The effects of socioeconomic factors on trajectories of language and motor development in infants

by

Davis C. Dyke

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Approved by

Dr. Mary Rudisill,Ph.D., Chair, Professor
Dr. Melissa Pangelinan, Ph.D., Associate Professor
Dr. Susan Teubner-Rhodes, Ph.D., Assistant Professor
Dr. Danielle Wadsworth, Ph.D., Professor

Abstract

Multiple domains develop simultaneously and interact throughout infancy and early childhood. Although relationships between motor and language skills have been examined cross-sectionally during the first three years of life, little is known regarding the individual factors that influence the development of these domains as well as the relationship between these domains. The present study addressed these knowledge gaps by evaluating the longitudinal trajectory of motor and language skills in a sample of infants (n = 50) ages 1 - 3 years of age, representing a broad range of socioeconomic status (SES). Performance on standardized motor and language assessments were examined with respect to age and sex – biologically assigned at birth (Specific Aim 1). After accounting for age and sex, socioeconomic factors were examined to determine their influence on each domain (Specific Aim 2). After controlling for age and sex, relationships between motor and language domains were examined (Specific Aim 2). Finally, a mediation analysis was used to determine if the relationships between SES factors and language domains is mediated by motor development (Specific Aim 3). First, it is hypothesized that age is positively related to the motor and language development (separately); it is unclear if sex will influence the development of these skills. Second, SES is positively associated with motor and language skills after accounting for age and sex. Third, it is hypothesized that there is a positive relationship between motor and language skills after accounting for age and sex. Fourth, motor development mediates the relationship between SES and language skills after accounting for age and sex. Overall, the results of this study are relevant to parents, clinicians, and early detection and intervention programs for motor and language skills during the first three years of life.

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List of Abbreviations

ADHD	Attention Deficit Hyperactivity Disorder
BSID	Bayley Scales of Infant Development
CT	Cortical Thickness
DST	Dynamical Systems Theory
Fm	Fine Motor
GM	Grey Matter
Gm	Gross Motor
MRI	Magnetic Resonance Imagining
NGST	Neuronal Group Selection Theory
NIH	National Institutes of Health
PLS-3	Preschool Language Scale, 3rd Edition
SA	Surface Area
SES	Socioeconomic Status
TBV	Total Brain Volume
WHO	World Health Organization
WM	White Matter

Chapter 1 - Introduction

Significant structural brain development takes place during infancy (Gilmore et al., 2012; Girault et al., 2020; Lyall et al., 2015). During the first year of life, total cortical gray matter (GM) volume increases 108%, with regionally specific rates of development ranging from 62-154% (Gilmore et al., 2012). GM increases in volume in the second year of life, but the rate of growth slows to about 19%, with regional differences ranging from 9-28% (Gilmore et al., 2012). Similar non-linear changes in GM volume were also reported by Knickmeyer and colleagues (2008) over the first two years of life. The trajectory of white matter (WM) differs from GM and is more consistent from year 1 to year 2. Specifically, WM increases by 11% during the first year of life and by 19% in the second year of life (Knickmeyer et al., 2008). These structural changes over the first years of life may underlie the corresponding development of language (Sheldrick & Perrin, 2013) and motor processes (Viholainen et al., 2006), as well as relationships between these behavioral domains (Nelson et al., 2014; Sket et al., 2019).

While the brain begins to rapidly grow, infants also begin to demonstrate rapid development of the motor and language systems. By around the first year of life, most infants will acquire the following motor milestones: rolling, sitting up, standing, cruising, and independent walking (Berger et al., 2017; Karasik et al., 2011). Across the second year of life, infants eventually learn to drink from a cup, take of a piece of clothing, eat with a utensil, as well as wash hands and brush teeth with assistance (Ertem et al., 2018). During early development infants also begin to produce vocalizations that begin spontaneously, which gradually become more defined as infants establish better phonological abilities (Nathani et al., 2006). Indeed, given the appropriate auditory input, babbling begins to morph into a more advanced expressive language after 9-months of age (Nathani et al., 2006). Eventually, vocabulary comprehension also expands rapidly after 11 months (median of 54 words). By 16 months of age, a child can comprehend almost 170 words (Fenson et al., 1994), and by 24 months children begin to combine words (Bates, Dale, & Thal, 2017). However, when assessing the communication development of toddlers, the greatest variability of individual's expressive communication occured across the second year of life when percentile scores ranged from 10 - 97% (Tsao et al., 2004). Specifically, in about 50% of children age 16 - 24 months, word production does not remain constant across individuals, as assessed by the MacArthur-Bates Communicative Delvelopment Inventories (Thal et al., 1997). These linguistic processes (i.e., expressive & receptive communication) typically occur before the end of the infant's second year of life and seemingly follow an orderly, developmental sequence (Stark et al., 1993).

Beyond the correspondence in language and motor milestones observed during infancy, researchers have suggested that there is a direct relationship between the motor and language systems (Iverson & Thelen, 1999). There are two lines of evidence for this hypothesis. First, several studies have found that the onset of motor skills (i.e., manipulative, locomotor) are associated with greater concurrent development of receptive language skills (Walle & Campos, 2014; West & Iverson, 2017) as well as productive language skills (Walle & Campos, 2014). It is hypothesized that manipulative and locomotor skills enable greater social/linguistic interactions between infants and caretakers. Second, others have found that earlier attainment of motor skills (e.g., independent sitting, walking) are associated with later development of expressive language skills during the second years of life (Oudgenoeg-Paz et al., 2012). Specifically, earlier attainment of unsupported sitting by infants (M = 8.18 months) was related to a larger rate of expressive language growth between 16 - 28 months (Oudgenoeg-Paz et al., 2012). This study also found that the age of independent walking was also found to predict the improvements (or delay) in expressive language vocabulary of infants aged 16 - 28 months (Oudgenoeg-Paz et al., 2012). However, if an infant does not attain sitting until after most infants typically do, he/she still has the capacity to develop speech. Furthermore, Walle and Campos (2014) suggest that the onset of walking (M = 14.73 months) is associated with increases in both receptive and expressive language capabilities. This is because when an infant has a greater ability to explore the environment, more opportunities for language exploration are afforded concurrently. Similarly, infant object manipulation skills (between 10 - 14 months of age) afford increased opportunities for language interactions with caregivers (West & Iverson, 2017). Indeed, the attainment of new motor skills affords new situational-interactions for the perception-action system. However, additional longitudinal studies are needed to determine the extent to which better *performance* of motor skills, rather than simply the *onset*, is related to concurrent and subsequent development of expressive and receptive language during early development.

Only recently have studies directly examined if changes in the brain are associated with language and motor skills during the first two years of life (Girault et al., 2020). For example, Girault et al. (2020) found a relationship between average cortical thickness (CT) and gross motor skills in 1-year-old infants as well as average CT and expressive and receptive language in 2-year-old infants. Although these findings provide support of the direct relations between brain structure and motor or language skills, it is unclear how structural development may facilitate interaction between the motor and language domains.

Despite the wealth of knowledge of typical developmental changes in brain and behavior over the first three years of life, most studies lack racially, ethnically, and socioeconomically diverse populations. Girault and colleagues (2020) found total cortical surface area (SA) across the first 2 years of life was positively correlated with the mothers' education level. Betancourt and colleagues (2016) reported reduced cortical GM volumes and deep grey matter volumes in 1-month-old infants from low socioeconomic status (SES) compared to those from high SES (Betancourt et al., 2016). Moreover, infants from low SES are demonstrably different in the types of oral/manual exploratory behaviors they exhibit (Clearfield et al., 2014; Tacke et al., 2015), engage in reduced amounts of play time (Milteer et al., 2012), and typically have inadequate availability to play toys/materials, as well as limited play space (Freitas et al., 2013). Infants from low SES also demonstrate stunted overall language scores (as measured by the Preschool Language Scale-5) as early as 7 months of age, compared to those from high SES (Betancourt et al., 2015). And by two years of age, children from higher SES groups are found to vocalize more words (Hoff, 2003; Hoff & Tian, 2005), have a greater number of word types, and total number of spoken utterances (Hoff, 2003). Additionally, parents with higher educational statuses are known to have infants who speak in more complex sentences (i.e., multi-clausal sentences) compared to simple sentences around two-years of age (Vasilyeva et al., 2008). However, no studies have examined if socioeconomic factors influence the *relationship* between motor and language systems development.

Therefore, the overarching purpose of this dissertation is to assess relationships between motor and language development in typically-developing infants from birth to age three and whether these relationships differ with respect to socioeconomic variables (i.e., income, parental education). This chapter will provide further details about infant brain development during the first three years of life, with specific attention to global and regional grey matter (i.e., CT and volume). Changes in brain development likely underlie the key developmental changes in motor and language development. Second, the chapter will describe changes in motor development with respect to key motor milestones (e.g., crawling, sitting, walking) and the trajectory of gross and fine motor development. Next, linguistic milestones (e.g., babbling, words) and the developmental trajectories for infant expressive and receptive language are summarized. The impact of socioeconomic variables on motor and language outcomes are presented. Last, the specific aims, hypotheses, a brief description of the proposed methods, and limitations/delimitations will be described.

Normal Brain Development: Birth - 3 years

Over the first three years of life, the brain undergoes changes in total volume (Choe et al., 2013; Dean et al., 2018; Groeschel et al., 2010), regional volume (Choe et al., 2013; Gilmore et al., 2007), and development of the cerebral cortex (i.e., CT - Jha et al., 2018; Lyall et al., 2015; Wang et al., 2019; and surface area (SA) - Jha et al., 2018; Li et al., 2013; Lyall et al., 2015)**.** For example, over the first three months of life, an infant's brain grows from about 34% to almost 55% of its total adult size (Holland et al., 2014). Total brain volume (TBV) increases by 101% over the first year of life and increases 15% in the second year of life (Knickmeyer et al., 2008). Total cortical hemispheric GM volume increases by 88% during year one and an increase of 15% during year two until year three (Knickmeyer et al., 2008). Changes in cortical GM are likely due to increased synaptic density via synaptic and axonal arborization (Knickmeyer et al., 2008). Cortical WM has a much less dramatic growth trajectory with increased volume of around 11% in year one and 19% in the second year (Groeschel et al., 2010; Knickmeyer et al., 2008). These relatively more subtle changes in cortical WM are likely driven by increased oligodendrocyte proliferation which contribute to myelination. Changes in the constituent components of the cerebral GM volume (i.e., CT and SA) exhibit nonlinear, but less drastic changes. Total and regional CT increase by 31% during the first year and 4.3% during the second (Lyall et al., 2015). Although is some discrepancy across studies regarding regional differences in CT growth during the first two years of life; the percentage change in CT is consistently lower in sensory/motor cortices (i.e., postcentral gyrus, paracalcarine areas). (Gilmore et al., 2012; Lyall et al., 2015). In contrast, greater changes were consistently observed in the insula, inferior frontal operculum, superior frontal gyrus, and temporal pole (Gilmore et al., 2012; Lyall et al., 2015).. These structural changes may underlie the development of higher-order cognitive and language processes.

Recent studies have reported relationships between the development of specific regions of the cerebral cortex and the development of cognition, language, and movement abilities. For example, Girault et al. (2020) observed positive relationships between gross motor scores and CT of the superior parietal cortex at one year of age. Although no unique relationships were observed between CT and language areas at one year, expressive language was positively related to CT of the left primary motor cortex and right middle orbitofrontal cortex at age two. In addition, receptive language was uniquely related to the CT in the right insula at age two (Girault et al., 2020). However, others have found a negative relationship between frontal lobe CT and language development, such that thinner cortices were related to higher language scores in children ages 2-3 years (Wedderburn et al., 2020). The discrepancy across these studies of CT and language development (e.g., regions and direction of the relationship) may be due to the inclusion of a larger proportion of children with potential developmental delay in Wedderburn et al. (2020). Additional studies are needed to confirm the regions of interest and direction of the relationship between language and motor skills during early childhood.

Infant Motor Development

Six motor milestones are exhibited by most typically developing infants (WHO et al., 2006). These milestones and their respective mean ages of attainment include: sitting without support (6.0 months), standing with assistance (7.6 months), hands-and-knees crawling (8.5

months), walking with assistance (9.2 months), standing alone (11.0 months), and walking alone (12.1) (WHO et al., 2006). Approximately 86% of infants develop through these milestones with only minor variations in the timing of hands-and-knees crawling, standing with assistance, and walking with assistance. About 9.4% of infants display some "other" pattern of development with respect to the order of the motor milestones and about 4.3% of infants do not crawl**.** Similar patterns of milestone acquisition have been reported with minor variations in the onset of the skills (Ertem et al., 2018). Specifically, these authors reported onset estimates for children at the 50th percentile with infants sitting with support at 4.3 months, sitting without support at 6.5 months, walking with support at 9.7 month**s**, standing alone at 10.0 months, and walking alone at 12.9 months. The attainment of early fine motor skills is contingent on infant body control and head control (Viholainen et al., 2006). These gross motor skills are thus related to the acquisition of future fundamental gross motor skills as well as fine motor development (e.g., reaching and manipulation; Viholainen et al., 2006). The development of fine motor skills follows a progressive pattern of finger, hand, and arm control that allow the infant to interact with their environment by reaching, lifting, carrying, and manipulating objects. These milestones and their respective mean ages of attainment include: unclenching the fist around 4 weeks of life, followed by playing the hands from 2 - 3 months, then reaching for objects and mouthing toys around 4 - 5 months, and eventually by 8 - 9 months of life the pincer grip is utilized and the infant can now bang two objects together (Viholainen et al., 2006). Taken together, there are considerable changes in gross motor skills during the first year of life that appear consistent in their onset with limited variability. Fewer changes in fine motor skills are observed over the first year of life, with most changes pertaining to object manipulation.

Over the second year of life, the motor repertoire for both gross and fine motor skills continue to expand. The median onsets for the major milestones during this period include: kick a ball/objects (13.9 months), begins scribbling with a pencil/stick (18.7 months), and walk up/down stairs with the assistance of a rail, or hand of caregiver (17.6 - 20.0 months; Ertem et al., 2018). These milestones reflect the infant's growing ability to interact with objects and the environment in a goal-oriented way.

The relationship between infant motor development and later motor skills was examined by Viholainen and colleagues (2006) using retrospective parent reported onset for infant gross and fine motor skills and motor performance of the children at age 3.5 years. A positive relationship between the onset of infant gross motor skills predicted gross motor performance of the children at 3.5 years, but the onset of infant fine motor skills did not predict fine motor performance at 3.5 years. Using structural equation modeling, early (gross) motor milestones predicted future attainment of fundamental gross motor skills but not fine motor skills. These results suggest a separate timeline for the development of fine and gross motor skills, and/or that reports of motor milestones do not predict developmental changes in fine motor control.

In sum, the studies above suggest that there is remarkable stability in the onset of gross and fine motor milestones despite significant cross-cultural differences and different methods for acquiring data (e.g., parental questionnaires, Largo et al., 1985; direct observation, Fink et al., 2020; structured interviews with parents, Ertem et al., 2018). It is possible that individual differences in motor development may only be evident using standardized assessments that examine the child's performance of age-appropriate motor tasks for those who are similar to the original samples used in initial test development (Mendonça et al., 2016).

Infant Language Development

Language acquisition, like motor acquisition, follows a normative pattern often divided into distinct stages. The preverbal stage, prior to the development of full speech, can be subdivided into four stages of expressive language development (Oller et al., 1999). They include the phonation stage, primitive articulation stage, expansion stage, and canonical stage (i.e., canonical and variegated babbling sequences; Oller et al., 1999). Although there is an orderly sequence to language development, when new verbal skills emerge, there may be periods of progression and regression of skills within a stage or across stages (Stark et al., 1993). The following sections will describe the component processes for each stage to provide insights to normative patterns of development. It is important to note that expressive and receptive language milestones appear consistent across different countries and the differences between boys and girls are small (Ertem et al., 2018).

During the phonation stage, infants develop the ability to discriminate speech sounds of their native language from other environmental sounds (Nazzi et al., 1998). The process of attuning to language properties is a crucial first stage in language acquisition, particularly *receptive* language development. Infants, including newborns, can attune to a native language's rhythmic patterning (Mampe et al., 2009; Nazzi et al., 1998). Some research suggests that infants may have a natural attunement to language, or an "acoustic advantage," allowing them to listen to, represent, and discern native-linguistic melodic (or prosodic) elements prior to birth (Mampe et al., 2009). Infants at two months (Hesketh et al., 1997), five months (Nazzi et al., 2000), and seven months of age (Kuhl et al., 2005) attune to, or begin to pay-attention to, their native language by discriminating the rhythmic properties that distinguish their mother-tongue from other languages and sounds in general. By attuning to the native language stream early in the language learning process, the infant can identify key elements of language (i.e., improve receptive communication for their native language).

During the primitive articulation stage, infant cries and vocalizations begin to exhibit acoustic features of their native language. Although this stage typically begins around 2-3 months of age when vocalized 'gooing' sounds (i.e., emergence of consonant sounds) are expressed (Oller et al., 1999), there is evidence to suggest that infants may learn prosodic features in utero by attending to the linguistic elements of intonation and prosody (Mampe et al., 2009). For example, when comparing the cries of German and French newborns, the patterns of contour in the cries as seen on spectrograms reflect the acoustic patterns of the native language (Mampe et al., 2009). These patterns of crying/vocalization denote the possibility that infants are representing and learning early elements of their native language. If the fetus can access the linguistic stream in the womb, then it seems this the type of exposure may set the foundation for later receptive and expressive language development during early infancy.

