conclusions.

EPT/VLBW infants at 2 years revealed that speech impairments are 2.6 times more likely in EPT children than in full-term peers (Wolke et al., 2008). Even after adjusting for general cognitive impairments, speech impairments remained twice as prevalent. Wolke et al. (2008) reported that infants born at 25 weeks gestation or less, use less developmentally appropriate speech sounds than full-term peers. These studies concluded that gestational age affected speech and language skills more than low birth weight. EPT children had greater deficits in language, phonetic awareness, and articulation. The infants studied were more likely to exhibit severely delayed or specific language impairment, even when using corrected ages adjusting for prematurity. EPT children continue to demonstrate significantly lower language skills than full-term peers at 2 years of age. Wolke concluded that EPT children exhibited more difficulties with rhyme detection, phoneme deletion, and overall articulation ability than FT children. In other studies, even when low incidence disorders and severely cognitively impaired EPT/VLBW subjects were controlled for, PT children consistently performed lower on language testing than FT normal birth weight peers (Ortiz-Mantilla et al., 2008).

Herold et al. (2008) observed that VLBW infants between 4 and 6 months did not differentiate prosodic stress patterns as did FT/NBW peers, even when age was adjusted for prematurity. These researchers concluded that deprivation from extended periods in the NICU kept these infants from recognizing familiar voices with varied prosodic features. Citing this early deficit, they attribute later sound production and discrimination disorders to be related to early deprivation. Some research indicates that deprivation of one-on-one speech models during extended periods in the NICU and/or subsequent hospitalizations delays development of feature recognition and sound discrimination (Northam et al., 2012).

Research conducted on specific disorders common in preterm infants has provided insights into the relationship between bronchopulmonary dysplasia (BPD) and speech-language development. Lewis et al. (2002) found that 48% of eight year-old VLBW children who had been diagnosed with BPD had greater deficits in articulation than other same-age VLBW and FT children. Preterm children diagnosed with neonatal BPD exhibited significant deficits in motor-speech skills and articulation when compared to VLBW and FT peers at 8 years of age (Lewis et al., 2002). The authors hypothesize that BPD children have poorer articulation skills secondary to localized brain injury and subsequently disordered brain development affecting the areas of fine and gross motor skills. Lewis et al. attribute the difficulty BPD children have in interpreting, recalling, and executing spoken directions to the differences these children exhibit in neural connectivity.

Wolke et al. (2008) attribute speech difficulties in preterm infants to be "significantly affected by specific motor problems and controlled by specific brain areas" (p. 261). The 2008 EPICURE study of EPT/VLBW infants posits that they more often present with oral motor problems secondary to brain injury in areas controlling motor-speech performance. These authors assert that when underlying motor problems persist, early motor-speech performance is impacted as well. Wolke et al. posit that early oral-motor/speech deficits result in subsequent phonologic disorders. Northam et al. (2012) concur with this observation and note that speech and, specifically, motor-speech precision, continue to be evidenced in adolescents who were preterm.

Conclusion

Studies concerning neurodevelopmental outcomes of preterm infants assert that deficits are associated with the altered brain structure and subsequently altered development of neural pathways. The functional neural pathways supporting speech and language skills extend beyond conventional language centers of the brain. The concepts of Broca's (production of speech and language) area and Werniche's (understanding of speech and language) area may be generally true in a typical brain but connected differently in the PT brain. The bilateral interaction of hemispheric coordination and alternative development of neurons supporting motor-speech and language learning perform differently in preterm infants.

Research providing analysis of associations or lack thereof between oral motor skills for vegetative function and later speech and expressive abilities in PT children is warranted. In young children who are born prematurely, a team-approach for assessment is imperative in order to understand fully how their brain differences impact normal childhood learning and functioning. Using data gathered from a site which is part of a national study, provides a larger sample population which has been carefully documented. Determining if there is a relationship between the feeding abilities of PT infants at 34 weeks gestational age and their standardized speech and expressive language measurements at approximately 10 years of age may provide further information about the association of early vegetative oral motor functions and later developing motor-speech skills. Early vegetative oral motor functions and motor-speech skills share the same basic oral-pharyngeal structures yet details of this relationship remain unclear. Greater information about the association of early feeding secondary to later speech and expressive abilities may begin to fill in the gap of much needed information as to whether early oral-motor skills impact subsequent speech and expressive development in an at-risk population.

CHAPTER III

METHODS

Participants

A total of 84 children met the inclusion criteria for this retrospective study comparing the feeding skills of extremely premature infants to their speech and expressive skills between the ages of 9 years, 3 months and 12 years, 6 months. All participants had feeding records indicating their primary method of feeding at 34 weeks. The gestational age of 34 weeks was selected for collection of feeding data because a typically developing fetus at that point in fetal development is coordinating oral motor and diaphragmatic movement patterns necessary for feeding at birth (Bingham, 2009; Hall, 2010). The participants consisted of 43 females and 41 males. More than half of the children were Caucasian (57.1%) and came from households that earned below $50,000 per year (65.8%). The majority of children in this sample were not diagnosed with bronchopulmonary dysplasia (65.8%) or intraventricular hemorrhage (85.7%). Demographic information for all participants is presented in Appendix B.

Participants in this study were a subset of the 136 children born between 23 to 27 weeks gestational age and were enrolled in the extremely low gestational age newborn (ELGAN) studies at Wake Forest Baptist Medical Center (WFBMC). Names of the participants were previously de-identified by the ELGAN research team and replaced by a study identification number for each child. The same study identification numbers were also used for the present study. The participating infants weighed between 490 and 1223 grams. Each child had neonatal intensive care unit (NICU) daily feeding records available from either Novant Forsyth Medical Center (NFMC) or Brenner Children's Hospital (BCH) indicating whether they were primarily (> 50%) orally fed by nipple/breast or primarily gavage fed (> 50%). At 34 weeks gestational age, 36 children were determined to be primarily oral feeders (POF) while 48 children were primarily tube fed.

Feeding data were collected from the daily flow sheets archived in the medical records of each infant's neonatal intensive care unit (NICU) hospitalization then de-identified by assignment of the study identification numbers used by the original ELGAN research team. Documentation of each participating infant's feeding abilities for each day at 34 weeks gestational age was collected. The daily flow sheets provided a percentage of the method of feeding (e.g., oral or tube that characterized each infant's intake for each day of that week). The method of feeding was recorded for each of the seven days at 34 weeks. The percentages of methods for each day were added and averaged to yield the 'primary' or most characteristic method of feeding for the infant that week. If a child was under a doctor's orders for nothing by mouth (NPO), the average obtained from the seven days prior to this order and the average obtained seven days after typical feedings were resumed, were used to characterize that specific period of time.

Normal, regular fetal respiration is present by 32 weeks gestation (Rajendran et al., 2009). Between 32 and 34 weeks gestation, a typically developing full term fetus coordinates respiration, sucking, and swallowing adequately to manage oral intake of amniotic fluid (Bauer et al., 2008; Lau, 2006). Documentation of the preterm infant's feeding abilities at 34 weeks was accessible in the daily flow sheets for every feeding throughout 24 hours of each day. The data were collected and used to categorize participants into two groups; primarily oral feeding (POF) and primarily tube feeding (PTF).

To assure reliability in averaging the primary feeding methods over a 24-hour period for each day of the 34th week, two researchers collected data separately and independently averaged the reported method of feeding for each day. The average for the seven days was then calculated. The feeding method most frequently accepted by the infant (> 50%) was thereby determined for that week. The researchers were blinded as to the other descriptive characteristics for the child by entering the feeding data on a de-identified separate form. The method of feeding by which the infant safely took the maximum amount of fluid (> 50%) was rated separately for comparison and rater reliability. Both researchers have more than 15 years of experience serving pediatric feeding teams. One researcher is a speech-language pathologist certified by the American Speech-Language-Hearing Association (ASHA). The other researcher is certified by the American Board of Pediatrics with subspecialty certification in developmental pediatrics. Inter-rater reliability of 99% was established on 20% of the total feeding data collected in accordance with procedures used in similar studies (Miller et al., 2006; Mizuno & Ueda, 2005).

All participants met the following inclusion criteria: (a) born between 2002 and 2005; (b) born before 28 weeks gestational age; (c) native speaker of English as the primary language; (d) no history or diagnosis of hearing impairment; (e) non-verbal ability score above 70; (f) no diagnosis of cerebral palsy; and (g) no diagnosis of a genetic or craniofacial syndrome. All participants had follow-up speech and expressive language testing as well as sensorimotor and visuomotor testing administered between the ages of 9 years, 3 months and 12 years, 6 months.

Procedures

The original ELGAN researcher's notes provided the medical history information from which data was collected for the gestational age at birth, birth weight, diagnoses of bronchiopulmonary dysplasia (BPD) and intraventricular hemorrhage (IVH) for each subject. The ELGAN 2 study protocols provided outcome measures for data collection of the children's scores on the Oral and Written Language Scales (OWLS, Carrow-Woolfolk, 1995), the Children's Communication Checklist-2 (CCC–2, Bishop, 2006), the Differential Ability Scales-II (DAS-II, Elliott, 2007), and the NEuroPsychological Assessment-II (NEPSY–II; Korkman, Kirk, & Kemp, 2007). The OWLS, DAS-II, and the NEPSY–II were administered individually to each child between 9 years, 3 months, and 12 years, 6 months by a master's level psychologist on the ELGAN study team. The CCC–2 questionnaire was given to the parents of participants to complete while their child was engaged in neuro-developmental assessment activities.

The following data were obtained:

- The Oral and Written Language Scales (OWLS; Carrow-Woolfolk, 1995) consisted of two subtests; Language Comprehension, and Oral Expression. The subtest of Oral Expression was used as a primary measure of the children's expressive skills. It is comprised of 96 items arranged in order of difficulty, designed to measure expressive language ability.

- The Children's Communication Checklist (CCC–2) subtests of Speech, Syntax, Semantics, and Coherence were used to examine the parent perceptions of their child's expressive communication skills. Each subtest yielded a scaled score which was used to quantify parent perceptions of specific speech and expressive language components of their child.
- The Differential Abilities Scale (DAS-II; Elliott, 2007) subtests for Word Definitions and Verbal Similarities provided standard scores for additional measurement of expressive abilities. The Word Definitions subtest measured the child's understanding of words as well as their ability and fluency to define those words in the absence of visual cues or context. The subtest of Verbal Similarities presented 34 series of three-word items read aloud to the child and asked that the child tell how the three words go together, the general category which would classify these three words (e.g., fruit, transportation, etc.) and an explanation of how the words were similar or differ from each other. This subtest assessed acquired verbal knowledge, and fluency as well as the application of verbal inductive reasoning; vocabulary and verbal development; logical and abstract thinking; and the ability of the child to distinguish between significant features of the three-word series.
- The Nonverbal Reasoning composite score of the DAS-II is widely accepted as a valid measure of cognitive abilities (Farmer, Golden, & Thurm, 2015;

Spencer-Smith, Spittle, Lee, Doyle, & Anderson, 2015). The Nonverbal Reasoning composite was additionally used in this study to control for cognitive impairment in subjects whose standard scores were 70 or below. Composite scores of 70 on the Nonverbal Reasoning section of the DAS-II are interpreted as borderline cognitive impairment. Composite scores below 70 were interpreted as extremely low cognitive functioning (Elliot, 2007; Farmer et al., 2015).

- The Developmental NEuroPSYchological Assessment (NEPSY–II, Korkman et al., 2007) provided scaled scores for the subtests of Finger Tapping—Repetitions and Finger Tapping—Sequences. Each of these subtests required the child to copy a modeled series of increasingly rapid finger movements, assessing dexterity, motor speed, and rapid motor processing, which served as measurements of the children's sensorimotor skills. The Visuomotor Precision combined scaled score served as the measure of visuomotor abilities for the study. The NEPSY–II subtest of Visuomotor Precision assesses a child's graphomotor speed, and fine motor coordination and accuracy by their ability to draw lines inside of shapes or 'tracks' that serve as boundaries inside which the lines should be confined.

Statistical Analyses

This study sought to determine whether the oral-motor feeding ability of an extremely preterm infant (EPT) at 34 weeks gestational age was associated with later outcomes for speech and expressive abilities measured by performance on standardized tests and parent reporting between the ages of 9 years, 3 months and 12 years, 6 months.

A second objective was to determine whether the oral-motor feeding ability of EPT infants at 34 weeks gestational age is associated with later outcomes for sensorimotor and visuomotor abilities measured by performance on standardized tests between the ages of 9 years, 3 months and 12 years, 6 months.

Quantitative Procedures

Description of the sample. To determine the distribution of sex, gestational age, birth weight, socioeconomic status, and race, as well as diagnoses of bronchopulmonary dysplasia (BPD) and intraventricular hemorrhage (IVH) across the sample of EPT children participating in the study, frequencies and percentages for these demographic variables were calculated (see Table 1). A characteristic pattern of lower socioeconomic status for preterm infants as a population has been established in multiple previous studies (Laughon et al., 2009; Weisglas-Kuperus, Baerts, Smrkovsky, & Sauer, 1993). Poverty, limited access to resources, decreased maternal education regarding health and nutrition, and the contributions of genetics are considered factors influencing the association of lower socioeconomic status and preterm birth (Blumenshine, Egerter, Barclay, Cubbin, & Braveman, 2010).