Emerging around 6 months of age is the expansion stage when infants begin to express full vowels, display marginal babbling characteristics (e.g., beginnings of consonant-vowel sound production), and can "blow raspberries" (Oller et al., 1999). During this stage, the infant manipulates and exploits features of the vocal tract to expand and create new sounds (i.e., full vowels) from consonant-like sounds requiring normal phonation. These new sounds, dubbed protophones, result from the switching from consonant to vowel production, leading to a phenomenon called marginal babbling. Marginal babbling marks the end of the preverbal stages and has the initial characteristics of speech but without the speed and precision that exists in fully acquired speech. It is the attunement of these embedded processes that leads to the last stage prior to adult-like speech (i.e., canonical babbling; Oller et al., 1999).

The last stage of the preverbal period is the "canonical stage", which may emerge between 6 months of age to 10 months (Oller et al., 1999). Although infants transition through multiple stages of cooing, gooing, babbling, and mimicry that serve as precursors for the expressive language system (Oller et al., 1999), during this period of babbling infants begin vocalizing different sound combinations. Infant canonical babbling consists of prelinguistic sounds called protophones or “critical infant sounds” that have increasing features of the native language sounds and distinct from general baby sounds (Oller et al., 1999). While some have identified the onset of canonical babbling as early as 6 - 8 months of age (Oller et al., 1999), others report that reduplicated canonical babble which lacks variation (e.g., mama, baba, dada) are observed around 7 - 10 months of age (Eilers et al., 1993).

The variegated babbling period, which forms the later part of the canonical stage, is characterized by phonetic variations and syllable segmentation with increasing patterns of complexity as an infants’ sound repertoire expands (Smith et al., 1989). Smith and colleagues (1989) define complexity in infant pre-speech as the period of time around 10 - 13 months marked by the addition of variegated patterns to the existing set of canonical, reduplicated babbling that already exists at about 7 - 10 months of age. The onset for this period is debated. While variegated vocalizations are observed as early as 6 - 9 months of age, it is not until around 14 - 17 months of age when the majority of utterances are fully variegated (Smith et al., 1989). But, as variegated babbles increase, reduplicated babble decreases (Smith et al., 1989).

Although first-word emergence around 13 months of age defines the eruptive stages of expressive language development in infants, it is the preverbal babbling stages (between 3 and 10 months) that set the foundation for language acquisition (Kuhl et al., 2005; Oller et al., 1999; Tsao et al., 2004). For example, consonant (C) and vowel (V) production allows infants to create multisyllabic units that display more complex variations as they age. Although between 6 and 13 months the amount of C, V, and C + V production does not vary much (~30%), a dramatic shift is noted around 14 - 17 months when C + V production represents about 50% of vocalizations (Smith et al., 1989). These shifts in patterns represent the increasing complexity of vocal/preverbal expressions that are associated with typical language development. The above milestones mark the significant stages of infant expressive language development.

Taken together, the preverbal periods of attunement and expression during infancy are critical in the development of receptive and expressive communication. It is important to note that few studies have been conducted in the last decade , lack representative samples, and implement various measures of expressive and receptive language (e.g., observational behavioral coding, parental reports, or standardized assessments, etc.). Longitudinal examinations using standard assessments with large samples are needed to determine key factors that influence individual differences in language development throughout infancy and early childhood.

Relationship between Infant Language and Motor Development

Robust relationships between language acquisition and motor development are observed across infancy. Evidence suggests that the onset of motor skills (i.e., manipulative, locomotor) are likely associated with greater concurrent development of receptive language skills (Walle & Campos, 2014; West & Iverson, 2017) as well as receptive and productive language skills (Walle & Campos, 2014) in the first two years of life. A recent systematic review sythensized the evidence regarding concurrent development of motor and language skills in infancy and early childhood (Gonzalez et al., 2019)

Longitudinal and retrospective cross-sectional studies have provided evidence of a directional relationship between early motor development (e.g., during the first year of life) and later language development. For example, a large cohort study found that low muscle tone, as measured by a standardized neurodevelopmental examination at 12 weeks, is associated with lower parent reported receptive and expressive communication at 18 months of age (Van Batenburg-Eddes et al., 2013). The onset of babbling and the onset of sitting coincide around 6 - 7 months of age (Eilers et al., 1993). Persistent use of the right-hand during motor activities during infancy (between 6 - 14 months) is positively associated with language skills at 24 months of age, as measured by the Bayley Scales of Infant Development, Third Edition **(**BSID-III) (Nelson et al., 2014). Changes in independent sitting from 3-5 months is directly related to the size of an infants' future receptive vocabulary at 10 and 14 months (Libertus & Violi, 2016). The onset of walking predicts future vocabulary sizes between 16 and 28 months of age (Oudgenoeg-Paz et al., 2012). Furthermore, after about 3 months of walking experience, toddlers have significantly better receptive and expressive language scores (Walle & Campos, 2014). Moreover, the systematic review by Gonzalez and colleagues (2019) found that the longitudinal relationships between motor and language development depended on the skills evalutated; the majority of these studies examined sitting and walking and are consistent with the findings described above. Taken together, these findings suggest consistent predictive relationships between motor skills, particularly sitting and walking, and language skills during infancy and early childhood.

The mechanisms underlying the relationship between motor and language development remains largely unknown. Some authors suggest that developmental cascades underlie these relationships (Libertus & Violi, 2016; Walle & Campos, 2014). That is, the onset of a new skill (e.g., learning to sit) may provide new affordances to infants, which in turn create interactional environments with new and expanded opportunities for language learning (Libertus & Violi, 2016). However, much of the support for developmental cascades is based on evidence from developmental disorders (e.g., specific language impairments, ADHD, Autism) in which motor system impairments are theorized to negatively impact language development (see Hill, 2001 for review). Additional, longitudinal studies are needed using systematic assessments of typically developing infants to determine the relationships between the trajectory of motor skills and the trajectory of receptive and expressive language as well as the factors that mediate this relationship.

Impact of Socioeconomic Environment on Brain, Motor, and Language Development

Adverse environments linked to low SES and its associated stressors are known to negatively influence infancy and early childhood development (see, Boyce & Kobor, 2015; Johnson et al., 2016, for review). For example, Hanson and colleagues (2013) reported that longitudinal changes in GM and overall brain growth were significantly reduced in infants and young children (5 months - 4 years old) from low-SES backgrounds compared with infants from higher SES households. Low-SES is also associated with lower brain volumes in infants (0 - 12 months), which leads to lower overall GM volume at 2 years of age (Betancourt et al., 2016).

Differences in motor development are also observed across SES. Compared to infants from high-SES backgrounds, infants from low-SES backgrounds display less mature oral and manual exploration (Clearfield et al., 2014) and immature object exploration and/or object manipulation behaviors during the first year of life (Tacke et al., 2015). Interestingly, although infants from low-SES, urban families did not differ from the normative sample for the BSID-II, toddlers from this population performed lower on both mental and psychomotor scales compared to the normative sample (Black et al., 2000). These results are consistent with the studies that suggest that most aspects of motor development during the first year of life (e.g., major motor milestones) may be robust to environmental differences. However, more subtle aspects of motor development during the first year of life (e.g., detailed analysis of object exploration/manipulation) and later refinement of motor skills during the second year of life appear more sensitive to individual differences. Additional longitudinal studies are needed to determine the extent to which SES affects the trajectory of motor development across the first two years of life.

With respect to language development, SES-related factors (e.g., maternal education, household income, etc.) also affect specific aspects of expressive and receptive language during the first three years of life (e.g., McGillion et al., 2017; Rowe, 2008; Vasilyeva et al., 2008). For example, early infant babbling from birth through 16 months (Eilers et al., 1993; Oller et al., 1995) and phoneme discrimination at 6 months (Tsao et al., 2004) are not affected by exposure to low-SES. However, later receptive and expressive language may be negatively impacted by SES and related factors. For example, maternal education level was moderately correlated with receptive and expressive language at 18-months (McGillion et al., 2017). More complex features of language (e.g., syntax) are also negatively affected by SES (Vasilyeva et al., 2008); live audio recordings of naturalistic speech showed that toddlers (ages 22 - 42 months) from high-SES backgrounds produced more complex sentences compared low-SES counterparts (i.e., multi-clausal sentences). Moreover, vocabulary at 3.5 years of age was significantly related to parental education and family income, which may be due to an increase in child-directed speech and parent knowledge of child development (Rowe, 2008). Thus, it is likely that the effects of SES on language development depend on the setting and opportunities for caregiver-child interactions which increase child-directed speech (Hoff-Ginsberg, 1991). Indeed, child-directed speech (Rowe, 2008) and maternal speech (i.e., overall input, languagage and literacy skills) are significant factors in infant and toddler language abilities.

Another potential confound with the previous literature examining SES is that the SES variable is not standardized. For example, SES measures include an income-to-needs ratio

(Betancourt et al., 2016; Noble et al., 2012), a 5-level scale (Oller et al., 1995) or 10-level scale (Lawson et al., 2013), and other categorical variable (i.e., high/mid, Hoff, 2003; low/mid/high, Piccolo et al., 2016). Additionally, SES may be constructed from reported household income (Hanson et al., 2013; Jha et al., 2019), by using maternal education coupled with a needs-assessment survey (Clearfield et al., 2014), or with the use of maternal education as a proxy for SES (Tacke et al., 2015). Thus, a standardized method is needed to categorize SES to enable comparisons across samples (i.e., total household income treated as a continuous variable). Moreover, previous studies have only addressed the impacts of SES on brain growth (Betancourt et al., 2016; Jednoróg et al., 2012; Noble et al., 2012), motor development (Clearfield et al., 2014, 2015; Tacke et al., 2015), or language development separately (Betancourt et al., 2015; Hoff, 2003; McGillion et al., 2017; Rowe & Goldin-Meadow, 2009). Indeed, the current state of the literature is unclear due to the variability in representing SES and therefore, assessing the impacts of SES on the trajectory of brain and behavioral domains requires further study.

Specific Aims and Directional Hypotheses

There are several important knowledge gaps that will be addressed in the present study. First, no study has examined the relationship between motor development as a construct (compared with a specific task) with respect to language development as a construct (compared to a specific aspect of language development). Second, it is possible to measure changes in motor development earlier than for language development; therefore, longitudinal study over a large age range is needed to determine the relationships between these constructs. Third, although there is evidence to suggest that socioeconomic factors are related to both domains, no study has examined how socioeconomic factors affect the *relationship* between these domains.

The purpose of this study is three-fold: 1) To determine the age and sex-related developmental trajectories of motor and language development from birth to 3 years of age; 2) To determine if household income as one meaure of socioeconomic status influences the trajectories of motor or language development and their relationships; and, 3) To determine the relationship between motor and language acquisition from birth to 3 years of age. To this end, a secondary data analysis of data from the National Institutes of Health Study of Normal Brain Development - Objective 2 (Almli et al., 2007) was examined. Linear-mixed effect mediation analysis was conducted to examine the following hypotheses:

Hypotheses

1. Motor development (measured by the BSID-II) and language development (measured by the PLS-3) will be positively associated with age and sex in infants from birth to 3 years of age.
2. Income will be positively associated with motor (BSID-II) and language (PLS-3) skills after controlling for age and sex.
3. Motor development (BSID-II) will be positively associated with the trajectory of language development (PLS-3) in infants from birth to 3 years of age after accounting for age and sex.
4. Motor development (BSID-II) will moderate the relationship between household income and language development (PLS-3), after controlling for age and sex.

By using a large, representative sample of infants and toddlers from birth to 3 years, the results should be more generalizable. The present results may provide insights regarding the mechanisms underlying the relationship between language and motor development. To date, little is known about the concurrent development between these domains and if they are in fact associated or affected by socioeconomic variables like income. If indeed income is positively associated with motor and language development then additional programs beyond Head Start are needed in low-SES communities and homes to provide the stimuli or resources necessary to close the developmental gap.

Limitations/Delimitations

A limitation of this study is that it is a secondary analysis of existing data. As such, the analyses will be limited to data acquired by the original study that place from 2001 - 2007 utilizing old versions of standardized assessments. For example, motor development was collected as part of the BSID-II, which includes a mental domain (cognitive, language, and perceptual skills combined) and a motor domain (fine and gross motor combined). The current version of this assessment is the BSID-IV, which has 5 domains: cognitive, expressive language, receptive language, gross motor, and fine motor. Therefore, it will not be possible to parse these different domains from the original dataset and the results can only be directly compared to studies using BSID-II. With this said, the BSID-II is a standardized and reliable tool for the measurement of motor skills (Bayley, 1993).

Another limitation is the fact that there is a limited number of individuals from different race categories. The original data collection aimed to represent the population based on a stratified sample of the US census from 2000 (i.e., 69.1% Caucasian, 12.1% African American, 12.5% Hispanic, 3.6% Asian, Native Hawaiian, & Other Pacific Islander, 0.1%, and 0.7% American Indian & Alaskan Native (Almli et al., 2007). In this study's current final sample, the demographic characteristics do not reflect the US census as described above (i.e., 90% Caucasian, 6% African American, 2% Hispanic, & 4% Asian). The limited racial variability precludes the ability to examine unique factors associated with race or ethnicity and socioeconomic factors. However, given the number of participants and the continuous nature of the income measurement, the study results will provide important, new insights regarding the impact of household income on key behavioral domains in Caucasian children.

Another limitation is the use of household income as a proxy for socioeconomic status. Although income is an important variable and typically used to access governmental subsidies (e.g., WIC, SNAP, Head Start), it may not represent all of the environmental factors that may influence development (e.g., parental education, access to environmental enrichment, quality of parental care, etc.). In order to understand the joint impact of these factors on motor and language development, a very large and diverse sample is needed in order to stratify the across these personal (e.g., race, ethnicity) and environmental factors that contribute to socioeconomic status. With this in mind, the present study adds to the literature by determining how income affects motor and language development while holding ethnicity, race, and parental education constant.

Chapter 2 - Background

Normal Brain Development: Birth - 3 years

It is well known that during the first two years of life there is an explosion of growth in the infant brain. Growth rates are initially as high as 1% per day, eventually slowing to a pace of about 0.4% per day around 90 days post-birth (Holland et al., 2014). Specifically (TBV) from birth to 3 months of age increase from 341 cm^3 to 558 cm^3 (Holland et al., 2014). Both male and female brains reach about 55% of their total respective adult volumes by the end of this period, but males grow more rapidly and are about 3% larger at this time compared to females (Holland et al., 2014). TBV increases by 101% over the first year of life and only by 15% in the second (Knickmeyer et al., 2008). Indeed, 80% of maximum TBV reached by about 1.5 years (Groeschel et al., 2010; Knickmeyer et al., 2008). Compared to the first two years of life, change in TBV is modest during early childhood (Groeschel et al., 2010; Matsuzawa et al., 2001; Sanchez et al., 2012).

Similar patterns are observed for total and cerebral gray matter (GM) and white matter (WM). During the first year of life, total GM increases by 149%, while total WM only increases by about 11% in the same time frame (Knickmeyer et al., 2008). In the second year, total GM continues to grow at a slower rate of 14%, while WM continues to increase at a rate of 20% (Groeschel et al., 2010; Knickmeyer et al., 2008). The difference in growth during infancy and early childhood for these two tissue components is even more apparent when considering the ages at which 80% of volume is achieved; 80% of GM is achieved right around 1 year of age for males and females, while 80% of WM is achieved at age 6.5 years for females and 8.5 years for males (Groeschel et al., 2010). These changes are due, in part, to mylenation and oligodendrocyte proliferation (WM), and dendritic arborization (GM, Groeschel et al., 2010).

Cortical SA growth is region specific and age related (Li et al., 2013; Lyall et al., 2015). For example, in the first two years of life, faster expanding regions were observed near speech and language centers, such as lateral frontal, lateral parietal, mid orbital frontal, and occipital lobes (Lyall et al., 2015), the inferior frontal gyrus, superior frontal gyrus, and fusiform gyrus (Gilmore et al., 2012), regions in the parietal lobe (Gilmore et al., 2007), and the cingulate cortex (Lyall et al., 2015). Slower expanding areas were observed in the superior temporal poles (Lyall et al., 2015), parietal lobe, frontal lobe, and some aspects of the middle temporal gyrus (Gilmore et al., 2012). Regions that exhibit the slowest growth trajectories were observed in the superior frontal and postcentral gyrus which are responsible for motor and sensory systems (Lyall et al., 2015). From ages 1 - 6 years, changes in SA follow a logarithmic or quadratic trajectory with substantial variability in growth across regions, ranging from 20 - 108% (Remer et al., 2017). The greatest changes were observed in the superior, middle, and inferior temporal regions and cingulate cortex, while the smallest changes were observed in the temporal pole, orbitofrontal, and occipital cortex (Remer et al., 2017). It is worthwhile to note that the sensorimotor regions exhibited modest change in SA from ages 1 - 6 years (Remer et al., 2017).

Recently, it has been suggested that CT and SA in particular regions might serve as the neural architecture for the progressive development of motor, language, and general cognitive abilities (e.g., Girault et al., 2020; Wedderburn et al., 2020). For example, Girault and colleagues (2020) assessed the relationship of CT and SA with motor, language, and general cognitive abilities in a large cohort of neonates/infants (n = 487). Cortical SA within regions of the temporal and frontal lobes was positively associated with language development in the first year of life, while CT in frontal and parietal lobes was negatively associated with language development (Girault et al., 2020). With respect to language outcomes, thinner cortices with larger SA in the frontal and temporal regions were associated with better receptive language outcomes during 2 - 3 years of age (Girault et al., 2020). Additionally, expressive language was positively related to CT of the primary motor cortex and right middle orbitofrontal cortex at age 2, but not at end of year one (Girault et al., 2020). Others have reported positive relationships between SA in left and right fusiform gyri and right lateral orbitofrontal regions with language scores on BSID-III (Wedderburn et al., 2020). Overall language development is also positively associated with the SA of the bilateral fusiform gyri and right lateral orbitofrontal cortex, and negatively associated with CT in these same regions. Thus, thinner cortices with more surface area related to higher language scores (Wedderburn et al., 2020).

These results are consistent with previous studies suggesting that CT first increases from birth until about two years of age (Lyall et al., 2015), which is followed by the thinning of CT in specific regions (Remer et al., 2017). However, most of the previous literature is not longitudinal, and only assess infants up to 2 years of age, or school aged children 5 years and older. The aforementioned studies mostly examine behavior/motor outcomes or language outcomes, but not both simultaneously. These early years are a very crucial period in neurodevelopment that may effect overall learning and behavioral difficulties (e.g., motor difficulties, language impairments, or generally lower cognitive function) that persist later into childhood (see Hill, 2001, for review; Iverson & Thelen, 2000) and should be examined conjointly.

Infant Motor Development

Motor development has been conceived by some as a mountain metaphor (Clark & Metcalfe, 2002). This metaphor can be interpreted to suggest that development is not a linear or stage-based process. Rather, motor development is considered a non-linear process based on the concepts of Dynamical Systems Theory (Smith & Thelen, 2003) and Neuronal Group Selection Theory

(Edelman, 1987). Indeed the infant is considered a complex, ever-changing organism and behaviors emerge in a “dynamic” way through the interactions between the infant, the environment, and the task at hand (Smith & Thelen, 2003). Thus, there is not *one* single factor responsible for development, and importantly, there is not a single trajectory for the broad repertoire of motor skills that emerge over the first three years of life (Smith & Thelen, 2003).

It is well known that infancy is a period of time characterized by the rapid development of many motor abilities, specifically, reaching, grasping, sitting, standing, walking, chewing, and talking as these are all subservient to future survival. Many of an infant’s behaviors are considered explorative, in that, infants will grasp, hold, twist, mouth, and touch objects to their face in an effort to gain information about object properties (Lobo et al., 2014). Most of these behaviors are evident within the first days and months of an infant’s life owing to a desire for environmental stimulation via object exploration (Molina & Jouen, 2004; Rochat, 1987). When infants are two and three months old, most of their exploring includes mouthing of objects to obtain information about texture (Rochat, 1989). Specific behaviors such as mouthing, looking, fingering, and combinations of these increase through about 5 months of age (Rochat, 1989), while finer exploratory behaviors, such as rotating, transferring, and object manipulation, are observed up until about 12 months of age (Ruff, 1984). Around the age of one, the initiation of self-feeding (i.e., with fingers) and independent walking occurs (Ruff, 1984). These two behaviors - self-locomoting and self-feeding - are necessary to survive; walking gets you to the food and feeding allows you to consume the food.

Importantly, infancy serves as the foundation of the continued development of the motor system. Indeed, infant motor experience is necessary for behavioral and neural changes to take place. Although early neuromaturational theories described motor development as a maturational process that is innate, contingent on the development of the nervous system, and is not experience-expectant/dependent, more recent theories propose an interaction between the brain and behavior (Johnson, 2000). Indeed, an individual's history and movement experiences determine their future motor repertoire in a sequential and cumulative manner (Metcalfe & Clark, 2002).

Development of the motor system can be conceptualized as a mountain divided into six observable periods/stages of maturation (Clark & Metcalfe, 2002): (a) the reflexive, (b) preadapted, (c) fundamental patterns, (d) context-specific, (e) skillful, and/or (f) compensation periods. During the first three years of life infants progress through the reflexive, preadaptive, and the beginning of the fundamental patterns stages. The reflexive period take place from prenatal development until about 2 weeks post-natal and is characterized by spontaneous and reflexive movements (e.g., rooting, suckling, postural reflexes, etc.). These movements are not only necessary for early survival but also necessary for building a relationship between the nervous system and the body (i.e., sensory receptors and muscles).

During the preadapted period (about 2 weeks - 12 months), species-specific behaviors such as rolling over (prone/supine), sitting, crawling, self-feeding, and walking emerge. The early portion of an infant's life involves the emergence of behaviors that are consistent across individuals and tend to follow a similar sequence (i.e., motor milestones; Clark, 2005). However, there is considerable inter-individual variability in the emergence and form of these behaviors during the first year of life (Clark, 2005). Moreover, environmental factors are critical for the emergence and form of these behaviors (Zoghi et al., 2019). For example, infants raised in small spaces or homes that lack objects for supportive locomotion may exhibit delayed or different trajectories for walking and environmental exploration (Bayley, 1969). In addition, cultural and socioeconomic differences in infant rearing influence the onset of motor milestones. Indeed, a large cross-sectional, cross-cultural study (i.e., Cambodia, Chile, Ghana, Guatemala, Lebanon, Pakistan, the Philippines, and the USA) observed a 2.1-month gap on average between the wealthiest country (US) and poorest country (Cambodia; Fink et al., 2020). Critically then, environment and experience influence the non-linear aspects of motor development (Berger et al., 2017; Fink et al., 2020; Hadders-Algra, 2018).

The fundamental patterns period takes place from about 12 months of age and continues into early childhood (~ 7 years of age). This is the period of time characterized by the emergence and development of specific locomoting patterns (e.g., running, skipping, jumping, etc.) and manipulative coordination of the limbs (e.g., drawing, cutting with scissors, throwing, catching, kicking) that will serve as the "building blocks" for the emergence of culturally-specific skills including sports (Clark, 2005). During years two and three, infants not only elaborate their motor repertoire in these two domains but also begin to combine skills across domain (e.g., running up to and kicking a ball, jumping and catching an objects).

Gross Motor Development

Gross motor skills include patterns of movement that primarily involve the coordination of large muscle groups and include postural skills and locomotor patterns. Indeed, early adoption of postural skills (e.g., maintaining head and trunk position) are necessary precursors for future gross motor behaviors (e.g., sitting, standing, walking). The pattern of gross motor milestones include the progressive changes in postural/body control, followed by locomotion and manual control during the first year or so of life. For example, approximately 3 - 4 months after birth, an infant adopts a mid-line head position (which is a requirement for postural control); once this is achieved, an infant now has the ability to develop subsequent skills contingent on postural stabilization (Viholainen et al., 2006). More complex movements, such as sitting independently (5 - 8 months), standing without support (9 - 13 months), and eventually independent walking (10 - 14 months; WHO et al., 2006), all depend on stabilizing the posture. Others have found that average onset of sitting independently at 6.6 months, standing without support at 11.2 months, and independently walking at 12.4 months (Thurman & Corbetta, 2019). These timelines corroborate early studies of the 1940-1960s that first identified the seemingly consistent progression of gross motor skills during the first year of life (Bayley, 1935; Gesell & Thompson, 1934).

After the first year of life, gross motor skills become increasingly dynamic and adapted to the environment. For example, two-year-olds learn to adapt movements to different sized objects while climbing, throwing, catching, and kicking.

Indeed, gross motor skills during the first year of life and, in particular, those involving postural control are predictive of later motor development. For example, one longitudinal study of 3.5-year-olds with familiar risk for dyslexia (n = 130) found that parent report of infant motor milestones for early body control (i.e., head control, turning, sitting, upright posture, walking, and manipulating) accounted for 38% of variance in performance on the Balance and Ball Skills subtests of the Movement Assessment Battery of Children (MABC) at age 3.5 years (Viholainen et al., 2006). The authors suggest that the development of postural control is an "essential mediator" between gross motor skills during infancy and early childhood. With this said, these results need to be verified with a typically developing sample (not one at risk for developmental problems) and based on performance of motor assessments and not parental report.

Fine Motor Development

Fine motor development includes the patterns of movement that *primarily* involve the coordination of small muscle groups that control the fingers, hands, face, mouth, and eyes. During prenatal development, fetuses have the capacity to open and close their hands, bring their hands to their face, mouth their hands, and perform sucking/swallowing movements (de Vries et al., 1982). Across the first year of life, there are considerable age-related changes in goal-directed behaviors such as reaching and grasping. For example, newborns begin to make reach-like movements (Rader & Stern, 1982), and explore objects with their bodies (Rochat, 1987). Consistent reaching towards stationary and moving objects does not emerge until 12-16 weeks (Halverson, 1931). Increases in the frequency of reaching are observed from 15-36 weeks, such that reaching constitutes only 10% of goal-directed behaviors at 15 weeks, while reaching constitutes about 80% of goal-directed behaviors at 36-weeks-old (Von Hosten & Lindhagen, 1979). Furthermore, although infants at 15-months-old have similar movement patterns to adults, these patterns are not fully matured yet (Konczak et al., 1997). Not until 16 months of age do infants begin to display a smoother movement path when reaching that is more comparable to an adults' (1997).

However, early motor behavior development is also contingent on infant body positioning and the postural support provided by caregivers (Bertenthal & von Hofsten, 1998; Lobo & Gallaway, 2012; Thurman & Corbetta, 2019). For example, after a three-week at home intervention focused on increasing infants postural positioning (e.g. more time spent in prone), the development of reaching was found to occur almost one year earlier in 4 of the infants in the experimental group and none in the control (Lobo & Gallaway, 2012). Infants in the experimental group were also found to transfer objects from one hand to the other about 2.5 weeks earlier than the matched controls (2012).

Much like the development of reaching behaviors, the development of exploratory behaviors (e.g., mouthing, fingering, manipulating, etc.) exhibit age-related differences, particularly over the first year of life. These behaviors allow infants to gain an understanding of objects in the world and the properties they exhibit via the use of haptic feedback and mouthing of objects (Ruff, 1984). The trajectory for mouthing behaviors increases during the first few months of life and peaks around 6 months; mouthing then decreases significantly by year two (Lobo et al., 2014; Rochat, 1989). Fingering behaviors are slightly protracted in comparison because of the fine motor control required to hold an object with one hand and scan it with the fingers of the other. At around 4 months of age, infants begin to exhibit fingering behaviors for finer-grained analysis of object properties (Rochat, 1989). At around 5 months of age there is a significant increase in object manipulation and exploratory behaviors bi-manually (Rochat, 1989). Consistent with Lobo et al. (2014) and Rochat (1989), Ruff (1984) found an age-related decrease in the amount of time spent mouthing objects and alternating between mouthing and looking at objects and a corresponding age-related increase in fingering objects across 6-, 9-, and 12-month olds (Ruff, 1984). There were no age-related differences in looking, handling, rotating, transferring or banging objects, suggesting that these manipulative behaviors are consistent across this age range.

Precocious object exploration can be facilitated through the use of "sticky mittens" in which mittens are covered in Velcro which enables infants to explore objects before they had the ability to properly grasp. Infants trained with sticky mittens (3 months of age) exhibited higher exploration percentages and higher mouthing percentages compared to infants without access to sticky mittens (Needham et al., 2002). Thus, if given the opportunity to explore objects at an earlier age, infants have the potential to become more advanced explorers in older ages, which has an array of cascading developmental effects.

Across the early developmental period from birth through three-years-old, many behaviors typical to humans are emerging in the language and motor domains. As development progresses after birth, many motor and linguistic behaviors follow similar trajectories across individuals (Clark, 2005) and across cultures (Fink, 2020). However, an infant's environment, specifically low-income levels (Fink, 2020), have been found to impact these trajectories across time such that it can facilitate or hinder overall development (Berger et al., 2017). Furthermore, precocious infants who obtain gross motor milestones early tend to have better receptive language development as compared to infants who obtain them on-time or late (Libertus & Violi, 2016; Valla et al., 2020). Precocity of behaviors can also be facilitated by earlier exposure to specific body positions (Lobo & Gallaway, 2012) or activities (Needham et al., 2002). However, most of the previous literature is outdated (Konczak et al., 1997; Rochat, 1989; Ruff, 1984), uses a cross-sectional design (Needham et al., 2002; Ruff, 1984), and/or does not contain diverse samples (i.e., participants are mostly Caucasian;Needham et al., 2002; Rochat; 1989). Additionally, most studies have not explored the broad range of development. For example, Rochat (1989) only studied infants until 6 months, Ruff (1984) until 12 months, Lobo and Gallaway (2012) and Konczak (1997) until 15 months, and finally Lobo et al. (2014) until two years of age. Lastly, wider and more diverse ranges in SES would assist in understanding the impacts of SES at the extreme ends of household income. For example, Lobo et al. (2014) only included one family in their sample that was below the poverty line. Thus, the results of this study seek to uncover the impacts of ethnicity and SES on language and motor development throughout a broader range of development and across the first three years of life. Additionally, this study is utilizing data from standardized assessments from which more definitive conclusions can be made.

Infant Language Development

Akin to the motor developmental patterns and phases, early language development milestones are orderly and systematic but not linear (Hsu et al., 2000; Stark et al., 1993). As infants begin to learn new sounds, not all previously learned vocal behaviors disappear when the beginnings of new ones emerge; this process represents a type of ebb-and-flow during language learning that is not linear (Hsu et al., 2000; Stabel et al., 2013; Stark et al., 1993). Prior to the development of speech, early detectable and meaningful vocalizations are called precursors, which are the ingredients necessary for the complete development of speech. Precursors include the production of specific sounds, called protophones, and are directly related to the organized advancement of a maturing linguistic system (Oller et al., 1999). These protophones are considered “primitive sounds” because infants, in general, produce them prior to any full word or syllable expressions (Oller et al., 1999). Thus, a “stage model (Brown, 1973) best fits the course of linguistic development because infants must progress through one stage before making it to the next — each previous stage builds upon the next, representing a type of prerequisite before moving into the next stage/phase of language development (Brown, 1973; Oller et al., 1999).

An infant’s very first sounds/vocalizations are not genuine protophones and when studied must be differentiated from other types of vocal behaviors. Identifying and separating specific infant sounds has been completed in prior work investigating vocal development from birth to 20 weeks of age (Kuhl & Meltzoff, 1996), and from birth to 18 months of age (Stark et al., 1993). Specifically, Stark and colleagues (1993) recorded infants and their caregivers to determine the developmental trajectory of infant vocal development by documenting all infant vocalizations. Their results confirm a period from birth until about 2 months of age consisting of cries, fussing, and vegetative noises associated with early infancy and distress signals (Stark et al., 1993). These sounds are separate from that of “language-like attempts” and are considered reflexive sounds, or reflexive phonation (Kuhl & Meltzoff, 1996). These reflexive sounds emerge, and peak early, and eventually decrease with age, occurring the most in young infants and the least in older children (Stark et al., 1993).

The stage at which this type of vocalization appears coincides with the phonation stage emerging after birth until about 2 months of life (Oller et al., 1999; Stabel et al., 2013). Between 12 and 23 weeks of age "reactive vocalizations" emerge (Stark et al., 1993). These sounds are the product of face-to-face interactions with caregivers, toys, and environmental objects (e.g., vocalizations made when watching a mobile). 'Cooing', according to Kuhl and Meltzoff (1996), is an additional stage from 1 - 4 months in which quasivocalic sounds are produced that represent the beginnings of quasivowel production. Once infants reach about 2 - 3 months of age they begin to phonate while making discernable 'gooing' sounds. This is the early stage of articulation, or the primitive articulation stage (Oller et al., 1999). This stage provides the infant with a bank of single sounds necessary to create syllables, resulting in more complex language. Corresponding to the stage model, this period is considered the expansion stage. In this stage, consonant-like sounds emerge with full vowel-like sounds and combine with phonation to produce "primitive protophone syllables" (Oller et al., 1999). Around 26 - 36 weeks old, infants are beginning to explore their environment and objects, and to utilize their expanding language repertoire. Vocalizing with caregivers develops into vocalizations produced alone when infants' attention is directed towards interesting objects, or activity sound making (Stark et al., 1993). This stage can last up until about 8 months of age complete with clearly vocalized vowel productions, expressive screaming, yelling, 'blowing raspberries', and even whispering (1993).

Intentional communicative acts began to emerge around 8 months and are a part of common vocalizations produced by most infants between 6 - 9 months; they are typically directed towards objects of interest rather than adults (Stark et al., 1993). It is possible that the directed vocalizations are the result of sensorimotor behaviors and experiences directed towards environmental stimuli such as with crawling, or with the mouthing and shaking of objects. Although sounds in this category are intentional, they are not meant to be socially communicative, per say. They may just be the product of infants internalizing their motor actions with their voice, but the cognitive function of this proposed verbal-action coupling has not been elucidated (Stark et al., 1993). These behaviors begin to emerge around 12 - 23 weeks of age, but become most frequent from 26 - 36 weeks, and subsequently decrease with maturity (Stark et al., 1993). In contrast, vocalizations deemed personal, regulatory, interactional, or imaginative do not emerge until around 36 weeks but continue to increase in frequency as a function of age (Stark et al., 1993). The literature above further exemplifies the notion that language development is progressive, but indeed, non-linear.