Since more than half (65.5%) of the children in this study came from households that earned below $50,000 annually and were Caucasian (57.1%), a correlational analysis of the socioeconomic status, sex, and race of the sample was conducted to compare these demographic factors to the general population of infants in the born in the U.S. in the year 2000. The year 2000 was used as the most recent U.S. Census (Census, 2000 PHC-T-30) data regarding number of babies born, sex, and race for comparison to the sample group in the study. The U.S. Census does not, however, provide information on the household income of the infants born in 2000. The year 2004 was selected for collection of this data because the Centers for Disease Control and Prevention have percentage distributions of the household income of children under five for that year but not the year 2000.

Table 1

Frequencies and Percentages for the Demographic Variables (*N* = 84)

Variables	*n*	%
Sex		
Male	41	48.8
Female	43	51.2
Race/Ethnicity		
Caucasian	48	57.1
Black	26	31.0
Hispanic	9	10.7
Asian	1	1.2
Annual Household Income		
Under $15,000	9	10.7
$15,000 to $29,999	19	22.6
$30,000 to $49,999	22	26.2
$50,000 or more	26	31.0

First hypothesis. H_0: POF Oral expression skills at 10 years = PTF Oral expression skills at 10 years of age. The null hypothesis was that there would be no significant difference in the oral expression skills between the POF and PTF groups at 10 years of age. Previous studies reported that preterm children consistently achieved lower speech and oral expression skills on standardized measures (Barre et al., 2010; Northam et al., 2012; Wolke et al., 2008). The standard scores on the OWLS subtest of Oral Expression and the two DAS- II subtests of Word Definitions and Verbal Similarities were used as the dependent variables for analysis between the two groups. A one-way analysis of variance (ANOVA) was conducted to determine whether children in the POF group later demonstrated significantly higher oral expression scores on standardized tests than same-age EPT children with less coordinated oral-motor skills for feeding (PTF).

Second hypothesis. H_0: POF Parent perceptions of speech and oral expression skills at 10 years = PTF Parent perceptions of speech and oral expression skills at 10 years. The null hypothesis was that the parent perceptions of the children's speech and oral expression skills in the POF group would be no different from the parent perceptions of the children's speech and oral expression skills in the PTF group at 10 years of age. Earlier research regarding parents' perceptions of their child's feeding skills indicated that parents generally accept their child's skills as average despite diagnoses otherwise (Jonsson et al., 2013). Measurement of parent perceptions regarding their EPT child's speech and oral expressive skills would contribute to this body of knowledge. The CCC–2 parent questionnaire subtests for Speech, Semantics, Syntax, and Coherence were used as the dependent variables with the two feeding groups. A one-way ANOVA procedure was conducted to determine whether EPT children categorized as POF at 34 weeks were perceived by their parents to demonstrate significantly better speech and expressive language component skills than the parents of same-age EPT children with less coordinated neonatal oral-motor skills for feeding (PTF).

Third hypothesis. H_0: POF Sensorimotor skills at 10 years = PTF Sensorimotor skills at 10 years of age. The null hypothesis was that there would be no significant difference in the oral expression skills between the POF and PTF groups at 10 years of age. Previous studies of EPT children found significant sensorimotor deficits across the life-span theorized to be related to general motor and oral motor relationships in early brain development (de Kieviet et al., 2009; Holsti et al., 2002). A one-way ANOVA was conducted to determine whether the POF group of EPT children at approximately 10 years of age, demonstrated significantly higher sensorimotor scores on standardized tests than the PTF group. The NEPSY–II sensorimotor subtests of Finger Tapping Repetitions and Finger Tapping Sequences scores were used as the dependent variables which measured sensorimotor skills. The data were analyzed comparing the two sensorimotor performance measurements between the two feeding groups.

Fourth hypothesis. H_0: POF Visuomotor skills at 10 years = PTF Visuomotor skills at 10 years of age. The null hypothesis was that there would be no significant difference in the visuomotor scores of the POF group and those of the PTF group, or H_0: POF = PTF (p = .05). Previous studies have reported that EPT children exhibit a higher frequency of visuomotor disorders which the authors associate with underlying mild motor impairment (de Kieviet et al., 2009; Ferrari et al., 2012). Examining the relationship of early oral motor function to later visuomotor performance could contribute to this body of knowledge. The Visuomotor Precision composite score of the NEPSY–II was used to measure the visuomotor performance of the children. A one-way ANOVA was conducted to determine whether the POF group demonstrated significantly higher visuomotor scores than the PTF group. The data analyzed the visuomotor performance scores between and within the two subject groups.

CHAPTER IV

RESULTS

This retrospective study compared the feeding skills of extremely low gestational age newborns (ELGANs) at 34 weeks gestational age to their speech and expressive-language skills at approximately10 years of age. Eighty-four children met the inclusion criteria for participation in the study. The 84 children were then categorized as being either primarily oral feeders (> 50% breast or bottle) or primarily tube feeders (> 50% nasogastric or orogastric) based on their feeding abilities at 34 weeks gestational age. Thirty-six children were determined to be primarily oral feeders (POF) and 48 children were determined to be primarily tube feeders (PTF) at 34 weeks gestational age.

Birth Histories of the Feeding Groups

Independent *t*-tests comparing the gestational ages and birth weights of the POF and PTF groups indicated that there was no significant difference in gestational age. There was, however, a significant difference in birth weights between the two groups. The findings indicate that POF babies characteristically had significantly higher birth weights than PTF babies ($p = .048$). Since multiple *t*-tests were used to analyze the two variables of gestational age and birth weight, a Bonferroni correction was made ($p \leq .025$ or .05/2). With the Bonferroni correction, there was no significant difference in either gestational age or birth weight between the two groups. Analysis of the birth history data obtained from the two groups of children are described in Table 2.

Table 2

Gestational Age and Birth Weight between the Two Feeding Groups

	Feeding Group				
	POF (n = 36)		**PTF (n = 48)**		
Birth History	*M*	*SD*	*M*	*SD*	*Sig.*
Gestational age	26.17	1.03	25.96	1.15	.392
Birth weight in grams	869.00	151.23	819.49	186.49	.048

Note. Gestational age and birth weight were analyzed as ordinal data; $p \leq .05$, with Bonferroni correction $p \leq .025$

Medical Diagnoses of the Feeding Groups

Independent *t*-test results indicated that the medical histories between the two groups differed significantly. The PTF group had a significantly higher incidence of bronchopulmonary dysplasia (BPD) than the POF group (p = .002). Whereas the POF group had a significantly higher incidence of intraventricular hemorrhage (IVH) than the PTF group (p = .032). Because of the multiple *t*-tests a Bonferroni correction was applied ($p \leq .0125$). After the Bonferroni correction, only the greater incidence of BPD in the PTF group remained statistically significant. Independent *t*-test results for comparison of the diagnoses of bronchopulmonary dysplasia (BPD) and intraventricular hemorrhage (IVH) between the two groups is presented in Table 3.

Table 3

Diagnoses of BPD and IVH between the Two Feeding Groups

	Feeding Group				
	POF (n = 36)		PTF (n = 48)		
Diagnosis	***n***	**%**	***n***	**%**	***Sig.***
BPD					.002*
No	26	72.2	18	37.5	
Yes	10	27.8	30	62.5	
IVH					.032*
No	27	75.0	45	93.8	
Yes	9	25.0	3	6.3	

Note. $p \leq .05$, with Bonferroni correction $p \leq .0125$. BPD = bronchopulmonary dysplasia, IVH = intraventricular hemorrhage

Demographic Characteristics of the Feeding Groups

The majority of POF infants were female (58.3%) whereas the majority of PTF infants were male (54.2%). There was, however, no significant difference between the two groups regarding sex (p = .257). The findings of the independent t-tests show that POF babies significantly differed from PTF babies in terms of ethnicity (p = .005). The majority of POF infants were African-American (70.8%) whereas the majority of PTF infants were Caucasian (50%). When a Bonferroni correction for multiple t-tests was applied, ethnicity remained a distinguishing characteristic between the two groups. There was no significant difference between the two groups for socioeconomic status (p = .841). The majority of children in both groups were from homes whose total annual income was below $50,000. The frequencies and percentages for the demographic variables and independent *t*-test results for comparisons between the groups are summarized in Table 4.

Table 4

Feeding Groups and Sex, Ethnicity, and Household Income

	Feeding Group				
	POF (n = 36)		**PTF (n = 48)**		
Variables	***n***	**%**	***n***	**%**	***Sig.***
Sex					.257
Male	15	41.7	26	54.2	
Female	21	58.3	22	45.8	
Race/Ethnicity					$.005^{*}$
Caucasian	14	38.9	34	70.8	
African-American	18	50.0	8	16.7	
Hispanic	3	8.3	6	12.5	
Asian	1	2.8	0	0.0	
Annual Income					.841
Under $ 15,000	3	8.3	6	12.5	
$15,000 to $29,999	8	22.2	11	22.9	
$30,000 to $49,999	11	30.6	11	22.9	
$50,000 or more	14	38.9	20	41.7	

Note. $p \leq .05$, with Bonferroni correction $p \leq .017$.

The representation of ethnic diversity appeared to be significantly different between the two feeding groups; therefore, further analysis of the ethnic diversity of the ELGAN study sample in comparison to the general U.S. population was warranted. A chi-square test of independence was used to analyze the ethnic representation of the study sample and the 2004 CDC Report of ethnic diversity in the general U.S. population of infants born in 2004. Further findings continued to indicate that the ethnic representations in the ELGAN study sample were significantly different from the general U.S. population of infants born in 2004. The majority of infants in the study were Caucasian (57.1%), as was the majority of U.S. infants in 2004 (56%); however, there was a greater representation of African-American infants in the ELGAN sample (31%) than in the general population (15%). There appeared to be an underrepresentation of mothers reporting ethnicity as Hispanic (9%) and Asian (1%) in the ELGAN sample in comparison to the U.S population of infants whose mothers reported Hispanic (23%) and Asian (6%) ethnicity, as summarized in Table 5.

Table 5

Analysis of Reported Ethnic Diversity in the ELGAN Sample and the 2004 CDC Report of Infants Born in the U.S.

	ELGAN Sample		Babies born in U.S. in 2004		
	n	%	*N*	%	Sig.
Total	84		4, 112,052		.000
Caucasian	48	57.1	2,296,683	56	
African-American	26	31.0	578,728	15	
Hispanic	9	10.7	946,349	23	
Asian	1	1.2	229,123	6	

Source: U.S. DHHS, CDC Report, 2004

Because there continued to be a significant difference between the ethnicity of the ELGAN sample and the U.S. population of infants, more detailed regional information was collected regarding the ethnicity of infants born in North Carolina in 2004 for comparison (NC Department of Health and Human Services [NC DHHS], 2004). The NC DHHS reports for 2004 provided information for the ethnicity reported by mothers only as "white" and "minority." NC DHHS statistics did not provide detailed information as to which ethnic populations comprised the "minority" category. All other ethnic groups were subsumed in the classification of "minority." A chi-square analysis was conducted to determine if there was a difference between the ethnic groups represented in the ELGAN study sample and the population of infants born in North Carolina in 2004 (NC DHHS, 2004). The findings indicate that ethnic representation for Caucasian births in the ELGAN sample (57.1%) was below the NC state average (73%), whereas the percentage of "minority" births in the ELGAN sample (42.9%) was greater than the state average (27%). A summary of this information is shown in Table 6.

Table 6

Ethnicity of Infants Born in NC in 2004 and the ELGAN Study Sample

	NC infants born in 2004	ELGAN sample	Sig.
	N (%)	*N* (%)	.026
Caucasian	87,230 (73)	48 (57.1)	
Minority	32,543 (27)	36 (42.9)	
Total	119,773	84	

Note. NC DHHS ethnic specific counts do not add to the total due to cases of unknown and unreported ethnicity, N.C. Dept. of Health and Human Services, 2004.

Since the majority of the children in the study sample came from households earning under $50,000 per year, further analysis of the demographics of the study sample relative to the general population of infants in the U.S. was also deemed necessary. Specific census data for the total number of infants born in the US in the year 2000 could not be located. The population of children in the year 2000 U.S. Census Report was delineated into age groups, with the youngest age group being all children under the age of 5 years. Census data for the year 2000 was selected as being closest to the 2002 to 2004 birth years of the children.

The household income for the majority of children in the sample (59.5%) was below $49,999 as was the household income for the majority of children in the U.S. under the age of five years (55.2%). A chi-square analysis was used to compare the *observed* rate at which families fell into each income bracket to the *expected* rate at which families would fall into each income bracket based on the 2000 U. S. Census data. The chi-squared analysis was used to determine the variance between the sample of children in the present study and the general population of children in the U. S. under five years of age. The chi-squared analysis found that $\chi^2(2) = 1.787$ $p = 0.4093$, indicating that the study group did not differ significantly from the general U.S. population of children in terms of household income. The frequencies and percentages of the household income for the 84 children in the study sample were comparable to those of the general population of 19,017,015 children in the U.S. in the year 2000 (U.S. Census, 2000) as indicated by $p = .4093$. This analysis is summarized in Table 7.

Table 7

Summary of Household Income of the ELGAN Sample Compared to the Household Income of the General U.S. Population of Children under Five Years of Age in the Year 2000

Annual Income	Study Sample *n*	Study Sample %	U.S. Population* *N*	U.S. Population* %	Sig $p \leq .05$
Less than $49,999	50	59.5	10,496,445	55.2	.4093
$50,000 to $74,999	13	15.5	4,121,139	21.7	
$75,000 and over	21	25.0	4,399,521	23.1	

*United States Census, Census 2000 PHC-T-30. U.S. population of children under five years of age.