The last category of vocalizations to emerge begins around 40 weeks of age and are called the imaginative type (Stark et al., 1993). This category represents about 30 percent of total vocalizations from weeks 72 - 88 and is reserved for the oldest toddlers (Stark et al., 1993). Once consistent consonant-vowel (C-V) constructions emerge, infants are considered to be in the marginal babbling phase (Oller et al., 1999; Smith et al., 1989). However, quick transitions between consonant and vowel sounds, like that of native speech, are not achieved in this stage. Thus, it is not until infants begin producing well-formed, rapid, and repeatable strings of C-V transitions that they are considered to be in the canonical stage (Oller et al., 1999; Smith et al., 1989; Kuhl & Meltzoff, 1996). When infants possess the ability to make well-formed consonant-vowel transitions, like those that occur in native speech, they are said to be in this very essential stage of vocal development. It emerges around 10 months and lasts until about 18 months of age, with “word-sounds” such as “mamama” or “bababa” being heard (Smith et al., 1989; Kuhl & Meltzoff, 1996). Between 18 months and 24 months of age, infants’ language begins expanding at an incredibly rapid pace. This is the “meaningful speech” stage, and it is the fifth and final stage according to Kuhl and Meltzoff (1996). However, these authors note that this stage is *not* mentioned in previous literature (Kuhl & Meltzoff, 1996).

The culmination of the aforementioned language development events leads to eventual mixing of babbles and meaningful speech to create longer, more complex utterances (Stabel et al., 2013). Sentence complexity is generally defined in infant language research as the mean length of utterances (MLU) (see Scarborough et al., 1991, for review). Interestingly, these same patterns of vocal development are seen across cultures and geographic regions with almost all milestones reached at 12 months and 76% of them reached at 36 months (Villar et al., 2019). Other authors note that although developmental differences in vocal development are indeed more variant than expected, they are not always tied to the geographic location or overall economic development of a country/region (Fink et al., 2020).

Previous literature has been able to confirm that vocal development is not linear, and in fact, includes regressive patterns also (Hsu et al., 2000). Growth followed by reduction in certain types of sounds demonstrates regression in typical language development not accounted for by earlier studies. For example, when Hsu and colleagues assessed the linguistic trajectories of "speech-quality" and "melody complexity" of vocalizations in infants with respect to language development early in life, they found multiple patterns of growth (Hsu et al., 2000). Specifically, a cubic and quadratic trend was found in complex syllable production, while a separate, quadratic trend was found for simple vocalized sounds (Hsu et al., 2000). The onset of this shift in vocalizations occurs around the 4th month of life and corresponds with Oller's "expansion stage" (Oller, 1980). The importance of Hsu and colleagues' study is that they were able to distinguish the specifics of infant sound productions by separating distress and non-distress signals. This type of detailed, granular, linguistic assessment of infant vocalizations had not been attempted in previous research. Hsu and colleagues' results provide new implications for how milestone attainment research should be expanded and revisited with closer scrutiny.

Taken together with previous research and theories, it is now well understood that language does not develop because of simple accumulations based on previously learned knowledge (Hsu et al., 2000; Smith et al., 1989). A dynamical systems theory (DST) approach seems to best describe the natural yet varied trajectory of language development across the early years of life. The "Mountain of Motor Development" metaphor, proposed by Clark and Metcalf (2002), might best encapsulate the non-linear nature of language and overall speech development throughout the lifespan.

While infants begin to express vocalizations at very early ages, they must also be able to discern environmental noises from communicative language sounds, specifically, the surrounding native language. Similar to other critical periods, there is a critical window for learning to differentiate language input from general environmental stimulus, and for discerning native from non-native language (Kuhl et al., 2005). This is an important ability for infants because phonetic discrimination of native-language at 7-months old can predict language outcomes at 18 months (increased word production) and 24 months (length of utterance and sentence complexity; Kuhl et al., 2005). Furthermore, if infants tend to attune to non-native language characteristics, and/or experience delayed attunement to native language characteristics, then future language deficits will be experienced (Kuhl et al., 2005). This critical phase is concurrent with the primitive articulation stage and may exist to allow for basic phoneme distinction. It is also suggested that infants may have this ability as early as two-months (Hesketh et al., 1997), but it may not be fully developed until about 7-months (Kuhl et al., 2005). Akin to an early developing motor system, early exposure and more practice with the language system affords significant improvements in language capabilities, as well. Therefore, an infant that is more adept at phonetically distinguishing native speech sounds may have more robustly fine-tuned language skills later in life.

In summary, the research above suggests that the preverbal periods of attunement and expression during infancy are critical in the development of receptive and expressive communication. However, most of these studies are over 20 years old (Bloom & Lahey, 1978), lack large representative samples, and employ different types of measures (e.g., observational behavioral coding, parental reports, verified assessments, etc.). Historical data provides a foundation for observational and longitudinal work (Bayley & Davis, 1935) but they do not represent current population characteristics. Furthermore, most studies represent basic statitistical approaches to highly nuanced behavioral, linguistic, and neurologic data across languages, cultures, and socioeconomic statuses. Thus, this paper extends the literature with regard to these domains.

Relationship between Infant Language and Motor Development

Recent literature suggests that motor and language developmental timelines overlap (Eilers et al., 1993), that these domains may be interdependent (e.g., Berger et al., 2017; Heiman et al., 2019; Moore et al., 2019; Valla et al., 2020; Walle & Campos, 2014), and that the relationships between language and motor development are consistent across cultures (He et al., 2015). The first line of evidence suggests that ability to control posture and locomotion during infancy affords object exploration and opportunities for linguistic interactions with caretakers (e.g., Berger et al., 2017; Iverson & Thelen, 1999; Libertus & Violi, 2016; Walle & Campos, 2014; West & Iverson, 2021). For example, Libertus and Violi (2016) found that improvements in sitting (from 3-5 months of age) significantly predicted receptive vocabulary at 10 and 14 months. Additionally, one longitudinal study found that an earlier onset for sitting is associated with a larger vocabulary between 16 to 24 months, while an earlier onset of walking is associated with greater changes in vocabulary during this period (Oudgenoeg-Paz et al., 2015).

Similarly, the *transition* between crawling and walking is also related to language development. For example, a longitudinal study found that although receptive and expressive vocabularies were the same for infants that walked and did not yet walk at 10.5 months, the *change* in receptive vocabulary was greatest between crawling and walking onset (i.e., during the transition in locomotor skills; Walle & Campos, 2014). A similar pattern was observed for the transition from crawling to walking onset for productive vocabulary, but the greatest change in productive vocabulary occurred between 6-8 weeks of walking experience. The authors suggest that the changes in receptive language may be facilitated by rapid exploration of the environment which increases parental attention and opportunities for joint attention that takes place during the transition from crawling to walking (i.e., unstable or precarious locomotion) changes in expressive language may take more time to manifest. Interestingly, in a follow up study, the same authors found that infant movement predicted receptive vocabulary size for both crawling and walking infants, suggesting that active infants may increase the number of interactions with the environment and prompt parental interactions. However, other predictors (e.g., parent input, parent movement, parent proximity) had a differential effect on infants' receptive and productive vocabularies in crawling infants and walking infants. Therefore, it is when the child is mobile that these properties of seem to increase the frequency of interactions with caregivers.

Beyond impacting later gross motor skills, early gross motor development during infancy is also associated with cognitive (Ghassabian et al., 2016) and language functions (Valla et al., 2020) later in development. For example, one large cohort study of children at risk for developmental delays (*n* = 599) found that if parents reported that their infant achieved standing with assistance at 10 months (one SD below the mean of the sample), their child's performance at age 4 years on the adaptive and cognitive domains of the Battelle Developmental Inventory, Second Edition were lower by 5.3 and 5.9 points respectively (Ghassabian et al., 2016). The onsets for sitting without support, crawling on hands and knees, walking with assistance, standing alone, and walking alone were not related to later development of motor, adaptive, cognitive, personal-social, or communication domains (Ghassabian et al., 2016). In contrast, Libertus and Violi (2016), found that the change in sitting performance from 3-5 months (n = 29) was a significant predictor of parent-reported receptive language vocabulary at 10 and 14 months; the change in grasping performance from 3-5 months was not a significant predictor. Thus, sitting with eyes facing forward, not down, offers more opportunities for intentional communication acts to be initiated.

Taken together, these results suggest that changes in locomotor skills afford a social environment that is rich with communicative opportunities and parental engagement to promote different aspects of language development. However, differences in the reported relationship between motor development and development of other domains may be due to the differences in the use of parent report and performance assessments as well as sample characteristics (age of the participants and number of participants).

Impact of Socioeconomic Status

Infancy is a sensitive period of development in which adverse environmental conditions (e.g., high maternal stress, low SES, low maternal/paternal education, and poor nutrition) may alter the trajectories of brain development and subsequent motor/language functions (Noble et al., 2012). Infants and children (five months to 4 years) from poor or near-poor households, examined longitudinally, exhibit significantly lower than average total GM volumes, reduced GM growth trajectories, and regionally-specific blunted growth in frontal and parietal regions of the brain

(Hanson et al., 2013). Individuals (ages 3 - 20 years of age) living in low SES environments display greater decreases in CT and steeper changes earlier in life as compared to their peers living in high-SES conditions who display a more linear thinning (Piccolo et al., 2016). A trajectory that displays this type of linear thinning over a prolonged period of time leads to a thicker cortex, thus increasing processing capacity, overall general cognitive development (e.g., IQ), and learning (Sowell et al., 2007). Thus, if cortical thinning is abbreviated and overall cortex is thinner in lower SES children, then this could be origin for the delays in development due to the impact of low-SES environments.

Deficits in motor behaviors are also observed in infants from low-income backgrounds (e.g., Black et al., 2000, Clearfield et al., 2014, Tacke et al., 2015). Infants aged 6 - 12 months from low SES backgrounds, when compared to those from high SES backgrounds, exhibit less complicated exploratory behaviors of objects and object manipulation (Tacke et al., 2015), and older infants (10 - 12 months) exhibit delayed means-end exploratory behavior, comparable to younger infants of high-SES (i.e., 6 - 8 months, Clearfield et al., 2014). Moreover, longitudinal assessments of fine and gross motor performance (measured with the BSID-II) suggest that deficits in motor behaviors may become more apparent with increasing age; although infants (<12 months) from low-income backgrounds exhibited scores consistent with their age range, toddlers (12 - 36 months) from low-income backgrounds exhibit scores that were lower than average (Black et al., 2000). The authors suggest that although the environment may be sufficient for supporting early motor development (i.e., during infancy), low-income toddlers may not have access to environments that are sufficiently stimulating to support more advanced skills (Black et al., 2000).

Consistent with motor development literature, language development may be differentially affected by SES with age. For example, some aspects of early language development (e.g., babbling) are not affected by exposure to low-SES (Eilers et al., 1993; Oller et al., 1995). Parental

SES was also not associated with a 6-month old's ability to discriminate phonemes (Tsao et al., 2004). SES also does not appear to affect phonetic discrimination in 9-month and 15-month old infants (Melvin et al., 2017). However, later developing language processes (e.g., syntax complexity) appear to differ by SES (Tsao et al., 2004; Vasilyeva et al., 2008). For example, high-SES 2-year-olds produced more syntactically complex sentences (i.e., utterances containing more than one verb phrase) as compared to low-SES 2-year-olds (Vasilyeva et al., 2008). This may be evidence for the adverse effects of low-SES on the brain more directly, which then indirectly influences the specific neural processes related to motor and language development. Beyond expressive and receptive language specifically, the home environment and parent education are key predictors of preacademic skills (e.g., early literacy and math skills) in 2 - 4-year-old children (Merz et al., 2014). These findings are also supported by others who report that the differences in language performance associated with SES may be due to the language environment of the home (Melvin et al., 2017).

To assess the influence of the home environment, researchers (e.g., Melvin et al., 2017) have employed the use of the Infant-Toddler Home Observation for the Measurement of the Environment (IT-HOME). This structural interview/checklist is a measure of quality of home life for children from birth through three years of age. The IT-HOME is a 45-item survey that assesses parental involvement, warmth, and responsiveness; discipline behaviors and routines; physical environment; and types of toys, books, and other available materials in the child's environment (Caldwell & Bradley, 1979). Specifically, when 9-month-olds were tested for phonetic discrimination (via PLS-4), SES was not significantly correlated with scores (Melvin et al., 2017). However, a significant negative correlation was found between phonetic discrimination scores and IT-HOME scores, suggesting infants from higher quality home environments are less able to discriminate between two non-native contrasts in phonemes (Melvin et al., 2017). This is perhaps an indication of a better perceptual attunement to their mother tongue (Melvin et al., 2017).

In summary, SES does indeed share an association with language performance and language discrepancies (Merz et al., 2020). However, replicating results and making robust conclusions across populations and large demographic samples is challenging due to the differences in current means of measuring SES and its indicators with only some authors assessing SES (as an Income-to-Needs ratio) as proxy for SES (Melvin et al., 2017). But, what this proxy actually represents in terms of specific aspects of the home (e.g., stress, access to books, parental talk, etc.) is less understood. Additionally, most previous studies address or assess language and motor behaviors individually, while little is known regarding low-SES background and its effects on brain, motor, and language development when measured concurrently — This study aims to address this knowledge gap.

Chapter 3 – Trajectories of Motor and Language Development from Infancy to Toddlerhood and the Impact of SES

Introduction

The first three years of life represent an important time for rapid development in the motor and language systems. Across cultures, most infants obtain six main motor milestones within the first 12 months of life (Fink et al., 2020; WHO et al., 2006) with only slight deviation/variations to the normally projected growth trajectories among children (Ertem et al., 2018; Largo et al., 1985) through two years of age. Expansion and refinement of the motor domain continues throughout toddlerhood, but the environment/experience has a considerable impact on this domain (Berger et al., 2017; Fink et al., 2020; Hadders-Algra, 2018).

Akin to the motor domain, language development is also explainable by, and typically follows, an orderly, or normative pattern (Eilers et al., 1993; Oller et al., 1999; Stark et al., 1993) that is consistent across cultures and countries, with only minor, non-significant differences reported between genders (Ertem et al., 2018). Environment, caregiver interactions, and motor milestone accomplishment (e.g., crawling to walking) have significant impacts on the changes in linguistic development during the first three years of life (Oudgenoeg-Paz et al., 2015; Iverson & Thelen, 1999; Libertus & Violi, 2016; Walle & Campos, 2014; West & Iverson, 2021). However, this literature is established based on previous literature that is mostly cross-sectional (Fink, 2019; Ertem, 2018), outdated (Who et al., 2006), and/or based on parental reports (Libertus & Violi, 2016). Thus, substantiating the reported claims found in and between motor/language skills during the first three years of life, with respect to their longitudinal nature, utilizing standardized, performance-based assessments is warranted.

Beyond the changes *within* these systems, there is growing evidence of the relationship *between* the development of motor and language systems during this period of time. Indeed, the development of motor skills influences concurrent (He et al., 2015; Walle & Campos, 2014) and future development (Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2012) of language skills during infancy and early childhood. For example, developmental changes in sitting (between 3-5 months of age) predicted receptive vocabulary at 10 and 14 months (Libertus & Violi, 2016). Moreover, the onset of walking coincides with immediate increases in receptive and expressive language (Walle & Campos, 2014). Although receptive and expressive language deceases after 2 weeks of walking experience, there is another increase in these language skills after 4 - 8 weeks of walking experience (Walle & Campos, 2014). Furthermore, when examined cross-sectionally at 12.5 months of age, walkers had larger overall receptive skills (34.38 words understood) and expressive vocabularies (7.3 words produced) as compared to non-walking peers (18.74 and 2.71, respectively; Walle & Campos, 2014). More environmental exploration leads to greater parental transactions, which increases the opportunity for language (Luo & Gao, 2022; Raviv, Kessenich, & Morrison, 2004; Walle & Campos, 2014). Similarly, the age at which independent walking is achieved is correlated with expressive language at 20, 24, 32, and 36 months (Oudgenoeg-Paz et al., 2012). Taken together, these studies suggest that the onset of significant posture/locomotor milestones may be related to current and future language development.

Additional longitudinal studies are needed to determine the extent to which better *performance* of motor skills, rather than simply parental report of the *age at acquisition*, is related to concurrent and future development of expressive and receptive language during infancy and early childhood. This is because a standardized assessment provides more accurate results than a parental report and is a more reliable and repeatable measure to determine the level of ability an infant/child has as compared to his/her peers. To this end, developmental assessments, including the BSID and the PLS, which evaluate infant/child performance of skills based on normative samples, are needed to enable quantitative comparisons of individuals across early development longitudinally (e.g., from age birth to 3 years).

It has already been established that socioeconomics affect the developmental trajectory of motor skills. For example, compared to infants from high-SES households, those from low-SES households tend to display immature object exploration/manipulation behaviors (Tacke et al., 2015) and reduced manual and oral exploration indicative of a divergent developmental trajectory (Clearfield et al., 2014). These SES-related disparities in motor development may become greater with age (Black et al., 2000). Disparities across SES may be due to differences in the home environment that provide opportunities to develop exploratory skills across the first year of life (Clearfield et al., 2014; Tacke et al., 2015). However, additional longitudinal studies, with samples representing the full range of SES, are needed to determine the extent to which SES influences the trajectory of motor development across the first three years of life and the factors that underlie this phenomenon.

With respect to the influence of socioeconomic factors on language skills, although aspects of early language development (e.g., babbling), and early speech perception during the first three years of life do not differ by SES (Eilers et al., 1993; Oller et al., 1995; Vasilyeva et al., 2008), later developing aspects of expressive language (i.e., production of complex sentences) are influenced by SES-related variables, such as parental education (Vasilyeva et al., 2008). As such, Vasilyeva and colleagues (2008) found that parental education was a significant predictor of the usage, quantity, and diversity of complex sentence production from 22 through 42 months of age. Further, caregivers are a possible type of buffer when children come from homes with less educated mothers who exhibit less complicated language output (Vernon-Feagans, Bratsch-Hones & Cox, 2013). Unfortunately, many of the studies examining the effect of SES and related variables included small samples sizes (e.g. n = 20, Eilers et al., 1993; n = 45, Vasilyeva et al., 2008) that did not represent the full range of SES. Therefore, additional longitudinal studies are needed with participants that represent a wider range of demographic characteristics to determine the extent to which SES and related variables (i.e., parental education) affect the developmental trajectory of receptive and expressive language during the first three years of life.

The present study addresses these knowledge gaps above by evaluating the longitudinal trajectory of motor and language skills in a sample of infants representing a broad range of SES while holding parental education constant. Performance on standardized motor and language assessments will be examined with respect to age and sex (Specific Aim 1). After controlling for age and sex, socioeconomic factors will be examined to determine their influence on each domain (Specific Aim 2) as well as the relationship between motor and language domains during the first three years of life (Specific Aim 3). It is hypothesized that there will be a positive relationship between motor skills and language skills with respect to age; it is unclear if sex will influence this relationship. Additionally, it is hypothesized that there will be a positive relationship between motor and language skills after accounting for age and sex. Second, it is hypothesized that SES will be positively associated with motor and language skills, after accounting for age and sex. Third, it is hypothesized that motor development will mediate the relationship between household income on language skills. Overall, the results of this study may be relevant to clinicians and early detection/intervention programs for motor and language skills during the first three years of life.

Methods

Participants

Data from the NIH Study of Normal Brain Development Objective 2 (Evans & Brain Development Cooperative Group, 2006) will be examined from participants' birth to 36 months of age. This age range was selected given the importance of this developmental time frame with respect to motor and language milestones (Ghassabian et al., 2016; Sheldrick et al., 2019; Visser-Bochane et al., 2020; WHO et al., 2006). Details about the participant recruitment and data collection are provided in prior publications (Almli et al., 2007). Briefly, newborns were recruited from on-site maternity wards and from well-baby clinics from Boston (*n* = 46) and St. Louis 2 (*n* = 60). Neonates were required to be between 37 weeks 4 days and 41 weeks 3 days gestational age at birth. Infants provided one to nine repeated measures (Evans & Brain Development Cooperative Group, 2006).

The diversity in the sample was matched to the demographics of children living in the Unites States according to the United States Census Bureau during this time, with respect to gender, family income, and race/ethnicity (Kreider & Elliott, 2009). For the purpose of this study, the family biographical history questionnaire was used to obtain details regarding income, parent education, and race/ethnicity of child/parent. This questionnaire was developed specifically for the Objective-2 component of the NIH Study on Normal Brain Development (Evans & Brain Development Cooperative Group, 2006). At the time of collection, household income was collected from each site as HUD adjusted income of all people in the household normalized to the number of people in the household (adjusted family income). In our sample, we had a reported 16% of participants (*n* = 8) from low SES households (<$35,000), 66% (*n* = 33) from middle SES households ($35,000 - $75,000), and 18% (*n* = 9) from high SES households (>$75,000). See NIH Supplemantary Manual for more detailed information regarding demographics.

The exclusionary criteria from the original study included bilingualism, mothers who smoked or used alcohol, multiple births, fetal distress, born prematurely, seizures, abnormal face, language disordered, certain psychiatric illnesses, standardized values on the Baley Scales of Infant Development, version 2 (BSID-II) and Preschool language Scales assessment, version 3 (PLS-3), <70, and a failed infant neurological exam (Evans et al., 2006). The inclusion criteria for the present analysis were the following: complete data from the motor assessment BSID-II and PLS-3 at least 3 repeated measurements (see details under statistical analysis), and complete demographic data (see Figure 1, below).

Table 1 presents details for the sample that met inclusion including the median, minimum, and maximum for the number of visits, BSID-II motor scale, PLS-3 auditory comprehension (AC), PLS-3 expressive communication (EC), household income, maternal education, paternal education, and age. Out of 116, 50 participants (27 females and 23 males) met inclusion criteria for the current study. All but one participant identified as Not Hispanic. The race distribution was: White (*n* = 45), African American (*n* = 3), and Asian/Pacific Islander (*n* = 2). For each participant, the median household income across repeated measures was computed due ot inconsistent reporting of this measure.

Figure 1 shows the participant flow and exclusion criteria. The original sample had 116 participants, 99 of these participants had complete behavioral data and demographics for the IV/DV of interest. Of the participants with complete data, 50 participants had 3 or more repeated measures, which was necessary to achieve statisitical convergence.

Table 1

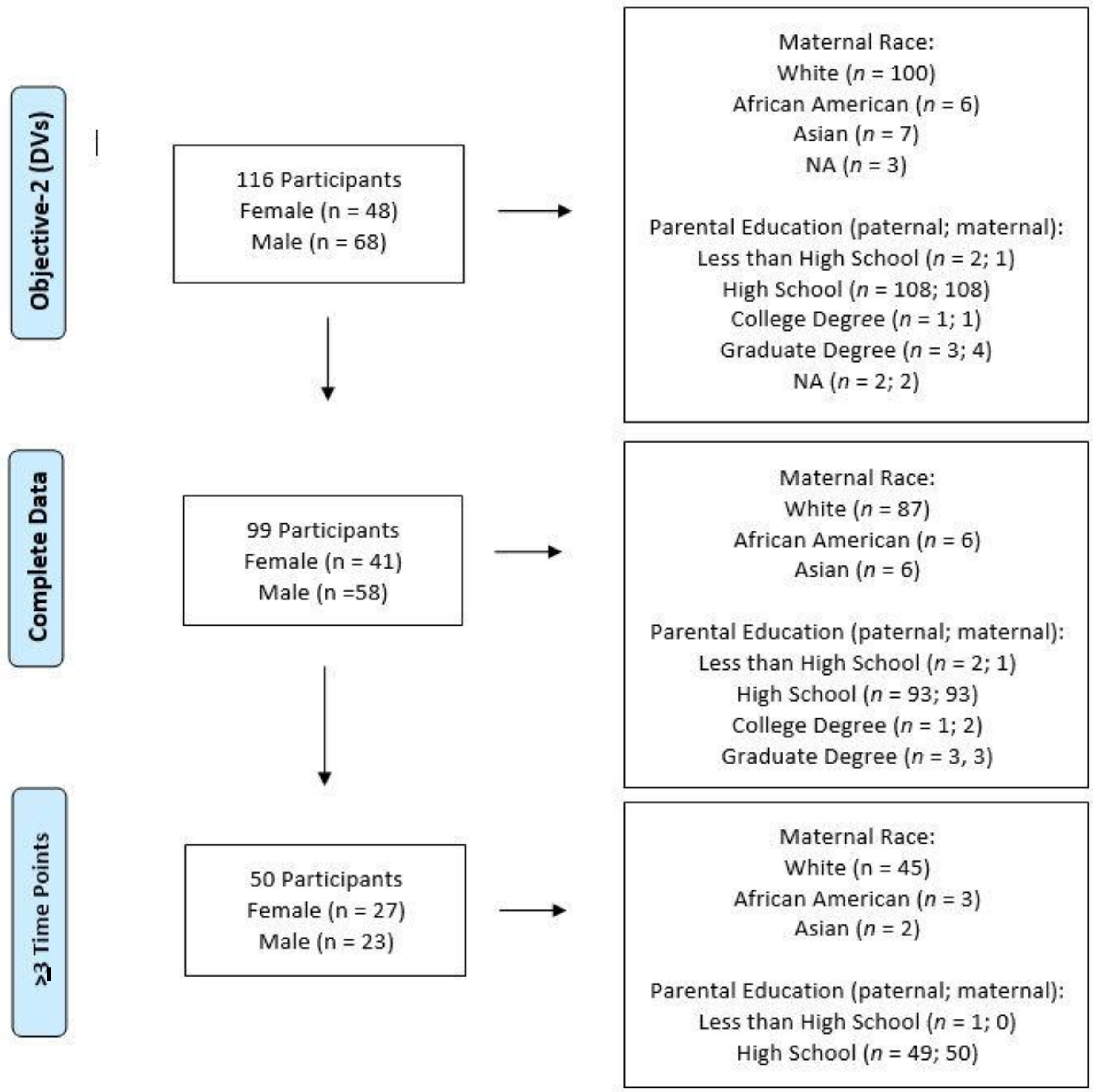
Participant demographics (n= 50).

	# of Visits	BSID Motor	PLS Auditory Comp	PLS Expressive Comm	Household Income	Maternal Education	Paternal Education	Age (Years)
Median	4	66.25	10.5	12	60930	High School	High School*	1.08
Min	3	37	6	6	2101	High School	Less than High School	0.47
Max	9	94	27	29	135401	High School	High School	2.60

**Note: Only 1 participant had paternal education less than High School*

Figure 1

Participant Selection and Exclusion Flowchart



Note. Participant details for each stage of the analysis including demographic details (i.e., number of participants, maternal education, median age, median household income).

Behavioral Measures

The full behavioral test battery from the original study (Evans et al., 2006) took approximately 20 mins for newborns, less than 90 mins for children 1:0 and younger, and < 3 hours for children older than 1:0. Of the assessments in the full behavioral test battery, the two primary outcome measures for the present study are the BSID-II (Bayley, 1993) and the PLS-3 (Zimmerman, 1992). The raw scores were used in this study as the original sample because the analyses included age and sex and key independent variables to create developmental trajectories — The standardized scores would accont for age and sex.

Bayley Scales of Infant Development, Second Edition (BSID-II)

The BSID-II is a reliable and validated standardized product assessment with three separate scales: Motor, Mental, and the Behavioral Rating Scale. The BSID-II was standardized based on a stratified sample to reflect the 1988 U.S Census with a total of 1,700 subjects aged 1 - 42 months (Nellis & Gridley, 1994). Reliability coefficients (Cronbach's alpha) for the motor scales was .84 and .88 for the mental scales (Almli et al., 2007). The assessment evaluates developmental abilities in the areas of motor (motor scale; fine and gross motor), language and cognition (mental scale), and social development (behavioral rating scale; Nellis & Gridley, 1994). BSID-II scores are reported as standardized scores with a mean of 100 (SD = 15) and the manual includes a qualitative interpretation of the final reported scores (Nellis & Gridley, 1994). The manual recommends general cutoffs, or classifications, for understanding overall performance listed as: accelerated performance (115 and up), within normal limits (85 - 114), mildly delayed (70 - 84), and significantly delayed (69 and below) (Black & Matula, 2000; Nellis & Gridley, 1994).

The motor scale evaluates bodily control, including fine and gross motor skill abilities, and is comprised of 111 items. Specifically, in younger infants (16 days - 4 months 15 days), the motor scale assesses whether the hands are fisted, if the infant can track an object/person (horizontally &

vertically), bring hands to mouth, and can follow a rolling ball, thrusts legs/arms, has established head control and crawling movements (Black & Matula, 2000). In slightly older infants (4 months 16 days - 8 months 30 days), items test infant hand/wrist control and manipulation, reaching, and head/trunk control (Black & Matula, 2000). Around 12 months of age (11 months 0 days - 13 months 15 days), items assess walking, the ability to bring objects to midline, and grasping/lifting objects (Black & Matula, 2000). In children 2 years of age and older (22 months 16 days - 38 months 30 days), perceptual-motor integration is also evaluated by examining performance on tasks such as imitating/copying block designs and shapes, holding a pencil, and cutting paper. The child will begin the testing on the item that corresponds to the starting point based his/her age in months and days (Black & Matula, 2000). Items are scored as passing (1) or not passing the task (0). If a child is able to self-correct after an initial failed attempt, credit shall still be given for that item (Black & Matula, 2000). A child must receive passing scores (1) on the first three items at their age-specific start; otherwise, the administrator must start from a younger age and test all items before moving forward (Black & Matula, 2000). The test is discontinued when the child does not pass (0) five items consecutively (Black & Matula, 2000). The total raw score for each scale is obtained, which can then be converted to a percentile score based on the corresponding age group in the standardized sample.

Preschool Language Scale – 3 (PLS-3)

The PLS-3; (Zimmerman, 1992) is a standardized product assessment of language development used to identify language delay and/or language disorders in infants and children, birth through 6 years, 11 months of age. It must be administered and scored by a qualified user such as a speech-language pathologist, educational diagnosticians, early childhood specialists, psychologist, and any other professional that has training and experience in diagnostic assessments

(Walker, 1994). The PLS-3 was standardized based on a stratified sample of 1,200 children, with an equal distribution of males to females, to reflect the 1988 U.S Census (Walker, 1994). It is a reliable and validated assessment that separates receptive and expressive communication into two scales: the Auditory Comprehension Scale (AC), and the Expressive Communication (EC) Scale. Standard scores for both subscales and the Total Language score (sum of the subscales) (*M* = 100, *SD* = 15) are provided, in addition to confidence bands (set at 68%, 80%, & 90%), percentile ranks, and age equivalents (Zimmerman, 1992). Test-retest reliability coefficients on the AC range from .47 - .88, EC range from .68 - .91, and the Total Language Scale range from .74 - .94 (Almli et al., 2007b). The accompanying manual was developed to reduce cultural of gender biases through the use of illustrations with female and male children of different ethnic backgrounds and involve scenes/activities without specifically stereotyped activities depicted (Walker, 1994). Additionally, the PLS-3 has been deemed an appropriate measure for low-SES, African-American children specifically (Hodges, 2018).

The assessment includes 10 items: 6 - 9 inch square piece of cellophane, one teddy bear about 6 - 12 inches large, and 3 plastic spoons. The AC subscale assesses comprehension of the following: 1. basic vocabulary; 2. gestures; 3. quantitative, qualitative, spatial, and time/sequence concepts; 4. morphological and syntactical structures; 5. integration of language skills in tasks such as inferencing and categorizing objects; and, 6. phonological awareness (Zimmerman, 1992). For infants, the AC scale is designed to assess how much language a child understands and specifically evaluates important precursors to language development such as appropriate object play and attention to speakers (Zimmerman & Castilleja, 2005). For example, test items for an infant 12-months of age include appropriate play with objects, identification of familiar objects, following simple directions, producing consonant sounds variety, engaging in turn-taking activities, following simple directions, having a vocabulary of at least one word, and babbling of two syllables together (2005). At the ages of 2 and 3, children interact/play with bright-colored toys and objects (Zimmerman, 1992). For example, items for that test a 30 - 35-month-old include using a variety of nouns, verbs, and modifiers during spontaneous speech/utterances, and simple descriptive concepts such as "big" (Zimmerman & Castilleja, 2005).

The EC subscale assesses vocal development and social expressive communication. It assesses a child's ability to produce speech sounds, use gestures, name objects, communicate wants/needs, describe pictures and events, define words, categorize, complete analogies, rhyme and segment words, and finally, speak in grammatically accurate sentences (Zimmerman & Castilleja, 2005; Zimmerman, 1992). For a child 12-17 months, the PLS assesses if the child can produce two syllables together, has at least one word in their vocabulary, and can produce a variety of consonant sounds (Zimmerman, 1992). Additionally, between 2 and 3 years of age, the PLS further assesses expressive language such as whether the child can name objects in photos, use words more than gestures, asks questions, uses plurals, can combine 3-4 words spontaneously, can answer "what" and "where" questions, and uses quantity words, to name a few (1992).

In both subscales, some of the youngest ages can be scored as "passed" even if the behavior is elicited by the examiner, seen during spontaneous interactions during the test (with caregiver or examiner), or if only reported by the caregiver with examples not noted during the assessment (Zimmerman & Castillleja, 2005). Typically, a child receives a pass criteria score of "1" and a fail criteria score of "0"; all the "1" scores are totaled to yield the subscale total for both EC and AC (Zimmerman & Castillleja, 2005). The final raw scores are converted normalized referenced scores, which includes a standard score, age equivalents, and percentile ranks. These scores are provided in 3-month intervals from birth through 11 months, and in 6-month intervals from 1 year through 6 years 11 months of age (Zimmerman & Castillleja, 2005).

Using Cronbach's coefficient alpha, the reliability of the PLS-3 is greater than .80 for the subtests; internal consistencies for ages above 1 year is .90 for the Total Test (Amli et al., 2007b; Zimmerman, 1994). However, it should be noted that the scales for both subtests fail to meet this criteria below 12 months of age: AC coefficients range from .47 - .74, and EC coefficients range from .68 - .75 (Zimmerman, 1992). The PLS-3 is not an assessment for determining severe language deficiency/disorder in children who are suspected of having any type of handicapping conditions. However, the PLS-3 allows clinicians to identify children who are possibly delayed when compared to their age-matched peers, and the assessment can show the specific area/s of deficit (e.g., vocal behaviors, social communication, morphology, semantics, syntax, preliteracy skills, integrative language skills (Zimmerman & Castilleja, 2005). Caregivers are able to see and understand the language tasks his/her child has failed during the test, compared to emerging, or mastered skills the child demonstrated (2005). The PLS-3 is considered an effective diagnostic tool for examining environmental influences on language (e.g., effects of low-SES) (2005). Scores from the PLS can be tracked using repeated testing and is therefore an effective assessment for longitudinal research (2005).