Neonatal Feeding Abilities and Later Speech and Expressive Skills

First Hypothesis

The first hypothesis was H_0: POF Oral expression skills at 10 years = PTF Oral expression skills at 10 years of age. The hypothesis was that there would be no significant difference in the oral expression skills between the POF and PTF groups at 10 years of age. The Oral and Written Language Scale (OWLS) subtest of Oral Expression (OE) and the Differential Abilities Scales-2 (DAS-II) subtests of Word Definitions (WD) and Verbal Similarities (VS) provided standardized measures of speech and oral expressive skills for the POF and PTF groups between 9 years, 3 months and 12 years, 6 months.

OWLS subtest of Oral Expression. The range of test scores was widely varied from 47 to 124 in the EPT sample of children. The POF children overall had slightly higher scores (M = 89.75) than the PTF children (M = 86.94). The PTF group demonstrated slightly lower scores but with less spread (SE = 1.5779) than the POF group (*SE* = 2.6041). Table 8 provides a summary of the descriptive statistics for the two feeding groups.

Table 8

Descriptive Statistics for the Feeding Groups on the OWLS OE

					95% Confidence Interval	
OWLS OE	*N*	*M*	*SD*	*SE*	Lower Boundary	Upper Boundary
POF	36	89.75	15.62	2.6041	84.463	95.037
PTF	48	86.94	10.93	1.5779	83.763	90. 112

One-way ANOVA. There was a wider range of scores *within* each of the feeding groups (*SS* = 14161.56) than there was *between* the POF and PTF groups (*SS* = 162.72) as summarized in Table 9.

Table 9

Results of Analysis of Variance (ANOVA) for Differences between Feeding Groups on OWLS Subtest of Oral Expression

OWLS Subtest of Oral Expression	**Sum of Square**	***df***	***Mean Square***	***F***	**Sig. $p \leq .05$**
Between Groups	162.72	1.00	162.723	0.942	0.335
Within Groups	14161.56	82.00	172.702		

Norms and reference group. The OWLS was based on normalized standard scores with a mean of 100 and a standard deviation of 15. The range of test scores on the OE subtest ranged from 47 to 124 in the EPT study sample. Most but not all children performed within normal limits for oral expression skills (POF *M* = 89.75, PTF *M* = 86.94. with some children performing well below average and some children performing well above average. The range of scores on the OWLS OE for the POF group fell slightly outside the normal limits on the OE subtest with the standard deviation of 15.62 slightly exceeding the 15-point general standard deviation of the subtest. The average score for the PTF group was slightly lower (*M* = 86.94) than the POF group (*M* = 89.75) but demonstrated less spread (*SD* = 10.93) than the POF group (15.62). Both feeding groups achieved scores generally within normal limits on this subtest of oral expression. Findings indicated that there was no statistically significant difference ($p = 0.335$) between the oral expressive skills of the two feeding groups on the OWLS subtest of Oral Expression. Table 9 summarizes the ANOVA results of the differences observed between the two feeding groups on the OWLS OE subtest.

DAS–II subtests of Word Definitions and Verbal Similarities. The POF children overall had slightly higher scores overall (*M* = 49.32) than the PTF children (*M* = 48.56). The POF group demonstrated slightly higher overall scores with less spread (*SE* = 1.6966) than the POF group (*SE* = 1.5917). The range of test scores on the VS was widely varied from 28 to 62. The POF group had slightly higher overall scores (*M* = 49.11) than the PTF group (*M* = 48.56). There was a wider range of spread within the scores of the POF (*SE* = 1.6966) than the PTF group (*SE* = 1.5917). Table 10 provides a summary of the descriptive statistics for the two feeding groups.

Table 10

Descriptive Statistics for the Feeding Groups on the DAS–II WD and VS

					95% Confidence Interval	
	N	*M*	*SD*	*SE*	Lower Boundary	Upper Boundary
DAS–II WD						
POF	36	49.32	10.18	1.6966	46.472	53.361
PTF	48	48.56	11.03	1.5917	45.36	51.765
DAS–II VS						
POF	36	49.11	9.00	1.5007	46.065	52.158
PTF	48	47.44	10.04	1.4495	44.522	50.353

One-way ANOVA. There was a wider distribution of scores *within* each feeding group on the WD subtest (*SS* = 9342.563) than *between* the POF and PTF groups (*SS* = 37.73). Likewise, there was a wider distribution of scores *within* each feeding group on the VS subtest (*SS* = 7577.368) than *between* the two feeding groups (*SS* = 57.62) summarized in Table 10.

Norms and reference groups. The DAS–II subtests of Word Definitions (WD) and Verbal Similarities (VS) were based on standardized T-scores (*M* = 50) and (*SD* = 10). The EPT children in the study sample demonstrated a range of scores between 12 and 78 on the WD subtest and between 27 and 61 on the VS subtests. The mean scores on all subtests indicated that most but not all children in the sample group demonstrated oral expression skills within normal limits. The children in the POF group achieved slightly higher scores overall (*M* = 49.92) with less spread in the distribution (*SD* = 10.18) on the

WD subtest. The children in the PTF group achieved only slightly lower scores (M = 48.56) with slightly greater spread in the distribution (*SD* = 11.03). The difference between the two groups as determined by a one-way ANOVA for the subtest of WD was not statistically significant ($p = 0.567$). The difference between the feeding groups on the subtest of VS was also not statistically significant ($p = 0.432$). Table 11 summarizes the ANOVA findings for the differences in performance on the two DAS–II subtests of oral expression for the two groups.

Table 11

Results of ANOVA for differences between Feeding Groups on DAS–II Subtests of WD and VS

DAS–II	Sum of Squares	*df*	*Mean Square*	*F*	Sig. $p \leq .05$
Word Definitions					
Between Groups	37.723	1	37.723	0.331	0.567
Within Groups	9342.563				
Verbal Similarities					
Between Groups	57.62	1	57.62	0.624	0.432
Within Groups	7577.368				

The first hypothesis was H_0: POF Oral expression skills at 10 years = PTF Oral expression skills at 10 years of age, that there would be no difference between the performance of the two neonatal feeding groups on measures of oral expression at 10 years. The one-way ANOVA procedures indicated that there was no difference between the performance of the two feeding groups on tasks of oral expression and that there was no statistical significance between the POF and PTF groups on tasks of oral expression at 10 years.

Second Hypothesis

The second hypothesis was H_0: POF Parent perceptions of speech and oral expression skills at 10 years = PTF Parent perceptions of speech and components of oral expression. The parent responses on the Children's Communication Checklist–2 (CCC–2) subtests of Speech, Syntax, Semantics, and Coherence were used as measures of parents' perceptions of their child's speech and components of oral expressive skills at approximately 10 years.

CCC–2 subtests of speech, syntax, semantics, and coherence. Parents of two participants in the PTF group were not able to complete the CCC–2 parent questionnaire. Therefore, the total number of children in the PTF group for the overall study (48) and the number of children in the PTF group for analysis of the CCC–2 subtests (46) is lower. The Speech scores for the EPT study group ranged from standard scores of 5 to 12. Parents rated children on their Syntax and Coherence with scores ranging from standard scores of 3 to 12 and Semantic scores for the overall group ranged from standard scores of 1 to 12. The POF group on the Speech subtest achieved $M = 9.11$ with $SD = 2.46$ with little difference in the PTF group whose $M = 9.00$ with $SD = 3.13$. The means and standard deviations for the two group performances on the CCC-2 subtests showed minimal differences between the two groups. Table 12 summarizes the descriptive statistics for the parent perceptions of the two feeding groups regarding their child's speech, syntax, semantics, and coherence for oral expression.

Table 12

Descriptive Statistics for the Parent Perceptions of Their Child's Speech and Components of Oral Expression on the CCC–2 for the Feeding Groups

					95% Confidence Interval	
CCC–2 subtest	*N*	*M*	*SD*	*SE*	Lower Boundary	Upper Boundary
Speech						
POF	36	9.11	2.46	.41	8.28	9.94
PTF	46	9.00	3.13	.461	4.61	9.93
Syntax						
POF	36	9.58	2.63	0.439	8.69	10.47
PTF	46	9.09	2.54	0.374	8.33	9.84
Semantics						
POF	36	8.89	2.40	0.4	8.08	9.70
PTF	46	8.20	2.60	0.383	7.42	8.97
Coherence						
POF	36	9.36	3.27	0.327	8.25	10.47
PTF	46	8.20	2.85	0.42	7.35	9.04

Note. Parents of 2 participants in the PTF group did not complete the CCC–2 parent questionnaire.

One-way ANOVA. The Speech subtest showed a wide distribution of scores *within* each of the feeding groups ($SS = 651.556$) with the least difference *between* the groups ($SS = 0.249$) of all the CCC–2 subtests. The Syntax scores *within* the two groups also indicated a wide spread *within* the groups ($SS = 532.402$) but smaller spread *between* groups ($SS = 4.976$). Scores for the Semantics subtest showed a greater difference *within* the groups ($SS = 504.794$) and less difference *between* the groups ($SS = 9.705$). The subtest of Coherence displayed the widest distribution *within* groups (*SS* = 739.545) as well as the greatest difference *between* groups (*SS* = .27.31).

Norms and reference group. The CCC–2 yields separate scaled scores for each subtest based on a mean of 10 and standard deviation of 3. Both feeding groups achieved mean scores within normal limits on all subtests of the CCC–2 with outlier scores well below and well above normal limits. The Speech scores for the study sample ranged from 5 to 12. The Syntax scores for the study sample ranged from 3 to 12. Test scores for the subtest of Semantics ranged from 1 to 12, and measures of expressive Coherence ranged from 3 to 12. ANOVA findings indicated, however, that there was no statistically significant difference between the two groups for parents' perceptions of their child's Speech intelligibility ($p = 0.862$), Syntax, ($p = 0.39$), Semantics, ($p = 0.219$) or Coherence of oral expression ($p = 0.089$).

The second hypothesis was that $H_{0:}$ POF Parent perceptions of speech and oral expression skills at 10 years = PTF Parent perceptions of speech and oral expression at 10 years. ANOVA findings were inconclusive indicating that parent perceptions of the children's speech and component oral expressive skills did not reveal a significant difference between the two feeding groups. ANOVA results for differences on the CCC–2 parent ratings between and within the two groups are summarized in Table 13.

Table 13

Results of ANOVA for Differences between Feeding Groups for Parents' Perceptions of Speech, Syntax, Semantics, and Coherence

CCC–2	**Sum of Square**	***df***	***Mean Square***	***F***	**Sig. $p \leq .05$**
Speech					
Between Groups	0.249	1	0.249	0.031	0.862
Within Groups	651.556				
Syntax					
Between Groups	4.976	1	4.976	0.748	0.39
Within Groups	532.402				
Semantics					
Between Groups	9.705	1	9.705	1.538	0.219
Within Groups	504.795				
Coherence					
Between Groups	27.431	1	27.431	2.967	0.089
Within Groups	739.545				

Neonatal Feeding Abilities and Later Sensorimotor and Visuomotor Skills

Third Hypothesis

The third hypothesis was H_0: POF Sensorimotor skills at 10 years = PTF Sensorimotor skills at 10 years. The NEuroPsychological Assessment–II (NEPSY–II) subtests of Finger-Tapping Repetitions and Finger-Tapping Sequences were used as standardized measures of the children's sensorimotor skills administered to the study group between 9 years, 3 months and 12 years, 6 months.

NEPSY–II subtests of sensorimotor skills. Thirty-six children categorized as POF and 47 children categorized as PTF completed the NEPSY–II sensorimotor subtests. One child in the PTF group was unable to complete the two NEPSY–II subtests, which lowered the total number of participants in that group. The two subtests of Finger-Tapping Repetitions and Finger-Tapping Sequences yielded two separate scaled scores. The children in the PTO group achieved a mean score of 9.89 with a standard deviation of 2.59, in contrast to the children in the PTF group who achieved a slightly higher mean score of 10.36 with a smaller standard deviation of 1.97. Table 14 summarizes the descriptive statistics of the sensorimotor subtests on the NEPSY–II for the two feeding groups.

Table 14

Descriptive Statistics for the Feeding Groups on the NEPSY–II Sensorimotor Subtests

					95% Confidence Interval	
NEPSY–II subtest	*N*	*M*	*SD*	*SE*	Lower Boundary	Upper Boundary
FT-Rep						
POF	36	9.89	2.59	0.432	9.01	10.77
PTF	47	10.36	1.97	0.288	9.78	10.94
FT-Seq						
POF	36	10.53	2.27	0.379	9.76	11.30
PTF	47	10.60	2.32	0.338	9.91	11.28

Note. One child in PTF group was unable to complete the NEPSY–II subtests

One-way ANOVA. There was a wider dispersion of scores *within* the two feeding groups for both the Finger Tapping-Repetitions (*SS* = 414.407) and the Finger Tapping-Sequences (*SS* = 428.291) than there was *between* the two groups (*SS* = 4.557; *SS* = 0.094). There was little difference in the ratio of test scores *between* the two groups for Finger Tapping-Repetitions (*MS* = 4.557 and within the two groups (*MS* = 5.116), however, the ratio between the two groups for Finger Tapping-Sequences (*MS* = 0.094) revealed a smaller ratio of difference *between* the scores for the two groups.

Norms and reference group. The NEPSY–II scaled scores are based on a mean of 10 and standard deviation of 3. The two feeding groups achieved mean scores within normal limits for both of the sensorimotor subtests, indicating that most of the EPT children had sensorimotor skills exhibited sensorimotor skills comparable to same-age peers. The POF group evidenced a lower mean score (*M* = 9.89) with wider dispersion (*SD* = 2.59) than the PTF group (*M* = 10.36, *SD* = 1.97) on the Finger Tapping-Repetitions. The PTF group also achieved slightly higher scores (*M* = 10.60) with slightly wider dispersion (*SD* = 2.32) on the Finger Tapping–Sequences than the POF group (*M* = 10.53, *SD* = 2.27). However, ANOVA results indicated that the POF group did not show a statistically significant difference between the PTF group on sensorimotor performance for either the Finger Tapping-Repetitions (*p* = .0348) or the Finger Tapping-Sequences (*p* = 0.894). Table 15 summarizes the ANOVA findings for differences on the test scores between and within the two feeding groups.

Table 15

Results of Analysis of Variance (ANOVA) between Feeding Groups for Sensorimotor Subtests on the NEPSY–II

NEPSY–II	**Sum of Square**	***df***	***Mean Square***	***F***	**Sig. $p \leq .05$**
Finger-Tapping Repetitions					
Between Groups	4.557	1	4.557	0.891	0.348
Within Groups	414.407		5.116		
Finger-Tapping Sequences					
Between Groups	.094	1	0.094	0.018	0.894
Within Groups	428.291		5.288		

Note. One child in PTF group was unable to complete the NEPSY–II subtests

Fourth Hypothesis

The fourth hypothesis was H_0: POF visuomotor skills at 10 years = PTF visuomotor skills at 10 years. The NEuroPsychological Assessment–II (NEPSY–II) subtest of Visuomotor Precision was used as the standardized measure of visuomotor precision skills in the POF and PTF groups between 9 years, 3 months of age and 12 years, 6 months of age.

NEPSY–II subtest of visuomotor precision. One child in the PTF group was unable to complete the Visuomotor Precision subtest, reducing the total number of children in that group to 47. The 36 children in the POF group achieved a slightly higher mean score (M = 8.36) with a greater dispersment (SD = 3.27), while the PTF group achieved lower overall scores (M = 7.11) with a smaller dispersement (SD = 2.62).

Table 16

Descriptive Statistics for the Feeding Groups on the NEPSY–II subtest for Visuomotor Precision

NEPSY–II	*N*	*M*	*SD*	*SE*	95% Confidence Interval Lower Boundary	95% Confidence Interval Upper Boundary
Visuomotor Precision						
POF	36	8.36	3.27	0.454	7.25	9.47
PTF	47	7.11	12.62	0.381	6.34	7.87

Note. One child in PTF group was unable to complete the NEPSY–II subtests

One-way ANOVA. ANOVA results found no statistically significant difference in the visuomotor performance skills between the two groups (p = .056). The POF group achieved slightly higher scores (M = 8.36) than the PTF group (M = 7.11), but had a wider distribution of scores (SD = 3.27) than the PTF group (SD = 2.62). There was greater variation *within* the scores of each group (SS = 688.774) than *between* the two groups (SS = 32.094).

Norms and reference group. The NEPSY–II scaled scores for visuomotor performance are based on a mean of 10 and standard deviation of 3. The EPT study group as a whole exhibited a wide variation in scores ranging from 2 to 16. The majority of scores for both groups was below the mean for the subtest (POT, M = 8.36; PTF, M = 7.11) indicating that most of the EPT children showed weaker visomotor skills than same-age peers. The findings for significance in the differences between the two feeding groups' performance on later visuomotor skills were closer to significance than the speech, expressive language and sensorimotor skills between the two groups but did not meet the robust alpha of $p \leq .05$. ANOVA results indicated that there was no difference between the visuomotor skills of the two feeding groups at 10 years of age.

Table 17 details the ANOVA results for differences between the two groups for the children's performance on the NEPSY–II subtest of visuomotor precision.

Table 17

ANOVA Results for Differences between Feeding Groups for Visuomotor Skills on the NEPSY–II

NEPSY–II	**Sum of Squares**	***df***	***Mean Square***	***F***	**Sig. *p* ≤ .05**
Visuomotor Precision					
Between Groups	32.094	1	32.094	3.774	0.056
Within Groups	688.774				

CHAPTER V

DISCUSSION

The present study compared the feeding skills of EPT infants at 34 weeks gestational age to their speech and oral expression skills at approximately10 years of age. Findings of the current longitudinal study did not indicate an association between successful neonatal oral feeding skills and higher scores on standardized measures for speech and oral expression skills in later childhood.

Feeding Skills in EPT Infants

The current investigation determined that at 34 weeks gestational age, the majority of the sample group of EPT infants exhibited difficulty with oral feedings. The assignment of feeding groups at 34 weeks gestational age was based on previous studies documenting the establishment of coordinating oral-motor structures for normal oral feeding between 32 and 34 weeks (Arvedson, 2006; Lau et al., 2012). Healthy preterm infants have typically established oral feeding skills for bottle or breast by 34 weeks.

Oral Feeders and Tube Feeders at 34 Weeks Gestation

Differences between the two feeding groups were investigated using independent *t*-tests. The finding of significant birth weight differences between POF and PTF groups is consistent with studies that reported that infants with a higher birth weight are healthier overall and survive the challenges of preterm birth better than those with lower birth weights (Delaney & Arvedson, 2008; Lau et al., 2012; Törölä et al., 2012). Differences in medical diagnoses between the POF and PTF groups revealed that a history of IVH was significant before the correction for multiple t-tests. The diagnosis of BPD remained statistically significant before and after corrections for multiple *t*-tests. The finding of BPD as a significant variable supported the concern that infants who were unable to coordinate and sustain rhythmic breathing, lacked the underlying respiratory support and coordination for the sequencing of suckling, swallowing, and breathing, which was necessary for successful oral feeding (Barlow, 2009; Crapnell et al., 2013; Lau et al., 2012). Infants with BPD are typically not able to regulate breathing adequately for essential respiration while coordinating jaw, lip and tongue movements for feeding. This incoordination of breathing while feeding puts infants at greater risk for aspirating liquids during swallowing. The findings of the present study are also consistent with earlier research that found that children who experienced episodes of oxygen deprivation and decreased oxygen saturation rates, as well incoordination of inspiration as the sequelae of BPD were at greater risk for feeding disorders (Lau, 2006; Crapnell et al., 2013; Poore & Barlow, 2009; Stumm et al., 2008).

The finding that the variable of sex was not significant between the two groups was consistent with the results of the study by Adams-Chapman et al. (2013) who reported no significant difference in the distribution of males and females in the group of children with feeding disorders (p = .372) with a sample population of 1477 children.

The annual household income for the sample group of EPT infants was consistent with the annual household income of the general population of U. S. children under the age of five years. The majority of EPT children in the study were from households with annual incomes below $ 50,000. Sadly, the majority of children in the U. S. under the age of five years in the year 2000 also lived in households whose annual income was below $50,000 (United States Census, Census 2000 PHC-T-30). While it is accurate to state that EPT children are characteristically from lower socioeconomic circumstances, this does not distinguish them from the general population of children in the U. S.

The variable of ethnicity was found to be a distinguishing demographic characteristic between the two groups before and after adjustments for multiple *t*-tests. The majority of children in the POF group were African-American (50%) while the majority of children in the PTF group were Caucasian (70.8 %). When the ethnic diversity of the ELGAN study sample was analyzed for differences in North Carolina ethnic diversity, a significant difference remained evident. Ethnicity itself does not impact feeding skills, which is the concern of the current study. The finding indicates that there is a significant difference in the Northwestern North Carolina ELGAN cohort when compared to the population of the U.S. The higher percentage of African-American children in the Winston-Salem ELGAN cohort is more a reflection of regional healthcare, public awareness, and prenatal care. It highlights the need to address the causes of preterm births. Unplanned pregnancies, teen pregnancies, and lack of transportation to access appropriate care are community challenges being addressed by local healthcare and public health providers across North Carolina (NC DHHS, 2003). The impact of social disadvantages is suspected to be more of a factor than ethnicity which impacts access to adequate prenatal care.

Speech and Oral Expressive Skills at Ten Years

Results of the one-way ANOVA procedures investigating the performances of the two feeding groups on the OWLS OE, DAS-II WD and VS subtests did not indicate that better neonatal feeding skills result in higher test scores on speech and oral expressive measures at ten years. While there no association between neonatal feeding skills and later outcomes on the speech and expressive tests used in this study, results may vary if other measures were investigated. The study sample of 84 EPT children is small in comparison to the total number of children in the national ELGAN study. The test measures of the OWLS OE and two DAS subtests did not thoroughly assess the motor-speech functions, articulation, phonology, phonological processing, or the infrastructure of expressive language such as working memory, processing speed, auditory processing, and executive function as other speech and language measures could provide. The results of this study remain inconclusive and warrant further investigation with a greater variety of skill-specific standardized measures of speech and oral expression.

Short Term Findings vs. Longitudinal Findings

Previous studies determined that poorer neonatal feeding skills in EPT children were predictive of lower communication scores in early childhood (Adams-Chapman et al., 2013; Mizuno & Udo, 2005). Mizuno and Ueda as well as Adams-Chapman et al., assessed both feeding skills and neurodevelopmental testing on EPT children 18 months of age. Both groups of researchers concluded that 18 to 24 month EPT children diagnosed with a feeding disorder exhibited more severely delayed skills on the Bayley

Scale of Infant Development-3rd Ed. (BSID-III) than EPT children of the same age with normal feeding behaviors.

There are several possible considerations for the differences in findings between previous studies and the current study. The differences in the gestational age of subjects, methods by which feeding disorders were diagnosed, the age at which outcome measurements were conducted, and the diversity of measurement tools used may account for the differences in conclusions. Assessing feeding in children at 18 months may more clearly distinguish infants with severe, vegetative oral motor dysfunction from those with transient and less severe feeding issues. Alternatively, comparison of the developmental evaluation scores of toddlers who exhibited feeding problems and poorer neurodevelopmental scores when assessed at the same age may indicate short-term associations which may not remain consistent with longer-term assessments. A more longitudinal perspective allowing more time for compensation and maturation of neuromotor systems may weaken this association. The positive effects of maturation and rehearsal of functional motor skills in developing systems over time is supported by multiple researchers. Children with pervasive disorganized oral motor skills for feeding may resolve or overcome their motor deficits over time by repetition and refinement throughout childhood to evolve a fully functional oral motor system in later years (Barlow 2009; Iverson, 2010, James & Swaim, 2011; Kent, 2015).

Conditions Impacting Neurodevelopmental Outcomes

Mizuno and Ueda (2005) as well as Adams-Chapman et al. (2013) included children with genetic syndromes as well as diagnosed motor and hearing impairments without controlling for English as a primary language or cognitive impairments. The current study controlled for English as the primary language, hearing impairment, cognitive impairment, diagnosed motor impairment, and genetic as well as craniofacial syndromes. It may be that by controlling for cognitive impairment alone, EPT infants with neonatal feeding difficulties and normal cognitive skills are more likely to experience optimized developmental skills later in childhood than those with below average cognitive abilities. It may also be that children whose primary language was not English, and those with hearing and motor impairments are less likely to experience optimal developmental gains secondary to language barriers, and the challenges of adapted learning necessary for those with hearing and motor impairments.

Parent Perceptions of EPT Children's Oral Expressive Skills

There were no significant differences between the two feeding groups regarding parents' perceptions of their children's speech, semantics, syntax, or coherence. This result may be consistent with the findings of Jonsson et al. (2013), whose study indicated that parents of PT children with feeding difficulties do not report that their child has a feeding disorder. These authors concluded that parents of PT children have lower expectations for their children and are more accepting of whatever skill levels are attained by the child given that they were born prematurely. Alternatively, the consistency in parent reporting between the two feeding groups may also verify that there are minimal differences in the speech and oral expression skills of those groups.

Influence of Early Identification and Treatment

The findings of the present study that did not determine a significant difference between the two feeding groups for speech or oral expression skills may indicate that there is a stronger relationship between neonatal feeding abilities and speech and oral expression abilities in early childhood which diminishes or is successfully compensated for over time. It may also be that by identifying children with feeding difficulties as infants, they are followed more closely by pediatricians and specialists to address concerns as they arise. This may also account for the absence of differences between the EPT children who demonstrated better coordinated oral motor skills for feeding than those who exhibited less oral motor coordination for feeding. The histories of the children who may have received special services and interventions through early intervention, preschool, and school programs were not incorporated in the present study. It may be that intensive speech-language services were provided throughout childhood to the children in both feeding groups and they received timely and successful intervention for remediation of their communication deficits.

Findings from the current study were inconclusive regarding the relationship between neonatal feeding abilities and sensorimotor performance at approximately 10 years of age. Results of the statistical analyses suggested that there was a difference in the visuomotor performance skills between the two feeding groups that approached significance ($p = .056$) but did not maintain any significance when adjustments were made to a more rigorous p-value (.017). This may have implications for future studies of larger sample size.