Statistical Approach

All statistical analyses were performed using R-Studio (version 1.4.1106) and R (version 4.1.2). Prior to the statistical analysis, all data were screened using Excel (version 2018) to remove errors/inconsistencies in parent reported data or data entry. Linear mixed-effects regressions (LMER) models using the "lmer", "lmer4", "nlme", "lmertest", and "AICmodavg" packages were used to evaluate the following models for each behavioral measure. The linear mixed-effects modeling approach accounts for associations amongst repeated measures for independent and dependent variables. Linear mixed-effects models also enable robust estimations given differences in the number of repeated measures and time between repeated measures across subjects. Maximum-Likelihood Estimation (ML estimation) was used to estimate the difference in model parameters. Age was modeled as a random intercept and random slope incrementally, and as a fixed effect (linear, quadratic, and cubic terms) in subsequent models. Sex was added as a fixed effect after modeling the age coefficients. Interactions between the age terms and sex were also modelled. Model selection for the developmental trajectories was based on the best fitting combination of terms with age and sex based on statistical comparison of the fit statistics (Akaike Information Criterion, Bayesian Information Criteria, and log-likelihood estimate). To determine the best fit model, each random and fixed effect was added iteratively and subsequent models were compared based on significant improvement in the model fit (Akaike Information Criterion, Bayesian Information Criteria, and log-likelihood estimate) using analysis of variance. For all analyses, $p < .05$ was used as a threshold to determine best fit parameters and best fit model.

Specific Aim 1: To examine performance on standardized motor (BSID-II) and language assessments (PLS-3 AC and PLS-3 EC) with respect to age and sex. The following statistical model was used:

Equation 1: $Yij = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + U0ij$

where:

Y_{ij} observed BSID-II Motor Scale Scores, PLS-AC, or PLS-EC for participant i at time j

β_0 *is the intercept term,* β_1-β_n are regression coefficients

X_1-X_n are age and sex fixed effects (age was modeled using linear, quadratic, and cubic terms)

$U0_{ij}$ are the random effects (i.e., individual adjustments) for each participant i across j measured timepoints (between 3 to 9 repeated measures) for the fixed intercept and the age terms.

H1a - There will be a positive relationship between BSID-II Motor Scale Score and age. There would be a difference in this age-related trajectory by sex.

H1b - There will be a positive relationship between PLS-3 AC (auditory comprehension) and age. There would be a difference in this age-related trajectory by sex.

H1c - There will be a positive relationship between PLS-3 EC (expressive communication) and age. There would be a difference in this age-related trajectory by sex.

Specific Aim 2: Examine influence of household income on performance on the BSID-II Motor, PLS-3 AC, and PLS-3 EC, after controlling for age and sex. The following statistical model was used:

Equation 2: $Yij = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \beta_{n+1}$Household Income + U0ij

where:

Y_{ij} observed BSID-II Motor Scale Scores, PLS-AC, or PLS-EC for participant i at time j

β_0 *is the intercept term,* β_1-β_n are regression coefficients

X_1-X_n are age and sex fixed effects (age was modeled using linear, quadratic, and cubic terms)

$U0_{ij}$ are the random effects (i.e., individual adjustments) for each participant i across j measured timepoints (between 3 to 9 repeated measures) for the fixed intercept and the age terms.

H2a - Household income (reported in thousands of dollars) will be positively associated with BSID-II Motor Scale scores, after controlling for age and sex.

H2b - Household income will positively associated with PLS-3 AC Scale scores, after controlling for age and sex.

H2c - Household income will positively associated with PLS-3 AC Scale scores, after controlling for age and sex.

Specific Aim 3: To determine if BSID-II Motor Scale Scores mediate the relationship between household income and PLS-3 AC or PLS-3 EC Scale Scores.

H3: BSID-II Motor Scale scores will mediate the relation between household income and PLS-AC and PLS-3 EC, after accounting for age and sex.

The following series of linear mixed-effects regressions were used. First, the BSID-II Motor Scale Scores were evaluated with respect to age, sex, and household income (Path A). Second, PLS-3 AC and EC were evaluated with respect to age, sex, and BSID-II Motor Scale scores (Path B). Third, PLS-3 AC and EC were evaluated with respect to age, sex, and household income (Path C). Last, PLS-3 AC and EC were evaluated with respect to age, sex, household income, and BSID-II Motor Scale score (Path C'). The following statistical model will be used for Path C':

Equation 3: Yij = $\beta_0 + \beta_1$Age + β_2Gender + β_3BSID-3 Motor + β_4Household Income + U0ij,

where:

Yij = PLS-3 AC and PLS-3 EC for participant i at time point j

β_0 is the intercept term, β_1-β_4 are regression coefficients, and U0ij is the random intercept for each participant i across j measured timepoints (between 3 to 9 repeated measures).

Full mediation occurs when the regression coefficient for median household income changes from being a statistically significant predictor of PLS-3 AC or PLS-3 EC (Path C) and then decreases to no longer reaching the apriori statistical threshold ($p < .05$) when BSID-II Motor Scale Score is included in the model (Path C'). Partial mediation is defined as when the regression coefficient for household income changes from being a statistically significant predictor of PLS-3 AC or PLS-3 EC (Path C) to a less statistically significant predictor when BSID-II Motor Scale Score is included in the model (Path C').

A sensitivity analysis was conducted for each hypothesis to determine the effect size of key predictor variables needed to achieve 80% power (see Appendix C). This value was compared to the actual effect size (regression coefficient) for the key predictor variable for each hypothesis.

Results

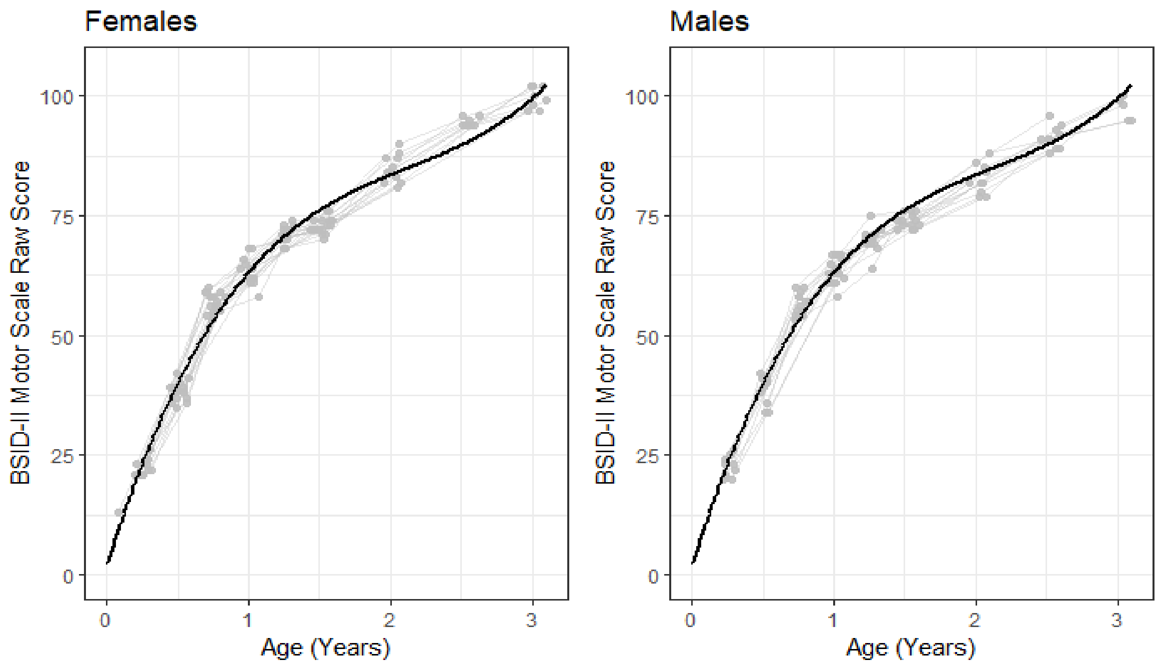
Specific Aim 1: Age and sex trajectories for motor and language development

BSID-II Motor Raw Score

To address Hypothesis 1a, Age and Sex were added as fixed effects to determine the best fit model for the BSID-II Motor Scores. Figure 2 presents the BSID-II Motor Scores (raw scores) as a function of age (in years) for each participant. Each participant's data are represented by small circles connected with a grey line connecting repeated measures. The estimated developmental trajectory is depicted in a solid thick line by the following equation: Predicted BSID-II Motor Scale Score = 1.942 + 93.54 * Age - 38.64 * Age^2 + 6.09 * Age^3. The final model for the BSID Motor raw scores included a random intercept for each subject. Age was modeled as linear ($F(1,196) = 1104.13$, $p < .001$), squared ($F(1,192) = 353.91$, $p < .001$), and cubic terms ($F(1,192) = 201.93$, $p < .001$). There was no significant main effect of Sex or interactions between Sex and the Age terms ($p > 0.05$ for all); these terms were not included in the final model.

Figure 2

BSID-II Raw Motor Scores for Females and Males as a Function of Age in Years

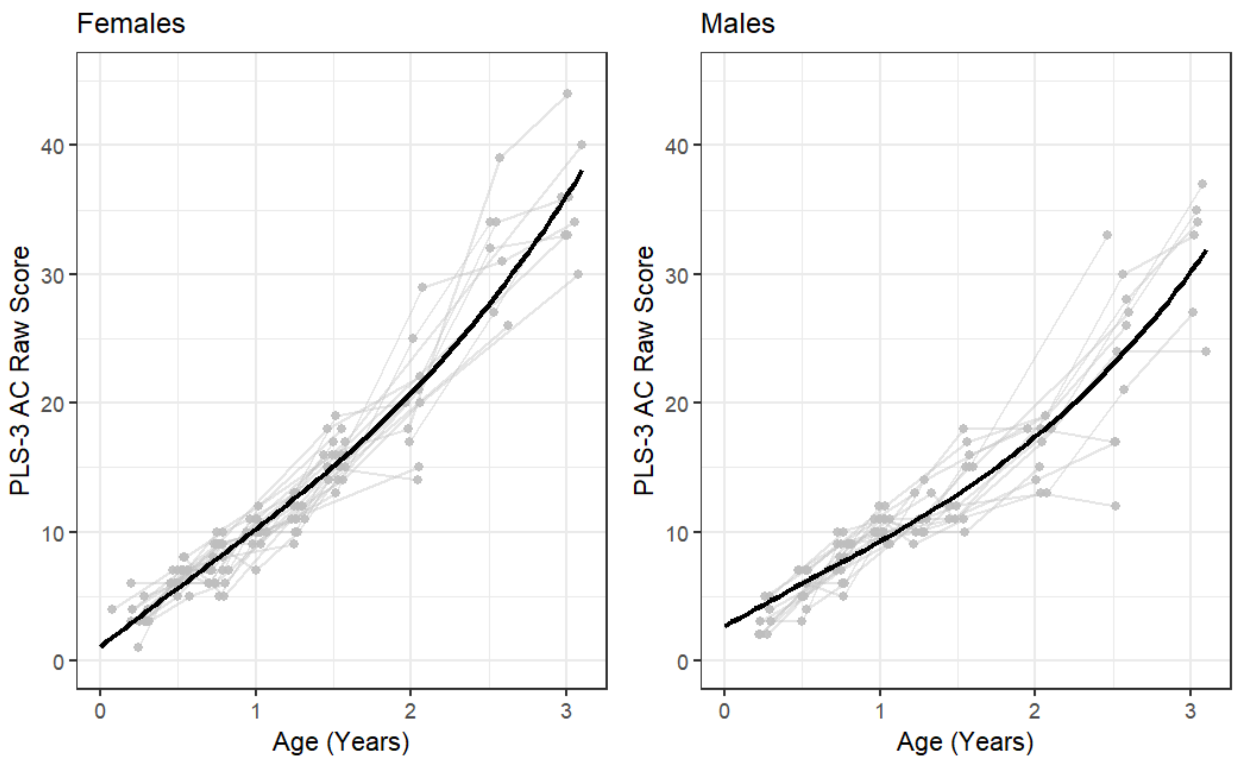


PLS-3 – Auditory Comprehension (AC) Scale

To address Hypothesis 1b, Age and Sex were added to determine the best fit model for the PLS-AC Scale Scores. Figure 2 presents the PLS-3 AC as a function of age (in years) for each participant. Each participants' data are represented by small circles connected with a grey line connecting repeated measures. The estimated developmental trajectories are depicted in a solid thick line by the following equations: Predicted PLS-3 AC Score (Females) = 1.09 + 9.48 * Age – 0.90 * Age^2 + 0.55 * Age^3. Predicted PLS-3 AC Score (Males) = 2.67 + 9.48 * Age – 0.90 * Age^2 + 0.55 * Age^3 – 2.50 * Age. The final model for the PLS-3 AC included a random intercept for each subject. Age was modeled as linear ($F(1,195) = 13.08$, $p < .001$), squared ($F(1,192) = 0.29$, $p = 0.588$), and cubic terms ($F(1,192) = 2.49$, $p = 0.116$). There was a main effect of Sex ($F(1,155) = 4.69$ $p < .05$), and an interaction between Sex and linear Age term ($F(1,217) = 28.61$, $p < .001$).

Figure 3

PLS-3 Auditory Comprehension Scale (AC) as a Function of Age in Years.



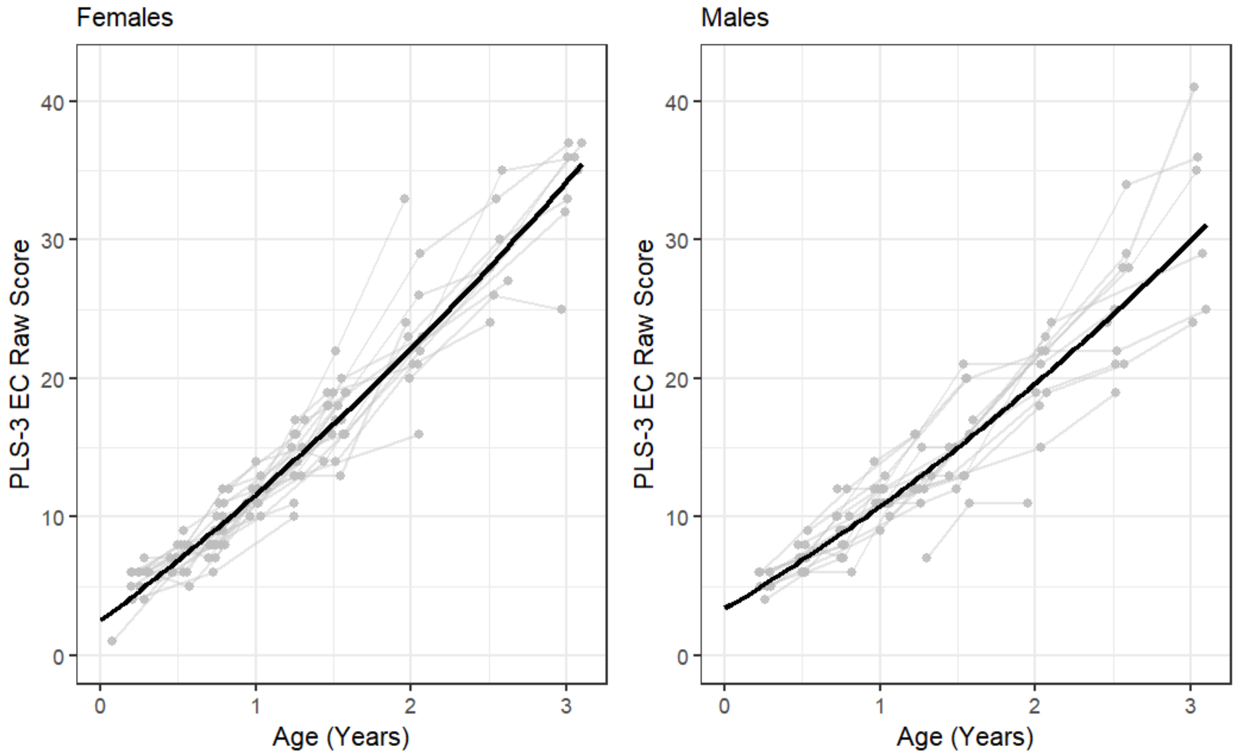
PLS-3 – Expressive Communication (EC) Scale

To address Hypothesis 1c, Age and Sex were added as fixed effects to determine the best fit model for the PLS-EC Scale Scores. Figure 4 presents the PLS-3 Expressive Communication as a function of age in years. Each participants'data are represented by small circles connected with a grey line connecting repeated measures. The estimated developmental trajectories are depicted in a solid thick line by the following equation: Predicted PLS-3 Expressive Communication Score (Females) = 2.53 + 8.35 * Age + 0.74 * Age^2 and Predicted PLS-3 Expressive Communication Score (Males) = 3.39 + 8.35 * Age + 0.74 * Age^2 – 1.69*Age. The final model for the PLS-3 Expressive Communication included a random intercept for each subject. Age was modeled as linear ($F(1,205) = 90.49$, $p < .001$) and squared terms ($F(1,196) =$

9.71, $p < 0.01$). There was no significant main effect of Sex ($F(1,129) = 1.35$ $p > .05$), but there was a significant interaction between Sex and linear Age term ($F(1,218) = 15.28$, $p < .001$) suggesting males start slightly higher than girls at birth but then achieve a lower final level at age 3.