Statistical Analyses

Because the range of tests scores within the each of the sample groups was so widely dispersed, alternative procedures for statistical analysis should be considered which could accommodate multivariate considerations. While most EPT children demonstrated age appropriate skills on the general expressive language measures in the study, there were a number of children on either side of the distribution curve who exhibited speech and language skills below and above average for their age. Further statistical analysis of how children above and below the mean could provide much more information about the entire sample. A linear model of regression which could incorporate additional variables such as length and frequency of therapeutic interventions, medications, length of time on ventilator, additional subtests of the DAS-II and NEPSY–II measuring executive function and working memory, may better indicate which variables have greater impact. Further statistical analysis of the differences within the each of the feeding groups would provide greater information about the range of skills rather than the mean performance of the groups.

Future Research

Given that one in every eight babies born in the U.S. is born prematurely, a sample of 84 EPT infants is relatively small. A larger number of study subjects might have significantly altered the number of participants in each feeding group to provide a better perspective of differences between feeding groups. The current study looked retrospectively at the medical and feeding records of children born between 2002 and 2004. More recent developments of systemized measures such as the Neonatal Oromotor

Assessment Scale (NOMAS) now used by many NICUs as standard protocols, could provide better observational data and more quantitative as well as qualitative information for reporting feeding behaviors in future studies. The finding of BPD as a significant characteristic between oral and tube feeding infants should be further investigated in future research to provide more specific information on the influence of respiratory distress on developing feeding and motor-speech functions as well as effects of respiratory treatments and medications in PT infants and young children. Results of this study are inconclusive regarding the relationship between neonatal feeding skills and speech and oral expression skills at 10 years. Future investigations of this relationship could benefit from the use of more specific measurement tools such as tests of phonemic expression, motor-speech abilities, and closer examination of the components of verbal expression. Further research regarding the relationship of neonatal feeding to later visuomotor skills in a larger sample is warranted as well.

REFERENCES

Aarnoudse-Moens, C. S. H., Weisglas-Kuperus, N., van Goudoever, J. B., & Oosterlaan, J. (2009). Meta-analysis of neurobehavioral outcomes in very preterm and/or very low birth weight children. *Pediatrics 124*(2), 717–728. doi:10.1542/peds.2008-2816

Abernethy, L. J., Palaniappan, M., & Cooke, R. W. I. (2002). Quantitative magnetic resonance imaging of the brain in survivors of very low birth weight. *Archives of Disease in Childhood, 87*(4), 279–283. doi:10.1136/adc.87.4.279

Adams-Chapman, I., Bann, C. M., Vaucher, Y. E., & Stoll, B. J. (2013). Association between feeding difficulties and language delay in preterm infants using Bayley Scales of Infant Development–Third Edition. *The Journal of Pediatrics, 163*(3), 680–685e3. doi:10.1016/j.jpeds.2013.03.006

Alcock, K. (2006). The development of oral motor control and language. *Down Syndrome Research and Practice, 11*(1), 1–8. doi:10.3104/reports.310

Allen, M. C., Cristofalo, E. A., & Kim, C. (2011). Outcomes of preterm infants: Morbidity replaces mortality. *Clinics in Perinatology, 36*(3), 441–454. doi:10.1016/j.clp.2011.06.011

American Speech-Language-Hearing Association. (2007). *Childhood apraxia of speech.* [Position Statement]. Retrieved from http://www.asha.org/docs/html/PS2007-0027.html.ww.asha.org/policy

Anderson, V., Jacobs, R., Spencer-Smith, M., Coleman, L., Anderson, P., Williams, J., . . . Leventer, R. (2010). Does early age at brain insult predict worse outcome? Neuropsychological implications. *Journal of Pediatric Psychology, 35*(7), 716–727. doi:10.1093/jpepsy/jsp100

Anderson, V., Spencer-Smith, M., & Wood, A. (2011). Do children really recover better? Neurobehavioural plasticity after early brain insult. *Brain: A Journal of Neurology, 134*(8), 2197–2221. doi:10.1093/brain/awr103

Arvedson, J. (2006). Swallowing and feeding in infants and young children. *GI Motility online.* Retrieved from http://www.nature.com/gimo/contents/pt1/full/gimo17.html

Aylward, G. P. (2005). Neurodevelopmental outcomes of infants born prematurely. *Developmental and Behavioral Pediatrics, 26*(6), 427–440. Retrieved from http://dx.doi.org/10.1097/00004703-200512000-00008

Barkat-Masih, M., Saha, C., Hamby, D. K., Ofner, S., & Golomb, M. R. (2010). Feeding problems in children with neonatal arterial ischemic stroke. *Journal of Child Neurology, 25*(7), 867–872. doi:10.1177/0883073809348354

Barlow, S. M. (2009). Oral and respiratory control for preterm feeding. *Current Opinion in Otolaryngology & Head and Neck Surgery, 17*(3), 179–186. doi:10.1097/M00.0b013e32832b36fe

Barlow, S. M., & Estep, M. (2006). Central pattern generation and the motor infrastructure for suck, respiration, and speech. *Journal of Communication Disorders, 39*(5), 366–380. doi:10.1016/j.jcomdis.2006.06.011

Barnhart, R. C., Davenport, M. J., Epps, S. B., Nordquist, V. M. (2003). Developmental coordination disorder. *Physical Therapy, 83*(8), 722–731. Retrieved from http://ptjournal.apta.org/content/83/8/722.full.pdf+html

Barre, N., Morgan, A., Doyle, L. W., & Anderson, P. J. (2010). Language abilities in children who were very preterm and/or very low birth weight: A meta-analysis. *The Journal of Pediatrics, 158*(5), 766–774e1. doi:10.1016/j.jpeds.2010.10.0320

Bassan, H., Limperopoulos, C., Visconti, K., Mayer, D. L., Feldman, H. A., Avery, L., . . . du Plessis, A. J. (2007). Neurodevelopmental outcome in survivors of periventricular hemorrhagic infarction. *Pediatrics, 120(*4), 785–792. doi:10.1542/ peds.2007-0211

Bauer, M. A., Prade, L. S., Keske-Soares, M., Haëffner, L. S. B., & Weinmann, A. R. M. (2008). The oral motor capacity and feeding performance of preterm newborns at the time of transition to oral feeding. *Brazilian Journal of Medical and Biological Research, 41*(10), 904–907. doi:10.1590/S0100-79X-2008001000012

Bayley, N. (1993). *Bayley Scales of Infant Development–2nd ed.* San Antonio, TX: Psychological Corporation.

Bednarek, N., Akhavi, A., Pietrement, C., Mesmin, F., Loron, G., & Morville, P. (2008). Outcome of cerebellar injury in very low birth-weight infants: 6 case reports. *Journal of Child Neurology, 23*(8), 906–911. doi:10.1177/0883073808318063

Beebe, D. W., Ris, M. D., Armstrong, F. D., Fontanesi, J., Mulhern, R., Holmes, E., & Wisoff, J. H. (2005). Cognitive and adaptive outcome in low-grade pediatric cerebellar astrocytomas: Evidence of diminished cognitive and adaptive functioning in national collaborative research studies. *Journal of Clinical Oncology, 23*(22), 5198–5204. doi:10.1200/JCO.2005.06.117

Bingham, P. M. (2009). Deprivation and dysphagia in premature infants. *Journal of Child Neurology, 24*(6), 743–749. doi:10,1177/0883073808329530

Bishop, D. (2006). *Children's communication checklist-2, 2nd Ed.* Toronto, Canada: Pearson Assessment Inc.

Blumenshine, P., Egerter, S., Barclay, C. J., Cubbin, C., & Braveman, P. A. (2010). Socioeconomic disparities in adverse birth outcomes: A systematic review. *American Journal of Preventive Pediatrics, 39*(3), 263–272. doi:10.1016/j.amepre.2010.05.012

Bracewell, M., & Marlow, N. (2002). Patterns of motor disability in very preterm children. *Mental Retardation and Developmental Disabilities Research Reviews, 8*(4), 241–248. doi:10.1002/mrdd.100049

Bunton, K. (2008). Speech versus nonspeech: Different tasks, different neural organization. *Seminars in Speech and Language, 29*(4), 267–275. doi:10.1055/s-0028-1103390

Calado, R., Monteiro, J. P., & Fonseca, M. J. (2011). Transient idiopathic dystonia in infancy. *Acta Paediatrica, 100*(4), 624–627. doi:10.1111/j.1651-2227.2010.02109.x

Carlo, W. A., McDonald, S. A., Tyson, J. E., Stoll, B. J., Ehrenkrantz, R. A., Shakaran, S., . . . Higgins, R. D. (2011). Cytokines and neurodevelopmental outcomes in extremely low birth weight infants. *The Journal of Pediatrics, 159*(6), 919–925. doi:10.1016/j.peds.2011.05.042

Carrow-Woolfolk, E. (1995). *Oral and Written Language Scales.* Circle Pines, MN: American Guidance Service.

Centers for Disease Control and Prevention. (2013). *Preterm birth.* Retrieved from http://www.cdc.gov/reproductivehealth/MaternalInfantHealth/PretermBirth.htm

Chakrabarty, S., Shulman, B., & Martin, J. H. (2009). Activity-dependent co-development of the corticospinal system and target interneurons in the cervical spinal cord. *Journal of Neuroscience, 29*(27), 8816–8827. doi:10.1523/JNEUROSCI.073509.2009

Cheng, H. J., Murdoch, B. E., Goozée, J. V., & Scott, D. (2007). Physiologic development of tongue-jaw coordination from childhood to adulthood. *Journal of Speech, Language, and Hearing Research, 50*(2), 352–360. doi:10.104/1092-4388(2007/025)

Connaghan, K. P., Moore, C. A., & Higashakawa, M. (2004). Respiratory kinematics during vocalization and nonspeech respiration in children from 9 to 48 months. *Journal of Speech, Language, and Hearing Research, 47*(1), 70–84. doi:10.1044/1092-4388(2004/007)

Constantino, J. M. & Gruber, C. P. (2012). *Social Responsiveness Scale-2, 2nd ed*. Los Angeles, CA: Western Psychological Services.

Counsell, S. J., Rutherford, M. A., Cowan, F. M., & Edwards, A. D. (2003). Magnetic resonance imaging of preterm brain injury. *Archives of Disease in Childhood, Fetal and Neonatal Edition, 88*(4), F269–F274. doi:10.1136/fn.88.4.F269

Crapnell, T. L., Rogers, C. E., Neil, J. J., Inder, T. E., Woodward, L. J. & Pineda, R. G. (2013). Factors associated with feeding difficulties in the very preterm infant. *Acta Paediatrica, 102*(12), e539–e545. doi :10.1111/apa.12393

Dayan, E., & Cohen, L. G. (2011). Neuroplasticity subserving motor learning. *Neuron, 72*(3), 443–454. doi:10.1016/j.neuron.2011.10.008

de Kieviet, J. F., Pick, J. P., Aarnoudse-Moens, C. S., & Oosterlaan, J. (2009). Motor development in very preterm and very low-birth-weight children from birth to adolescence. *The Journal of the American Medical Association, 302*(20), 2235–2242. doi:10.1001/jama.2009.1708

Delaney, A. L. & Arvedson, J. C. (2008). Development of swallowing and feeding: prenatal through first year of life. *Developmental Disabilities Research Reviews, 14*(2), 105–117. doi:10.1002/ddrr.16

DeMauro, S. B., Patel, P. R., Medoff-Cooper, B., Posencheg, M., & Abbasi, S. (2011). Post discharge feeding patterns in early-and late-preterm infants. *Clinical Pediatrics, 50*(10), 957–962. doi:10.1177/009922811409028

Deuber, C., & Terhaar, M. (2011). Hyperoxia in very preterm infants. *Journal of Perinatal and Neonatal Nursing, 25*(3), 268–274. doi:10.1097/JPN.Ob013e318226ee2c

Dodd, B., & McIntosh, B. (2010). Two-year-old phonology: Impact of input, motor and cognitive abilities on development. *Journal of Child Language, 37,* 1027–1046. doi:10.1017/S0305000909990171

Dudink, J., Kerr, J. L., Paterson, K., & Counsell, S. J. (2008). Connecting the developing preterm brain. *Early Human Development, 84*(12), 777–782. doi:10.1016/j.earlhumdev.2008.09.004

Elliott, C. D. (2007). *Differential Abilities Scale-II* (2nd ed.). Toronto, Canada: Pearson Assessment, Inc.

Farmer, C., Golden, C., & Thurm, A. (2015). Concurrent validity of the differential ability scales with the Mullen Scales of Early Learning in young children with and without neurodevelopmental disorders. *Child Neuropsychology, 21*(1), 1–14. doi:10.1080./09297049.2015.1020775

Ferrari, F., Gallo, C., Pugliese, M., Guidotti, I., Gavioli, S., Coccolini, E., . . . Bertoncelli, N. (2012). Preterm birth and developmental problems in the preschool age. *The Journal of Maternal-Fetal and Neonatal Medicine, 25*(11), 624–627. doi:10.3109/14767058.2012.696.164

Finan, D. S., & Smith, A. (2005). Jaw stretch reflexes in children. *Experimental Brain Research, 164,* 58–66. doi:10.1007/s00221-005-2217-x

Fortin, G., & Thoby-Brisson, M. (2009). Embryonic emergence of the respiratory rhythm generator. *Respiratory Physiology & Neurobiology, 168*(1), 86–91. doi:10.1016/j.resp.2009.06.013

French, N., Kelly, R., Vijayasekaran, S., Reynolds, V., Lipscombe, J., Buckland, A., . . . Meldrum, S. (2013). Voice abnormalities at school age in children born extremely preterm. *Pediatrics, 131*(3), e733–e739. doi:10.1542/peds2012-0817

Goldenberg, R. L., Culhane, J. F., Iams, J. D., & Romero, R. (2008). Epidemiology and causes of preterm birth. *The Lancet, 371*(9606), 75–84. doi:10.1016/S01406736(08)30040-9

Gozzo, Y., Vohr, B. R., Lacadie, C., Hampson, M., Katz, K. H., Maller-Kesselman, J., . . . Ment, L. R. (2009). Alterations in neural connectivity in preterm children at school age. *NeuroImage, 48*(2), 458–463. doi:10.1016/j.neuroimage.2009.06.046

Grabski, K., Lamalle, L., Vilain, C., Schwartz, J. L., Vallée, N., Tropres, I., …, & Sato, M. (2011). Functional MRI assessment of orofacial articulators: Neural correlates of lip, jaw, larynx, and tongue movements. *Human Brain Mapping, 33*(10). doi:10.1002/hbm.21363

Green, J. R., Moore, C. A., & Reilly, K. J. (2002). The sequential development of jaw and lip control for speech. *Journal of Speech, Language, and Hearing Research, 45*(1), 66–79. doi:10.1044/1092-4388(2002/005)

Green, J. R., & Nip, I. S. B. (2010). Organization principles in the development of early speech: Catalysts, constraints, and synergy. In B. Maasen & P. H. H. M. van Lieshout (Eds.), *Speech motor control: New developments in basic and applied research* (pp. 171–190). New York, NY: Oxford University Press.

Greer, J. J., Funk, G. D., & Ballanyi, K. (2006). Preparing for the first breath: Prenatal maturation of respiratory neural control. *Journal of Physiology, 570*(3), 437–444. doi:10.1113/jphysiol.2005.097238

Grigos, M. I. (2009). Changes in articulator movement variability during phonemic development: A longitudinal study. *Journal of Speech, Language, and Hearing Research, 52*(1), 164–177. doi:10.1044/1092-4388(2008/07-0220)

Grigos, M. I., & Kolenda, N. (2010). The relationship between articulatory control and improved phonemic accuracy in childhood apraxia of speech: A longitudinal case study. *Clinical Linguistics & Phonetics, 24*(1), 17–40. doi:10.3109/02699200903-329793

Grigos, M. I., & Saxman, J. H., & Gordon, A. M. (2005). Speech motor development during acquisition of the voicing contrast. *Journal of Speech, Language, and Hearing Research, 48*(4), 739–752. doi:10.104/1092-4388(2005/051)

Guenther, F. H. (2006). Cortical interactions underlying the production of speech sounds. *Journal of Communication Disorders, 39*(5), 350–365. doi:10.1016/j.jcomdis.2006.06.013

Guillén, U., DeMauro, S., Ma, L., Zupancic, J., Roberts, R., Schmidt, B., & Kirpalani, H. (2012). Relationship between attrition and neurodevelopmental impairment rates in extremely preterm infants at 18 and 24 months. *Archives of Pediatric and Adolescent Medicine, 166*(2), 178–184. doi:10.1001/archpediatrics.2011.616

Hall, J. G. (2010). Importance of muscle movement for normal craniofacial development. *The Journal of Craniofacial Surgery, 21*(5), 1336–1338. doi:10.1097/SCS.0b013e3181ebcd4f

Härtel, C., Schilling, S., Sperner, J., & Thyen, U. (2004). The clinical outcomes of neonatal and childhood stroke: Review of the literature and implications for future research. *European Journal of Neurology, 11*(7), 431–438. doi:10.1111/j.1468-1331.2004.00861.x

Herold, B., Höhle, B., Walch, E., Weber, T., & Obladen, M. (2008). Impaired word stress pattern discrimination in very-low-birthweight infants during the first 6 months of life. *Developmental Medicine & Child Neurology, 50*(9), 678–683. doi:10.1111/j.1469-8749.2008.03055.x

Ho, A. K., & Wilmut, K. (2010). Speech and oro-motor function in children with developmental coordination disorder: A pilot study. *Human Movement Science, 29,* 605–614. doi:10.1016/j.humov.2010.01.007

Holsti, L., Grunau, R. V. E. & Whitfield, M. F. (2002). Developmental coordination disorder in extremely low birth weight children at nine years. *Journal of Developmental and Behavioral Pediatrics, 23*(1), 9–15. Retrieved from http://uv7gq6an4y.search.serialssolutions.com/?ctx_ver= Z39.882004&ctx_

Inder, T. E., Tao, J., & Neil, J. J. (2011). Common lesions in the newborn brain. *Topics in Magnetic Resonance Imaging, 22*(1), 25–32. doi:10.1097/RMR.0b013e31824525ce

Iverson, J. M. (2010). Developing language in a developing body. *Journal of Child Language, 37*(2), 229–261. doi:10.1017/S0305000909990432

Iverson, J. M., & Fagan, M. K. (2004). Infant vocal-motor coordination: Precursor to the gesture-speech system? *Child Development, 75*(4),1053–1066. Retrieved from http://ejournals.ebsco.com/direct.asp?ArticleID=4015ABA5C7E8D532A44B

James, K. H., & Swain, S. N. (2011). Only self-generated actions create sensori-motor systems in the developing brain*. Developmental Science, 14*(4), 673–678. doi:10.1111/j.1467-7687.2010.01011

Jiang, R., Bush, J. O., & Lidral, A. C. (2006). Development of the upper lip: Morphogenetic and molecular mechanisms. *Developmental Dynamics, 235*(5), 1152–1166. doi:10.1002/dvdy.20646

Jobe, A. (2010). "Miracle" extremely low birth weight neonates. *Obstetrics & Gynecology, 116*(5), 1184–1190. doi:10.1097/AOG.0b013e3181f60b1d

Jonsson, M., van Doom, J., & van den Berg, J. (2013). Parents' perceptions of eating skills of pre-term infants from birth to 3 years. *International Journal of Speech and Language Pathology, 15*(6), 604–612. doi:10.3109/17549507.2013.808699

Kempley, S., Gupta, N., Linsell, L., Darling, J., McCormick, K., Mannix, P., . . . Leaf, A. (2014). Feeding infants below 29 weeks' gestation with abnormal antenatal Doppler: Analysis from a randomized trial. *Archives of Disease in Childhood-Fetal and Neonatal Ed., 99*(1), F6–F11. doi:10.1136/archdischild-2013-304393

Kent, R. D. (2004). The uniqueness of speech among motor systems. *Clinical Linguistics & Phonetics, 18*(6/8), 495–505. Retrieved from http://content.ebscohost.com.libproxy.uncg.edu/ContentServer

Kent, R. D. (2015). Nonspeech oral movements and oral motor disorders: A narrative review. *American Journal of Speech-Language Pathology, 24*(4), 763–789. doi:10.1044/2015_AJSLP-14-0179s

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. *Journal of Speech, Language, and Hearing Research, 51*(1), S225–S239. doi:10.1044/1092-4388(2008/018)

Kolb, B., & Teskey, G. C. (2010). Age, experience, injury, and the changing brain. *Developmental Psychobiology, 52*(4), 311–325. doi:10.1002/dev.20515

Kolk, A., Ennok, M., Laugesaar, R., Kaldoja, M. L., & Talvik, T. (2011). Long term cognitive outcomes after pediatric stroke. *Pediatric Neurology, 44*(2),101–109. doi:10.1016/j.pediatrneurol.2010.08.012

Korkman, M., Kirk, U., & Kemp, S. (2007). *NEPSY–II* (2nd ed.). Oxford, UK: Pearson Assessment.

LaPointe, L. L., Murdoch, B. E., & Stierwalt, J. A. G. (2010). The neurologic basis of speech and language. In *Brain based communication disorders* (pp. 36–38). San Francisco, CA: Plural Publishing.

Lau, C. (2006). Oral feeding in the preterm infant. *Neoreviews, 7*(1), e19–e27. doi:10.1542/neo.7-1-e19

Lau, C., Geddes, D., Mizuno, K., Schaal, B. (2012). The development of oral feeding skills in infants. *International Journal of Pediatrics, 2012,* Article ID 572341. doi:10.1155/2012/572341

Laughon, M., O'Shea, M., Allred, E. N., Bose, C., Kuban, K., Van Marter, L. J., . . . Leviton, A. (2009). Chronic lung disease and developmental delay at 2 years of age in children born before 28 weeks gestation. *Pediatrics, 124*(2), 637–648. doi:10.1542/peds.2008-2874

Lawn, J. E., Gravett, M. G., Nunes, T. M., Rubens, C. E., Stanton, C., & the GAPPS Review Group. (2010). Global report on preterm birth and stillbirth (1 of 7): Definitions, description of the burden and opportunities to improve data. *BMC Pregnancy Childbirth, 10* (Suppl. 1), s1–s22. doi:10.1186/1471-2393-10-S1-S1

Lee, E. S., Yeatman, J. D., Luna, B, Feldman, H. M. (2011). Specific language and reading skills in school-aged children and adolescents are associated with prematurity after controlling for IQ. *Neuropsychologia, 49*(5), 906–913. doi:10.1016/j.neuropsychologia.2010.12.038

Leviton, A., Dammann, O., Engelke, S., Allred, E., Kuban, K. C., O'Shea, T. M. (2010). The clustering of disorders in infants born before the 28th week of gestation. *Acta Paediatrica, 99*(12), 1795–1800. doi:10.1111/j.1651-2227.2010,01973

Lewis, B. A., Singer, L. T., Fulton, S., Salvator, A., Short, E. J., Klein, N., & Baley, J. (2002). Speech and language outcomes of children with bronchopulmonary dysplasia. *Journal of Communication Disorders, 35*(5), 393–406. Retrieved from http://www.sciencedirect.com/science/article/pii/S0021992402000850

Limperopoulos, C., Chilingaryan, G., Guizard, N., Robertson, R. L., & Du Plessis, A. J. (2010). Cerebellar injury in the premature infant is associated with impaired growth of specific cerebral regions. *Pediatric Research, 68*(2), 145–150. doi:10.1203/PDR.0b013e3181e1d032

Locke, J. L. (2004). Motor patterns of phonology. In B. Manaasen, R. Kent, P. van Lieshout, & W. Hulstijn (Eds.), *Speech motor control in normal and disordered speech* (pp. 185–191). Oxford, England: Oxford University Press.

Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. L. (2004). *Autism Diagnostic Observation System–2* (2nd ed., Modules 1–4). Torrence, CA: Western Psychological Services.

Lubsen, J., Vohr, B., Myers, E., Hampson, M., Lacadie, C., Schneider, . . . Ment, L. R. (2011). Microstructural and functional connectivity in the developing preterm brain. *Seminars in Perinatology, 35*(1), 34–43. doi:10.1053/j.semperi.10.006

Lund, J. P., & Kolta, A. (2006). Brainstem circuits that control mastication: Do they have anything to say during speech? *Journal of Communication Disorders, 39*(5), 381–390. doi:10.1016/j.jcomdis.2006.06.014

Luu, T. M., Ment, L., Allan, W., Schneider, K., & Vohr, B. R. (2011). Executive and memory function in adolescents born very preterm. *Pediatrics, 127*(3), e639–e646. doi:10.1542/peds.2010-1421

Maas, E., Robin, D. A., Hula, S. N. A., Freedman, S. E., Wulf, G., Ballard, K. J., & Schmidt, R. A. (2008). Principles of motor learning in treatment of motor speech disorders. *American Journal of Speech-Language Pathology, 17*(3), 277–298. doi:1044/1058-0360(2008/025

Maassen, B., & Ziegler, W. (2004). The role of the syllable in disorders of spoken language production. In B. Maasen, R. Kent, H. Peters, P. van Leishout, & W. Hulstijn, W. (Eds.), *Speech motor control in normal and disordered speech* (pp. 422–423). New York, NY: Oxford University Press.