Figure 4

Raw Expressive Communication Scores for Females and Males as a Function of Age in Years



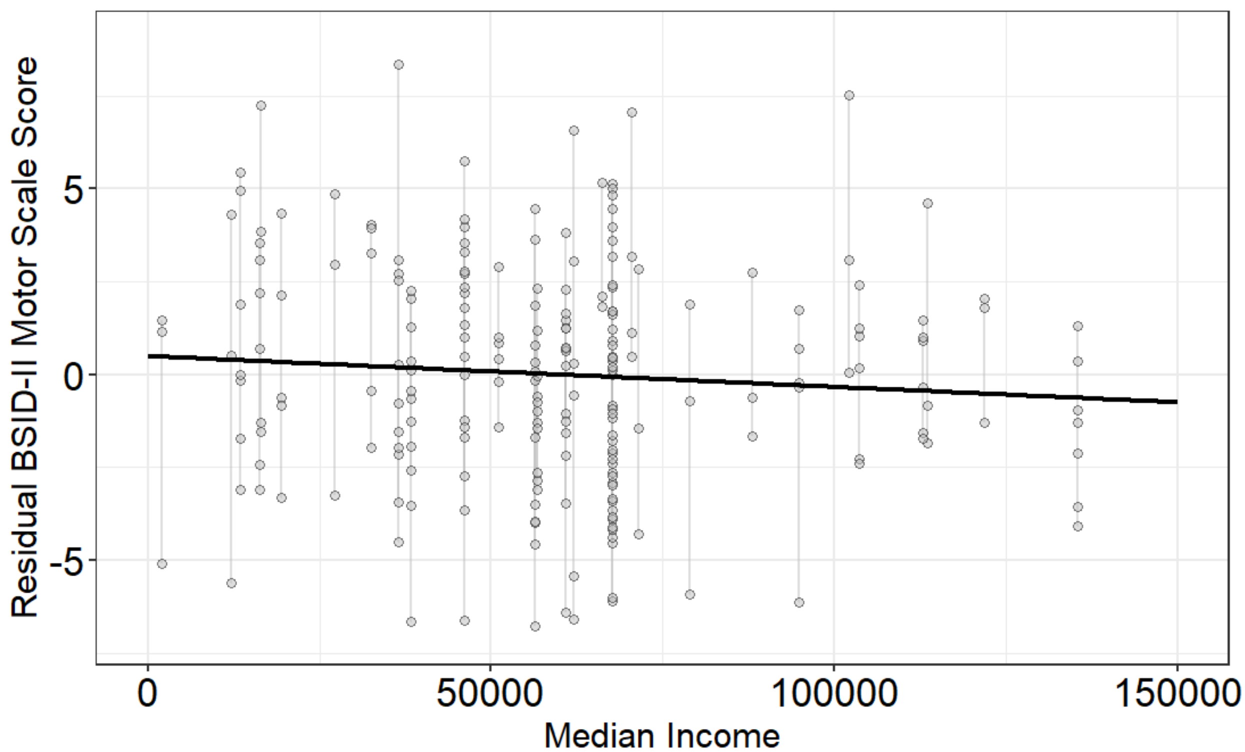
Specific Aim 2: Relationship between Income and Motor and Language Development

To address Hypothesis 2a, Median Household Income was added as a fixed effect to the best fit model for BSID-II Motor, PLS-3 AC, and PLS-3 EC, after accounting for age and sex. Figures 5, 6, and 7 depict the residual BSID-II Motor, PLS-3 AC, and EC Scale Scores, respectively, as a function of Median Household Income after accounting for the best fit age and sex trajectories.

For BSID-II Motor, Age was modeled as linear ($F(1, 194) = 1087.77$, $p < .001$), squared ($F(1, 191) = 348.94$, $p < .001$), and cubic terms ($F(1, 190) = 199.38$, $p < .001$). There were no significant main effect or interaction with Sex, therefore, Sex was removed from the model. There was no significant effect of Median Household Income for Motor Scale Scores ($F(1, 39) = 2.34$, $p = .134$).

Figure 5

Residual BSID-II Motor Scale Scores as a Function of Median Household Income After Controlling for Age and Sex

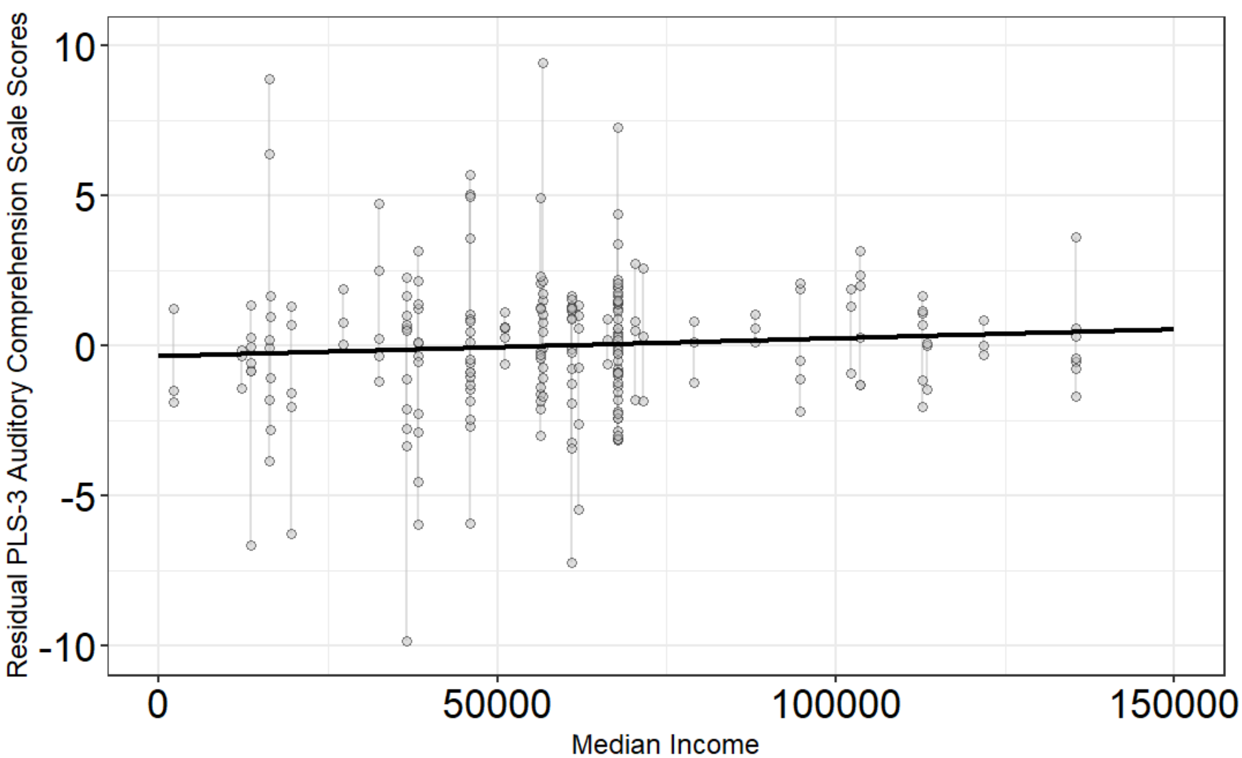


Note. The estimated residual BSID-II Motor Scale Scores are depicted in a solid thick line by the following equation: Predicted Residual BSID-II Motor Scale Scores = .49 – 8.30e-6 * Median Income. Each participant's data are depicted by small circles connected with a gray line across repeated measures.

For PLS-AC, Age was modeled as linear ($F(1, 195) = 13.33$, $p < .001$), squared ($F(1, 192) = .31$, $p = .581$), and cubic terms ($F(1, 192) = 2.50$ $p = .116$). There was a main effect of Sex ($F(1, 154) = 5.33$, $p < .05$), and a significant interaction between Age and Sex $F(1, 216) = 30.30$, $p < .001$ suggesting males start slightly higher than girls at birth but then achieve a lower final level at age 3. There was no significant effect of Median Household Income for PLS-AC Scale Scores ($F(1, 46) = 1.91$, $p = .174$).

Figure 6

Residual PLS-3 AC Scale Scores as a Function of Median Household Income After Controlling for Age and Sex



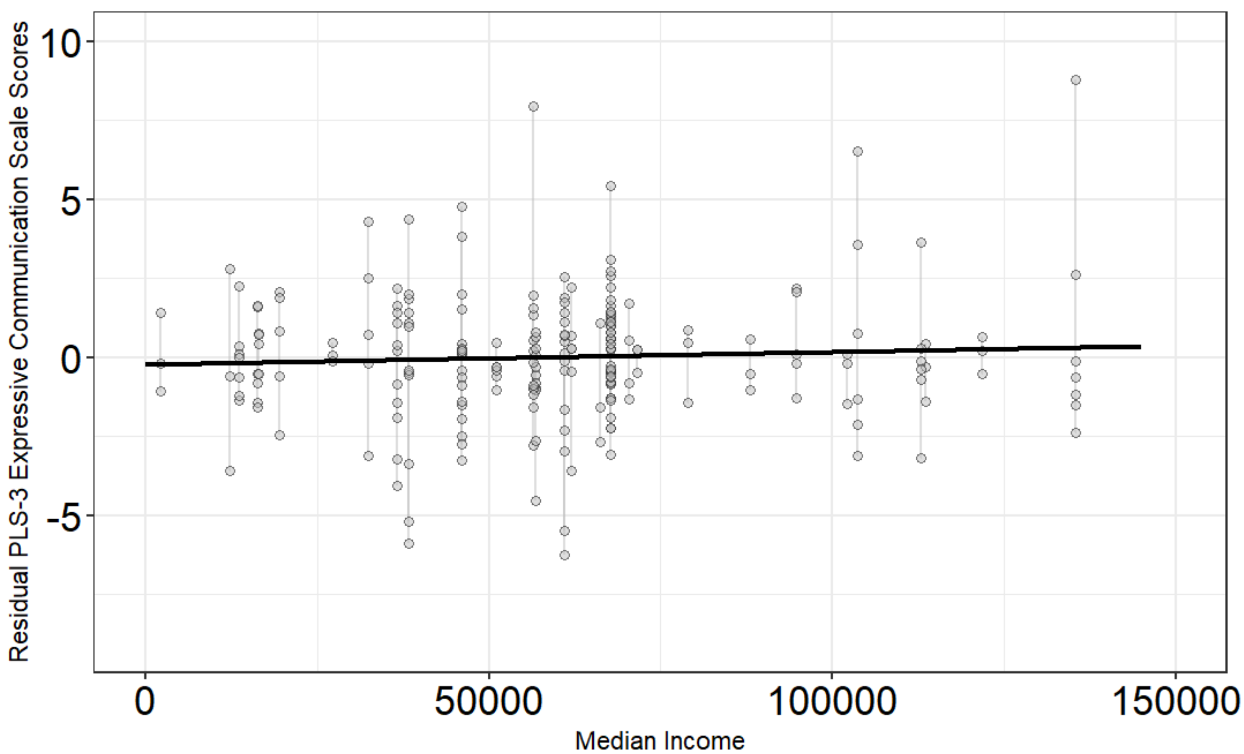
Note. The estimated residual PLS-3 AC Scale Scores are depicted in a solid thick line by the following equation: Predicted residual PLS-3 AC Scale Scores = -.36 + 5.98e-06 * Median Income.

Each participant's data are depicted by small circles connected with a gray line across repeated measures.

For PLS-EC, Age was modeled as linear ($F(1, 210) = 23.17$, $p < .001$) and squared terms ($F(1, 196) = 17.27$, $p < .001$). There was a marginal main effect of Sex ($F(1, 122) = 2.85$, $p = .094$), and a significant interaction between Age and Sex ($F(1, 216) = 28.84$, $p < .001$). There was a significant main effect of Median Household Income for PLS-EC Scale Scores ($F(1, 119) = 6.68$, $p < .05$) and a significant interaction between Median Household Income and the linear Age term ($F(1, 211) = 28.98$, $p < .001$).

Figure 7

Residual PLS-3 EC Scale Scores as a Function of Median Household Income After Controlling for Age and Sex



Note. The estimated residual PLS-3 EC Scale Scores are depicted in a solid thick line by the following equation: Predicted residual PLS-3 EC Scale Scores = -0.24 + 3.97e-06*Median Income. Each participant's data are depicted by small circles connected with a gray line across repeated measures.

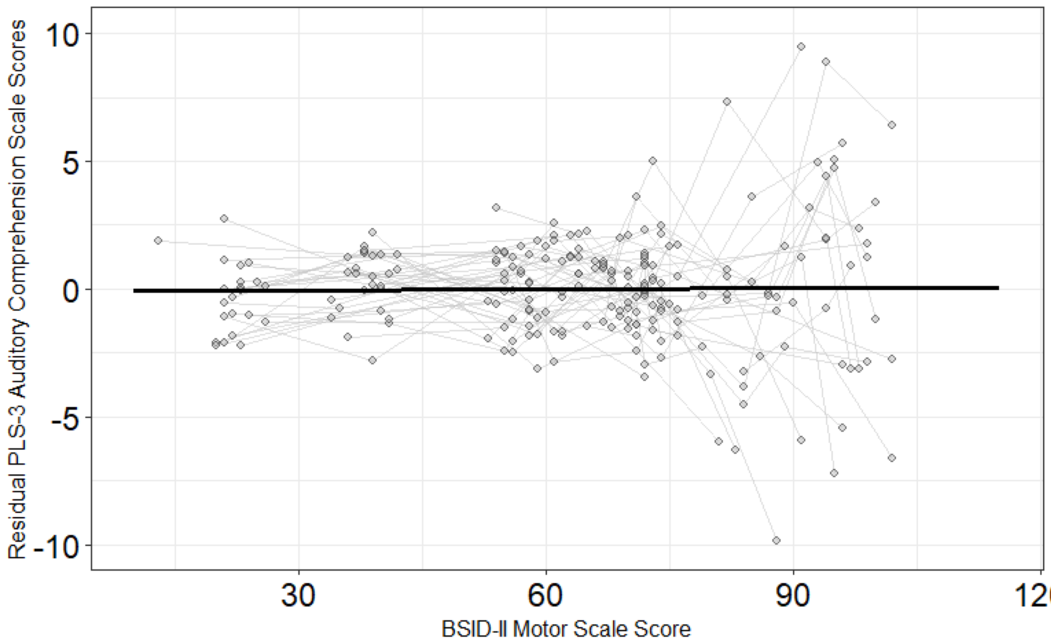
Specific Aim 3: Does BSID-II Motor Scale Score Mediate the Relationship Between Household Income and PLS-3 Auditory Comprehension and PLS-3 Expressive Communication?

To address Specific Aim 3, BSID-II Motor Scale Scores were added as a fixed effect to the best fit model for PLS-3 AC and PLS-3 EC Scale Scores (direct pathway; Path B), after accounting for age and sex. Figures 8 and 9 depict the residual BSID-II Motor Scale Scores as a function of PLS-3 AC and PLS-3 EC Scale Scores, respectively.

For PLS-3 AC, Age was modeled as linear ($F(1, 218) = 0.11$, $p = .736$), squared ($F(1, 216) = .41$, $p = .522$), and cubic terms ($F(1, 211) = .08$, $p = .779$). There was a significant main effect of Sex ($F(1, 155) = 4.57$, $p < .05$), and a significant interaction between Age and Sex ($F(1, 216) = 27.34$, $p < .001$). There was no significant effect of BSID-II Motor Scores ($F(1, 218) = 1.54$, $p > .05$).