Mantilla, C. B., & Sieck, G. C. (2008). Key aspects of phrenic motoneuron and diaphragm muscle development during the perinatal period. *Journal of Applied Physiology, 104*(6), 1818–1827. doi:10.1152/japplphysiol.01192.2007

Martin, J. H., Choy, M., Pullman, S., & Meng, Z. (2004). Corticospinal system development depends on motor experience. *Journal of Neuroscience, 24*(9), 2122–2132. doi:10.1523/JNEUROSCI.4616-03.2004

Mathur, A. M., Neil, J. J., & Inder, T. E. (2010). Understanding brain injury and neuro-developmental disabilities in the preterm infant: The evolving role of advanced magnetic resonance imaging. *Seminars in Perinatology, 34*(1), 57–66. doi:10.1053/j.semperi.2009.10.006

Max, J. E., Bruce, M., Keatley, E., & Delis, D. (2010). Pediatric stroke: Plasticity, vulnerability, and age of lesion onset. *Journal of Neuropsychiatry and Clinical Neurosciences, 22*(1), 30–39. doi:10.1002/dev.20185

McFarland, D. H., & Tremblay, P. (2006). Clinical implications of cross-system interactions. *Seminars in Speech and Language, 27*(4), 300–309. doi:10.1055/s-2006-955119

Ment, L. R., Kesler, S., Vohr, B., Katz, K. H., Bumgartner, H., Schneider, K. C., . . . Reiss, A. L. (2009). Longitudinal brain volume changes in preterm and term control subjects during late childhood and adolescence. *Pediatrics, 123*(2), 503–511. doi:10.1542/peds.2008-0025

Miller, J. L., Macedonia, C., & Sonies, B. C. (2006). Sex differences in prenatal oral-motor function and development. *Developmental Medicine & Child Neurology, 48*(6), 465–470. doi:10.1017/S0012162206001009

Miller, J. L., Sonies, B. C., & Macedonia, C. (2003). Emergence of oropharyngeal, laryngeal and swallowing activity in the developing fetal upper aerodigestive tract: An ultrasound evaluation. *Early Human Development, 71*(1), 61–87. doi:10.1016/-S0378-3782(02)00110-X

Mizuno, K., & Ueda, A. (2005). Neonatal feeding performance as a predictor of neuro-developmental outcome at 18 months. *Developmental Medicine & Child Neurology, 47*(5), 299–304. doi:1017/S0012162205000587

Moore, T., Hennessy, E. M., Myles, J., Johnson, S. J., Draper, E. S., Costeloe, K. L, & Marlow, N. (2012). Neurological and developmental outcome in extremely preterm children born in England in 1995 and 2006: The EPICure studies. *British Medical Journal, 345*(e7961), 1–13. doi:10.1136/bmj.e7961

Mosch, S. C., Max, J. E., & Tranel, D. (2005). A matched lesion analysis of childhood versus adult-onset brain injury due to unilateral stroke. *Cognitive and Behavioral Neurology, 18*(1), 5–17. doi:10.1097.01.wnn.0000152207.80819.3c

Mullen, K. M., Vohr, B. R., Katz, K. H., Schneider, K. C., Lacadie, C., Hampson, M., . . . Ment, L. R. (2011). Preterm birth results in alterations in neural connectivity at age 16 years. *NeuroImage, 54*(4), 2563–2570. doi:10.1016/j.neuroimage.2010.11.019

Murphy, S. L., Xu, J., & Kochanek, K. D. (2013). Deaths: Final data for 2010. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics. *National Vital Statistics Reports, 61*(4), 1–118. Retrieved from http://www.cdc.gov/nchs/data/nvsr/nvsr61/ nvsr61_04.pdf

Myers, E., Hampson, M., Vohr, B., Lacadie, C., Frost, S. J., Pugh, K. R., . . . Ment, L. R. (2010). Functional connectivity to a right hemisphere language center in prematurely born adolescents. *NeuroImage, 51*(4), 1445–1452. doi:10.1016/j.neuroimage.2010.03.049

Newman, R., Ratner, N. B., Jusczyk, A. M., Jusczyk, P. W., & Dow, K. A. (2006). Infants' early ability to segment the conversational speech signal predicts later language development: A retrospective analysis. *Developmental Psychology, 42*(4), 643–655. doi:10.1037//0012-1649.42.4.643

Nip, I. S. B., Green, J. R., & Marx, D. B. (2009). Early speech motor development: Cognitive and linguistic considerations. *Journal of Communication Disorders, 42*(4), 286–298. doi:10.1016/j.jcomdis.2009.03.008

Nip, I. S. B., Green, J. R., & Marx, D. B. (2011). The co-emergence of cognition, language, and speech motor control in early development: A longitudinal correlation study. *Journal of Communication Disorders, 44*(2), 149–160. doi:10.1016/j.jcomdis.2010.08.002

Northam, G. B., Liégeois, F., Chong, W. K., Baker, K., Tournier, J. D., Wyatt, J. S., . . . Morgan, A. (2012). Speech and oromotor outcome in adolescents born preterm: relationship to motor tract integrity. *The Journal of Pediatrics, 160*(3), 402–408. doi:10.1016/j.peds.2011.08.055

Nosarti, C., Giouroukou, E., Healy, E., Rifkin, L., Walshe, M., Reichenbert, . . . Murray, R. M. (2008). Grey and white matter distribution in very preterm adolescents mediates neurodevelopmental outcome. *Brain, 131*(1), 205–217. doi:10.1093/brain/awm282

Oller, D. K. (2010). Vocal motoric foundations of spoken language—A commentary on Iverson's 'Developing language in a developing body: The relationship between motor development and language development.' *Journal of Child Language, 37*(2), 275–279. doi:10.1017/So305000909990456

Orchinik, L. J., Taylor, H. G., Espy, K. A., Minich, N., Klein, N., Sheffield, T., & Hack, M. (2011). Cognitive outcomes for extremely preterm/extremely low birth weight children in kindergarten. *Journal of the International Neuropsychological Society, 17*(6), 1067–1079. doi:10.1017/S135561771100107X

Ortiz-Mantilla, S., Choudhury, N., Leevers, H., & Benasich, A. A. (2008). Understanding language and cognitive deficits in very low birth weight children. *Developmental Psychobiology, 50*(2), 107–126. doi:10.1002/dev.20278

O'Shea, T. M., Allred, E. N., Dammann, O., Hirtz, D., Kuban, K. C. K., Paneth, N., & Leviton, A. (2009). The ELGAN study of the brain and related disorders in extremely low gestational age newborns. *Early Human Development, 85*(11), 719–725. doi:10.1016/j.earlhumdev.2009.08.060

O'Shea, T. M., Allred, E. N., Kuban, K. C. K., Hirtz, D., Specter, B., Durfee, S., . . . Leviton, A. (2012). Intraventricular hemorrhage and developmental outcomes at 24 months of age in extremely preterm infants. *Journal of Child Neurology, 27*(1), 22–29. doi: 10.1177/0883073811424462

Owens, R. E., Metz, D. E., & Farinella, K. A. (2010). *Introduction to communication disorders: A lifespan evidence-based perspective* (4th ed., pp. 65–66). Upper Saddle River, NJ: Allyn & Bacon.

Palmer, M. M. (1983). Neonatal Oral-Motor Assessment Scale.

Panigrahy, A., Winsnowski, J. L., Furtado, A., Lepore, N., Paquette, L., & Bluml, S. (2012). Neuroimaging biomarkers of preterm brain injury: toward developing the preterm connectome. *Pediatric Radiology, 42*(Suppl. 1), S33–S61. doi:10.1007/s00247-011-2239-4

Peterson, B. S., Vohr, B. R., Kane, M. J., Whalen, D. H., Schneider, K. C., Katz, K. H., . . . Ment, L. R. (2002). A functional magnetic resonance imaging study of language processing and its cognitive correlates in prematurely born children. *Pediatrics, 110*(6), 1153–1162. Retrieved from http://pediatrics.aa.publications.org/content/1106/1153.full pdf+html

Poore, M., & Barlow, S. M. (2009). Suck predicts neuoromotor integrity and developmental outcomes. *Perspectives in Speech Science and Orofacial Disorders, 19*(1), 44–51. doi:10.1044/ssod19.1.44

Poore, M., Zimmerman, E., Barlow, S. M., Wang, J., & Gu, F. (2008). Patterned orocutaneous therapy improves sucking and oral feeding in preterm infants. *Acta Paediatrica, 97*(7), 920–927. doi:10.1111/j.1651-2227.2008.00825.x

Rajendran, G. P., Kessler, M. S., & Manning, F. A. (2009). Congenital central hypoventilation syndrome (Ondine's curse): Prenatal diagnosis and fetal breathing characteristics. *Journal of Perinatology, 29*(10), 712–713. doi:10.1038/jp.2009.49

Rees, S., Harding, R., & Walker, D. (2011). The biological basis of injury and neuroprotection in the fetal and neonatal brain. *International Journal of Developmental Neuroscience, 29*(5), 551–163. doi:10.1016/j.ijdevneu.2011.04.004

Reilly, K. J., & Moore, C. A. (2009). Respiratory movement patterns during vocalizations at 7 and 11 months of age. *Journal of Speech, Language, and Hearing Research, 52*(1), 223–239. doi:10.1044/1092-4388(2008/06-0215)

Reissland, N., Mason, C., Schaal, B., & Lincoln, K. (2012). Prenatal mouth movements: can we identify co-ordinated fetal mouth and lip actions necessary for feeding? *International Journal of Pediatrics,* [serial online] Article: 848596, 5p. doi:10.1155/2012/84859 Retrieved from http://uncg.worldcat.org/title/prenatal-mouth-movements-can-we-identify-co-ordinated-fetal-mouth-and-lip-actions-necessary-for feeding/oclc/808003601&-referer=brief_results

Rutter, M., Bailey, A., Berument, S. K., Lord, C., & Pickles, A. (2003). *Social Communication Questionnaire*. Torrence, CA: Western Psychological Services.

Samara, M., Johnson, S., Lamberts, K., Marlow, N., & Wolke, D. (2009). Eating problems at age 6 years in a whole population sample of extremely preterm children. *Developmental Medicine & Child Neurology, 52*(2), e16–e22. doi:10.111/j.1469-8749.2009.03512.x

Samra, H. A., McGrath, J. M., & Wehbe, M. (2011). An integrated review of developmental outcomes and late-preterm birth. *Journal of Obstetric, Gynecologic, and Neonatal Nursing, 40*(4), 399–407. doi:10.1111/j.1552-6909.2011.01270.x

Singer, L. T., Siegel, A. C., Lewis, B., Hawkins, S., Yamashita, T., & Baley, J. (2001). Preschool language outcomes of children with history of bronchopulmonary dysplasia and very low birth weight. *Journal of Developmental and Behavioral Pediatrics, 22*(1), 19–26. Retrieved from http://ovidsp.uk.ovid.com.libproxy.uncg.edu/sp3.12.0b/ovidweb.cgi

Slattery, J., Morgan, A., & Douglas, J. (2012). Early sucking and swallowing problems as predictors of neurodevelopmental outcome in children with neonatal brain injury: a systematic review. *Developmental Medicine and Child Neurology, 54*(9), 796–806. doi:10.1111/j.1469-8749.2012.04318.x

Smith, A. (2006). Speech motor development: Integrating muscles, movements, and linguistic units. *Journal of Communication Disorders, 39*(5), 331–349. doi:10.-1016/j.jcomdis.2006.06.017

Smith, A., & Zelaznik, H. N. (2004). Development of functional synergies for speech motor coordination in childhood and adolescence. *Developmental Psychobiology, 45*(1), 22–33. doi:10.1002/dev.20009

Sparrow, S. S., Balla, D. A., & Cicchetti, D. V. (1984). *Vineland Adaptive Behavior Scales.* Circle Pines, MN: American Guidance Service.

Spencer-Smith, M. M., Spittle, A., Lee, K., Doyle, D. W., & Anderson, P. J. (2015). Bayley III cognitive and language scales in preterm children. *Pediatrics, 135*(5), e1258–1265. doi:10.1542/peds.2014.3039

Spittle, A. J., Treyvaud, K., Doyle, L. W., Roberts, G., Lee, K. J., Inder, T., . . . Anderson, P. (2009). Early emergence of behavior and social-emotional problems in very preterm infants. *Journal of American Child and Adolescent Psychiatry, 48*(9), 909–918. doi:10.1097/CHI.0b013e3181af83235

Steeve, R. W., & Moore, C. A. (2009). Mandibular motor control during the early development of speech and nonspeech behaviors. *Journal of Speech, Language, and Hearing Research, 52*(6), 1530–1554. doi:10.1044/1092-4388(2009/08-0020)

Steeve, R. W., Moore, C. A., Green, J. R., Reilly, K. J., & McMurtrey, J. R. (2008). Babbling, chewing, and sucking: Oromandibular coordination at 9 months. *Journal of Speech, Language, and Hearing Research, 51*(6), 1390–1404. doi:10.1044/ 1092-4388(2008/07-0046)

Stumm, S. L., Barlow, S. M., Estep, M., Lee, J., Cannon, S., Carlson, J., & Finan, D. (2008). Respiratory distress syndrome degrades the time structure of the non-nutritive suck in preterm infants. *Journal of Neonatal Nursing, 14*(1), 9–16. doi:10.1016/j.jnn.2007.11.001

Sutton, P. S., & Darmstadt, G. L. (2013). Preterm birth and neurodevelopment: A review of outcomes and recommendations for early identification and cost-effective interventions. *Journal of Tropical Pediatrics, 59*(4), 258–265. doi:10.1093/tropej/fmt012

Terband, H., Maassen, B., van Lieshout, P., & Nijland, L. (2010). Stability and composition of functional synergies for speech movements in children with developmental speech disorders. *Journal of Communication Disorders, 44*(1), 59–74. doi:10.1016/j.jcomdis.2010.07.003

Thiel, A., Habedank, B., Herholz, K., Kessler, J., Winhuisen, L., Haupt, W. F., & Heiss, W. D. (2006). From the left to the right: How the brain compensates progressive loss of language function. *Brain and Language, 98*(1), 57–65. doi:10.1016/j.bandl.2006.01.007

Thompson, D. K., Inder, T. E., Faggian, N., Warfield, S. K., Anderson, P. J., Doyle, L. W., & Egan, G. F. (2012). Corpus callosum alterations in very preterm infants: Perinatal correlates and 2 year neurodevelopmental outcomes. *NeuroImage, 59*(4), 3571–3581. doi:10.1016/j.neueroimage.2011.11.057

Thompson, D. K., Warfield, S. K., Carlin, J. B., Pavlovic, M., Want, H. X., Bear, M., . . . Inder, T. E. (2007). Perinatal risk factors altering regional brain structure in the preterm infant. *Brain, 130*(3), 667–677. doi:10.1093/brain/awl277

Tich, S. N. T., Anderson, P. J., Hunt, R. W., Lee, K. J., Doyle, L. W., Inder, T. E. (2011). Neurodevelopmental and perinatal correlates of simple brain metrics in very preterm infants. *Archives of Pediatric and Adolescent Medicine, 165*(3), 216–222. doi:10.1001/archpediatrics.2011.9

Törölä, H., Lehtihalmes, M., Yliherva, A., & Olsén, P. (2012). Feeding skill milestones of preterm infants born with extremely low birth weight (ELBW). *Infant Behavior and Development, 35*(2), 187–194. doi:10.1016/j.infbeh.2012.01.005

Tsai, S., Chen, C., & Lin, M. (2010). Prediction for developmental delay on Neonatal Oral Motor Assessment Scale in preterm infants without brain lesion. *Pediatrics International, 52*(1), 65–68. doi:10.1111/j.1442-200X.2009.02882.x

United States Census. (2000). Census 2000 PHC-T-30. Characteristics of Children Under 18 Years by Age, for the United States, Regions, States, and Puerto Rico: 2000 Household and Family Characteristics of Children Under 18 Years for the United States: 2000 Source: U.S. Census Bureau, Census 2000, special tabulation. Internet Release date: March 16, 2004 http://www2.census.gov/programs-surveys/decennial/2000/phc/phc-t-30/tab02.pdf

United States Department of Health and Human Services, Center for Disease Control and Prevention, National Center for Health Statistics, Health, United States. (2004). Retrieved from www.cdc.fob/nchs/data/hus/hus04trend.pdf

van Noort-van der Spek, I. L., Franken, M. C., J. P., & Weisglas-Kuperus, N. (2012). Language functions in preterm-born children: A systematic review and meta-analysis. *Pediatrics, 129*(4), 745–754. doi:10.1542/peds.2011-1728

Visscher, C., Houwen, S., Moolenaar, B., Lyons, J., Scherder, E. J. A., & Hartman, E. (2010). Motor proficiency of 6-9-year-old children with speech and language problems. Developmental Medicine & Child Neurology, 52(11), e254–e258. doi:10.1111/j.1469-8749.2010.03774x

Vohr, B. (2007). How should we report early childhood outcomes of very low birth weight infants? *Seminars in Fetal & Neonatal Medicine, 12*(5), 355–362. doi:10.1016/j.siny.2007.05.003

Volpe, J. J. (2009). Brain injury in premature infants: a complex amalgam of destructive and developmental disturbances. *The Lancet, 8*(1), 110–124. doi:10.1016/S1474-4422(08)7029-1

Volpe, J. J., Kinney, H. C., Jensen, F. E., & Rosenberg, P. A. (2011). Reprint of "The developing oligodendrocyte: Key cellular target in brain injury in the preterm infant." *International Journal of Developmental Neuroscience, 29*(6), 565–582. doi:10.1016/j.ijdevneu.2011.07.008

Weisglas-Kuperus, N., Baerts, W., Smrkovsky, M., & Sauer, P. J. (1993). Effects of biological and social factors on the cognitive development of very low birth weight children. *Pediatrics, 92*(5), 658–665.

Weschler, D. (2009). *Weschsler Individual Achievement Test* (2nd ed.). San Antonio, TX: Pearson Assessment Inc.

Wilson, E. M., Green, J. R., & Weismer, G. (2012). A kinematic description of the temporal characteristic of jaw motion for early chewing: Preliminary findings.

Journal of Speech, Language, and Hearing Research, 55(2), 626–638.doi:10.1044/1092-4388(2011/10-0236)

Wocadlo, C., & Rieger, I. (2007). Phonology, rapid naming and academic achievement in very preterm children at eight years of age. *Early Human Development, 83*(6), 367–377. doi:10.1016/j.earlhumdev.2006.08.001

Wohlert, A. B., & Smith, A. (2002). Developmental change in variability of lip muscle activity during speech. *Journal of Speech, Language, and Hearing Research, 45*(6), 1077–1087. doi:10.1044/1092-4388(2002/086)

Wolke, D., Samara, M., Bracewell, M. & Marlow, N. (2008). Specific language difficulties and school achievement in children born at 25 weeks of gestation or less. *Journal of Pediatrics, 152*(2), 256–262e1. doi:10.1016/j.peds.2007.06043

Woythaler, M. A., McCormick, M. C., & Smith, V. C. (2011). Late preterm infants have worse 24 month neurodevelopmental outcomes than term infants. *Pediatrics, 127*(3), e622–e629. doi:10.152/peds.2009-3598

Zharkova, N., Hewlett, N., & Hardcastle, W. J. (2011). Coarticulation as an indicator of speech motor control development in children: An ultrasound study. *Motor Control, 15*(1), 118–140. Retrieved from http://uncg.worldcat.org/title/coarticulation-as-an-indicator-of-speech-motor-control-development-in-children-an-ultrasound-study/oclc/704848059&referer=brief_results

APPENDIX A

LONGITUDINAL STUDIES OF PRETERM INFANTS: ELGAN STUDIES

Longitudinal studies of preterm (PT) infants provide a unique opportunity to assess a variety of health, cognitive, motor, and functional abilities over the course of a child's development. One such study is the ELGAN research project, named for the participants who were all extremely low gestational age newborns (ELGANs) born before 28 weeks gestation. The ELGAN studies are national observational studies of preterm infants designed to collect information through interviews with parents, neurodevelopmental testing of the children at progressive ages, and analyses of medical and developmental information. Women delivering infants before 28 weeks gestation were enrolled. ELGANs are considered to be the population of PT infants most vulnerable to adverse psychological and developmental outcomes (Leviton et al., 2010). The ELGAN studies are intended to provide greater information about the causes of medical problems and developmental issues associated with infants born prematurely.

The original ELGAN study (ELGAN1), conducted from 2002-2004, was designed to identify characteristics and exposures that increase the risk of structural and functional neurologic disorders in ELGANs. Children were followed from birth through 24 months adjusted age (AA). Standardized batteries of physical, neurological, and neurodevelopmental tests were administered to the children at 24 months AA. Blood samples taken weekly in the neonatal intensive care unit (NICU) were used to measure protein levels for biomarker analyses. These analyses provided insight into the presence, intensity, and length of duration of inflammation and infection in the children. In addition, the children were tested at 24 months AA using the Bayley Scales of Infant Development, Second Edition (BSID-II), Vineland Adapted Behavior Scale (VABS), and the Child Behavior Checklist (CBCL). A uniform neurological assessment protocol, a uniform medical history form including imaging history, a social factors form (SES information), the nurse administered Gross Motor Functional Classification Scale (GMFCS), and a 17-item parent questionnaire about feeding, food preferences, and therapies was also included for examiners to complete during a full day assessment sessions at 2 years adjusted age (AA). Additional historical medical information regarding feeding and neonatal status is available for each infant in detailed NICU records.

The ELGAN 2 study began in August, 2013, and concluded in February, 2015. ELGAN 2 researchers administered a battery of standardized medical, psychological, neurological, and neurodevelopmental tests to the children who participated in the ELGAN 1 study, now 9 years, 3 months to 12 years, 6 months of age. The ELGAN 2 study includes the following: Social Communication Questionnaire (SCQ; Rutter, Bailey, Berument, Lord, & Pickles, 2003), select subtests on the Developmental Neuropsychological Assessment-II (NEPSY–II), a standardized measure of neuropsychological skills (Korkman, Kirk, & Kemp, 2007), select subtests on the Differential Abilities Scale-II (DAS-II), a standardized measure of cognitive abilities including verbal and visual working memory, immediate and delayed recall, visual recognition and matching, processing and naming speed, phonological processing, and basic number concepts (Elliott, 2007), the Oral and Written Language Scale (OWLS), standardized tests of oral and written receptive and expressive language skills (Carrow-Woolfolk, 1995), the Autism Diagnostic Observation Schedule (ADOS) Modules 1-4, an assessment of autism features (Lord et al., 2004), Social Responsiveness Scale-2 (SRS-2) identifying the presence and severity of impairment in autism (Constantino & Gruber, 2012), and the Children's Communication Checklist-2 (CCR-2), an assessment of children's communication skills providing scaled and normed scores (Bishop, 2006).

APPENDIX B

PARTICIPANT DEMOGRAPHIC INFORMATION

STUDY ID#	SEX	GA	BW	SES	RACE	FS 34 WKS	BPD	IVH
2300491 J	2	26	810	5	1	1	1	0
2300601 B	2	24	704	99	2	1	0	0
2301151 G	1	27	893	7	1	2	0	0
2300851 E	2	27	890	7	3	1	0	0
2300852 C	2	27	1090	2	3	2	0	0
2300011 B	1	27	910	99	2	1	1	0
2300031 L	1	24	720	8	1	2	0	0
2300081 G	2	27	613	8	1	2	1	0
2300101 A	2	27	880	2	1	2	1	0
2300111 L	1	24	635	5	2	1	1	1
22300131 J	1	26	940	6	1	2	1	0
2300181 E	2	24	680	2	3	1	1	0
2300171 F	1	27	1026	4	1	1	0	0
2300172 D	1	27	1167	4	1	2	1	1
2300173 B	2	27	750	4	1	2	0	0
2300211 J	1	26	934	6	1	2	1	0
2300301 I	2	26	820	5	1	1	0	0
2300351 D	1	26	990	9	1	2	0	3
2300371 B	2	27	975	1	2	1	0	1
2300421 E	2	24	604	6	1	2	1	0
2300411 C	1	27	682	4	2	2	1	0
2300461 A	1	26	757	6	2	1	1	0
2300471 L	1	25	770	1	1	2	0	0
2300481 K	2	27	963	2	2	1	0	0
2300522 A	1	25	787	4	2	2	1	0
2300551 L	1	26	534	7	1	2	1	0
2300571 J	2	26	784	4	2	1	0	0

STUDY ID#	SEX	GA	BW	SES	RACE	FS 34 WKS	BPD	IVH
2300581 I	2	26	610	2	1	2	1	0
2300591 H	1	26	919	3	3	2	1	0
2300611 A	2	27	620	99	1	2	1	0
2300661 H	2	26	934	1	2	2	0	0
2300641 J	2	27	917	1	1	2	1	0
2300691 E	1	26	1128	8	1	2	1	0
2300692 C	1	26	969	8	1	1	0	0
2300701 L	2	26	518	3	1	2	1	0
2300731 I	2	27	860	3	2	1	0	0
2300741 H	1	24	630	3	3	2	1	0
2300761 F	1	25	780	6	1	1	1	3
2300841 F	1	26	859	2	2	1	0	0
2300861 D	1	27	790	5	1	2	1	0
2300871 C	2	27	965	4	2	1	0	0
2300911 G	1	25	730	6	2	2	1	0
2300921 F	1	25	880	5	1	1	1	3
2301001B	2	27	712	8	1	1	1	0
2301051I	1	26	870	3	1	2	1	0
2301061 H	2	27	1040	2	2	1	0	0
2301101 L	1	25	820	5	3	1	0	0
2301111 K	2	27	1223	6	1	1	1	0
2301141 H	2	27	770	9	1	1	0	0
2301251 E	1	25	811	4	1	2	0	0
2301271 C	2	27	904	2	3	2	1	0
2301281 B	2	27	1025	10	1	1	0	1
2301291A	2	27	920	8	1	2	0	0
2301292K	2	27	860	8	1	1	1	0
2301361B	2	27	780	10	1	2	1	0
2301391 K	2	25	680	5	1	2	0	0
2301451 A	2	27	780	99	4	1	0	0
2301541 L	1	27	1200	3	1	1	0	1

STUDY ID#	SEX	GA	BW	SES	RACE	FS 34 WKS	BPD	IVH
2301542 J	1	27	1110	3	1	2	1	4
2301561 J	2	24	555	2	1	2	1	0
2301601 A	1	26	1125	99	2	1	0	1
2301611 L	1	26	980	99	2	2	0	0
2301631J	2	26	490	1	3	2	1	0
2301671 F	1	24	680	99	1	2	1	0
2301692 B	1	26	800	1	2	2	0	0
2301761 E	1	27	1180	7	1	2	0	0
2301751 F	2	26	872	4	1	1	0	0
2301871 B	2	24	665	99	1	2	1	0
2301861 C	1	24	800	1	2	1	0	0
2301941 C	2	27	1040	5	2	1	0	1
2301951 B	2	27	1090	3	2	1	0	0
2301961 A	2	27	1035	6	1	2	0	0
2302061 G	1	27	1020	4	1	2	0	0
2302091D	1	26	855	5	2	1	0	0
2302101 K	2	26	932	6	1	2	0	0
2302161 E	2	27	620	4	3	2	1	0
2302151 F	1	25	740	2	2	1	0	0
2302141 G	2	27	890	4	2	2	0	0
2302171 D	2	27	1134	1	1	2	0	0
2302191 B	1	26	837	10	1	1	0	1
2302192 L	1	26	797	10	1	2	1	0
2302211 H	1	23	550	4	2	2	1	0
2301831 F	1	24	793	3	1	2	1	0
2301781 C	2	27	1200	1	2	1	0	0