Figure 8

Residual PLS-AC Scale Scores as a Function of BSID-II Motor Scale Scores After Controlling for Age and Sex

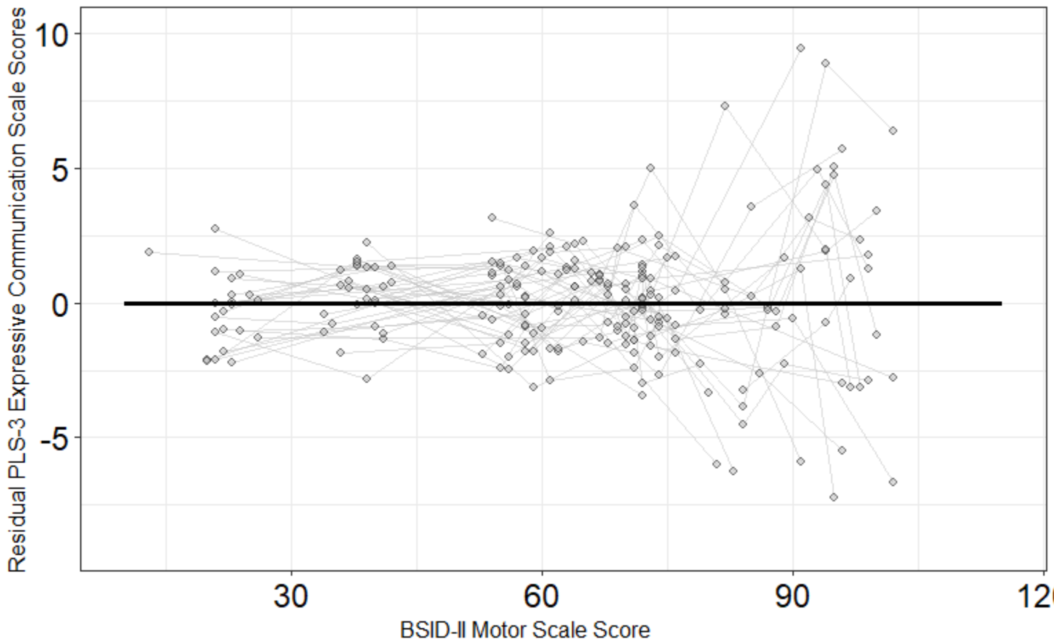


Note. The estimated residual PLS-3 AC Scale Scores are depicted in a solid thick line by the following equation: Predicted residual PLS-3 AC Scale Scores = -0.09 + 1.34e-3 * BSID-II Motor Scale Scores. Each participant's data are depicted by small circles connected with a gray line across repeated measures.

For PLS-3 EC, Age was modeled as linear ($F(1, 201) = 11.53$, $p < .01$), squared ($F(1, 200) = 3.23$, $p > .05$). There was no significant main effect of Sex ($F(1, 130) = 1.33$, $p > .05$), but there was a significant interaction between Sex and the linear Age term ($F(1, 218) = 14.95$, $p < .001$). There was no significant effect of BSID-II Motor Scores ($F(1, 192) = 0.005$, $p > .05$).

Figure 9

Residual PLS-EC Scale Scores as a Function of BSID-II Motor Scale Scores After Controlling for Age and Sex

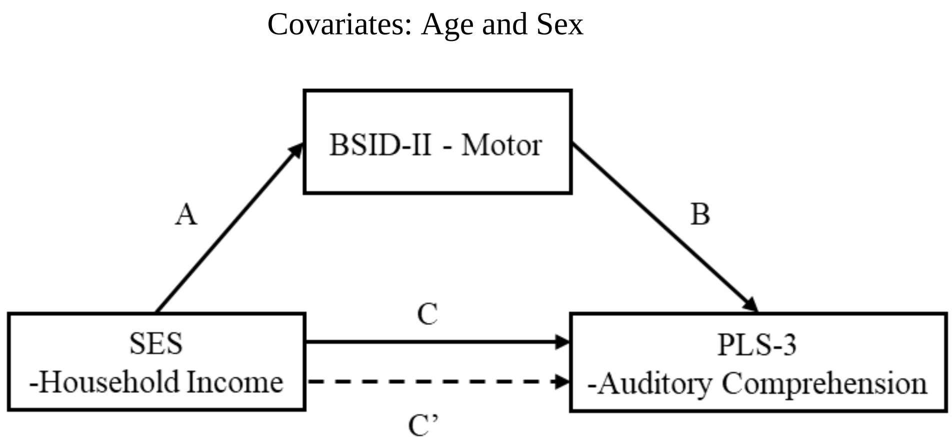


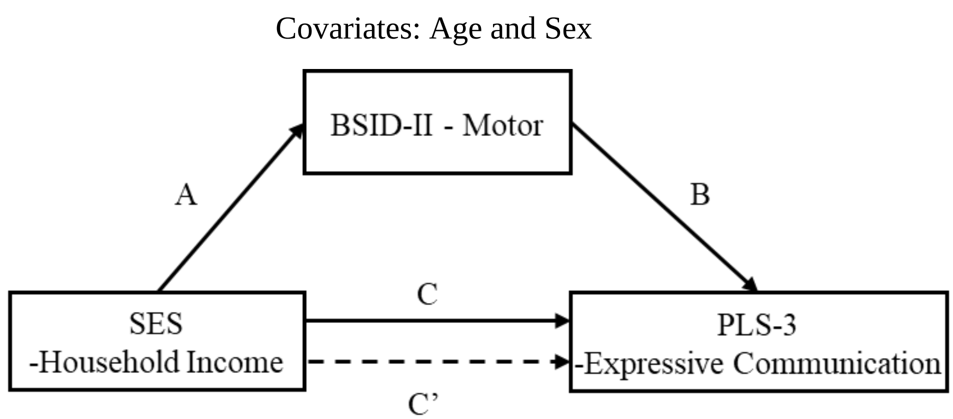
Note. The estimated residual PLS-3 EC Scale Scores are depicted in a solid thick line by the following equation: Predicted residual PLS-3 EC Scale Scores = -1.05e-13 + 1.54e-15*BSID-II Motor Scale Scores. Each participant's data are depicted by small circles connected with a gray line across repeated measures.

Figure 10 depicts the Mediation Analysis. PLS-3 AC and PLS-EC, the following additional paths were examined: Path A: Median Household Income predicting BSID-II Motor Scale Score (see Hypothesis 2a); Path C: Median Household Income predicting PLS-3 AC or EC (see Hypotheses 2b and 2c); and, Path C': Median Household Income predicting PLS-2 AC or EC after accounting for BSID-II Motor Scale Score. Table 2 provides the path coefficients for the mediation analyses.

Figure 10

Mediation Model





Note: ‘A’ = direct effects of Median Household Income on BSID-II Motor Scales Scores. ‘B’ = direct effects of BSID-II Motor Scale Scores on PLS-3 AC or PLS-3 EC Scale Scores. ‘C’ = direct effect of Median Household Income on PLS-3 AC or PLS-3 EC Scale Scores. ‘C`’ mediating effects of BSID-II Scale Scores on Median Household Income on PLS-3 AC and EC Scale Scores.

Table 2

Mediation Models for SES, BSID-II Motor Scale Scores, and PLS-AC/EC Scores

Path	Estimate (*β*)	Standard Error	*p*
Median Household Income – BSID-II Motor Scale Score – PLS-3 AC			
Path A (Median Household Income – BSID-II Motor Scale Score)_	-1.31e-5	8.56e-6	.134
Path B (BSID-II Motor Scale Score – PLS-3 AC)	0.07	0.05	.215
Path C (Median Household Income - PLS-3 AC)	1.04e-5	7.53e-6	.174
Path C' (Median Household Income - BSID-II Motor - PLS-3 AC)	1.12e-5	7.52e-6	.144
Median Household Income – BSID-II Motor Scale Score – PLS-3 EC			
Path A (Median Household Income – BSID-II Motor Scale Score)_	-1.31e-5	8.56e-6	.134
Path B (BSID-II Motor Scale Score – PLS-3 EC)	2.48e-3	3.53e-2	.944
Path C (Median Household Income - PLS-3 EC)	**-3.11e-5**	**1.20e-5**	**.011**
Path C' (Median Household Income - BSID-II Motor - PLS-3 EC)	**-3.11e-5**	**1.21e-5**	**.011**

SES (Median Household Income) to PLS-3 AC Scale Scores via BSID-II Motor Scale Scores

After accounting for age and sex, none of the paths were significant, suggesting that there was no evidence of a relationship between those variables.

SES (Median Household Income) to PLS-3 EC Scale Scores via BSID-II Motor Scale Scores

After accounting for age and sex, Path C (*ß* = -3.11e-05, SE = 1.20e-05, $p = .011$) and Path C' were significant (*ß* = -3.11e-05, SE = 1.21e-05, $p = .011$). Thus, the relationship between Median Household Income and PLS-3 EC was not mediated by BSID-II Motor Scale Scores.

Discussion

This study examined developmental trajectories of motor and language performance in infants from birth to 3 years of age. Consistent with previous literature, non-linear developmental trajectories of motor and language performance were observed. In addition, the effects of household income, as a proxy for socioeconomic status, on motor and language development were also investigated. Although there was no influence of household income on motor performance or auditory comprehension, household income was a significant predictor of expressive communication. Lastly, the relationship between motor and language performance was examined. Surprisingly, there were no relationship observed between motor performance and auditory comprehension or expressive communication. As such, motor performance did not influence the relationship between household income and auditory comprehension or expressive communication. Although these results are somewhat contrary to our hypotheses, this study adds to the extant literature by demonstrating that for this racially and educationally homogeneous sample, household income influences the development of expressive language skills.

Developmental Trajectories

When modelling the developmental trajectories for each domain, the most parsimonious models for motor and language scores included linear and polynomial age terms. These results broadly support previous studies suggesting nonlinear development of these domains during infancy (Berger et al., 2017; Fink et al., 2020; Hsu et al., 2000). For motor development, the present results suggest that the greatest period of change is from birth to approximately 1 year of age with an additional spurt from 2.5 to 3 years. These results are consistent with historic data of infant motor milestones (e.g., sitting up, rolling, crawling, standing, walking, etc.) observed during the first year of life (Bayley, 1935; Gesell & Thompson, 1934). It is possible that the later spurt may be due to an increase in the repertoire of complex motor skills requiring multi-segment coordination and increased precision in fundamental motor skills (e.g., running, jumping, throwing, kicking). Indeed, these results are consistent with a previous study that observed a relationship between parent-reported infant motor milestones during the first year of life and subsequent balance and ball skills at 3.5 years (Viholainen et al., 2006). In modelling the age-related trajectory of motor skills, sex was not a significant predictor of motor performance during this period of development. This finding aligns with previous literature in which no sex differences were observed in infant motor milestones (Ertem et al., 2018; Fink et al., 2020; Largo et al., 1985; WHO et al., 2006). However, others have reported sex differences in BSID-III Motor Scale at age 36 months (Krogh & Vaever, 2019), with girls achieving higher values than boys. Interestingly, follow-up analyses of the motor subtests (gross and fine motor subtests) revealed that the sex differences in overall motor skills may be driven by sex differences in fine motor skills; no such differences were observed for gross motor skills (Krogh & Vaever, 2019).

The developmental trajectories for language (auditory comprehension and expressive communication) followed slightly different patterns that were influenced by sex. Specifically, the trajectory for auditory comprehension included linear, squared, and cubic age terms indicating a nonlinear development from birth to age 3 years. The intercept and linear age terms differed by sex such that males had a higher intercept but smaller linear age-related slope, leading to a lower final level of auditory comprehension at age 3 years. These results are in line with Krogh & Vaever

(2019), who observed sex differences in the BSID-III Language Scales standard scores at 10, 13, 24, and 36 months with girls achieving higher values than boys. Sex differences in the BSID-III Receptive Communication Subtest standard scores were also observed at 13, 24, and 36 months (Krogh & Vaever, 2019). Although Fenson et al. (1994) reported girls performed slightly above boys in phrases and words understood from 8-16 months, the sex effect only accounted for just over 1% of variance. With that said, those authors reported a similar nonlinear and increasing patterns of receptive communication from 8-16 months consistent with the present findings. It is important to note that in the present and previous studies, raw or standardized subtest scores were evaluated. An analysis of at the item or construct level would be useful to determine which specific language of skills differ by sex. This information is crucial to determine areas in which enrichment may reduce sex differences in this period of early development.

The trajectory for expressive communication included linear and squared age terms. Similar to the auditory comprehension model, the intercept and linear age terms differed by sex such that males had a higher starting value, but a smaller linear age-related slope, leading to lower final values for expressive communication at age 3 years. These results build upon previous literature examining aspects of expressive communication in infants from 1 month to 6 months of age (Hsu et al., 2000), birth to 18 months (Stark et al., 1993), and 8-16 months of age (Fenson et al., 1994). These previous studies observed age-related increases and subsequent decreases in simple vocalizations (Hsu et al., 2000) and reactive sounds (Stark et al., 1993) in the first year of life. Stark and colleagues (1993) also reported exponential increases in complex and social vocalizations after age 1 year. Fenson and colleagues (1994) also observed significant and non-linear increases in words produced after age 1 year. Together, the present results recapitulate the previously observed protracted development of expressive communication, relative to receptive communication. With regard to sex differences, although Krogh and Vaever (2019) observed sex differences in the Language Scales of the BSID-III at 10, 13, 24, and 36 months, these overall sex differences were likely driven by differences in *receptive communication subtest* at 13, 24, and 36 months, with girls achieving higher scores than boys. No such sex differences were observed for the *expressive language subtest*. Fenson et al. (1994) reported higher word production for girls than boys from 8-16 months as well as word production, grammatical abilities, word combinations, maximum sentence length, and sentence complexity at 16-30 months. However, similar to the receptive communication outcomes described above, the sex effect only accounted for just over 1-2% of variance. Taken together, the present results provide new evidence of a sex difference in the pattern of receptive and expressive language acquisiton during the first three years of life.

Impact of Income on Motor and Language Development

The present study adds to the developmental literature in that parental education was held constant by virtue of the demographics of the present sample (i.e., all but one parent had a high school education). As a result, the present study is able to parse the effects of household income from confounding SES-related variables (i.e., parental education) on motor and language domains. Moreover, the present study reduces the likelihood for confounding SES and race given that the majority of the present sample was Caucasian. Although racial homogeneity may limit the generalizability of the results, the results may accurately and uniquely capture the relationship between household income, motor development, and language development for Caucasian infants/toddlers. The present study did not observe an effect of household income on motor development from birth to 3 years of age. These results are inconsistent with previous studies. For example, Tacke and colleagues (2015) reported lower early exploratory and object manipulation skills in 6-12-month-old infants classified as low SES compared those from high SES (Tacke et al., 2015). With this said, low SES in that study was determined by parent report of reliance on state food or shelter, or qualifications for Early Head Start. High SES was based on maternal education of "some college" or above. In the present study, while all but one parent had a high school education, the median household income was over $60,000. Therefore, differences between Tacke and colleagues (2015) and the present study may be due to differences in motor tasks evaluated (fine motor vs. all motor) or SES stratification. Another study found lower performance on the BSID-II (all domains) for low-SES toddlers compared to low-SES infants recruited from a low-income, urban community (Black et al., 2000). Although the level of parent education in that study is similar to the present sample, other demographics differ and may contribute to lack of congruence regarding the effects of SES. Specifically, the sample in Black and colleagues (2000) was 80% African American (20% Caucasian), the majority of the infant and toddlers were from single parent households (98% and 89%, respectively), and the majority were on some form of public assistance (i.e., medical assistance, AFDC, or WIC). In contrast, the present study was 90% Caucasian, all participants came from two-parent households, and as mentioned above, the median household income was much higher. Collectively, these results suggest that motor skills may only differ for infants and toddlers from the lowest levels of SES and that many other environmental/community factors may contribute to lower scores for those children (e.g., single-parent households, need for public assistance, low-resource communities).

With respect to the language measures, the effect of household income on receptive communication (auditory comprehension) did not reach conventional statistical significance after accounting for the developmental trajectory, but was in the expected direction. One previous study also did not find an effect of SES on the performance on a sound discrimination task at 6 months of age or speech discrimination at 13 months of age (Tsao et al., 2004). With this said, that study had a very homogeneous sample with high maternal/paternal education and work status. In contrast, studies of toddlers have reported significant effects of SES on receptive language skills, but that environmental factors such as home stimulation and parent engagement may underlie the effect of SES. For example, Luo and Gao (2022) examined whether maternal language interactions contribute to SES-disparities in receptive language skills in 3-year-olds. They found maternal use of referential questioning was positively related to receptive language skills, but that the strength of the relationship differed by income; there was a significant relationship for children from low- and middle-SES (maternal education or income-to-needs ratio), but not those from high-SES. Similarly, Raviv and colleagues (2004) examined the factors that contributed to relationships between SES, as measured by maternal education and income-to-needs ratio, and verbal comprehension in 3-year-olds. Although there were significant associations between verbal comprehension and maternal education or income-to-needs ratio, these associations were partially mediated by cognitive stimulation in the home environment and maternal sensitivity. These studies suggest that SES may not affect early receptive communication skills, but SES does influence later developed skills via differences in home environment and parental-child interactions.

Household income was significantly related to expressive communication after accounting for the developmental trajectory and was in the expected direction. Similar to the findings on receptive communication, early expressive language during the first year of life (e.g., babbling) was previously shown unrelated to SES (Eilers et al., 1993; Oller et al., 1995). Although the present results suggest that SES contributes across expressive language across infancy, it is likely that the magnitude of these effects increase with age. Indeed, similar to receptive communication, later development of expressive communication has been found to be influenced by SES and related factors. In toddlers, SES was previously reported to be positively related to vocabulary production (Fenson et al., 1994). Luo and Gao (2022) reported a positive relationship between maternal education, but not income-to-needs ratio, and expressive vocabulary at age 3 years. Further, Raviv et al. (2004) found that both maternal education and income-to-needs ratio were associated with expressive language skills at age 3. Moreover, these authors found that cognitive stimulation at home and maternal sensitivity mediated the relationship between the SES factors and expressive language. These results suggest that the relationship between SES-related factors and expressive language skills may be nuanced and influenced by home environment and parental factors.

Relationships Among Motor and Language Domains

Contrary to our hypotheses there was no relationship between motor development and language development after accounting for the developmental trajectory from birth to 3 years. Previous studies have found that the onset of specific motor milestones (e.g., sitting or walking) has been shown to be related with *concurrent* development of receptive (Walle & Campos, 2014; West & Iverson, 2017) and expressive language (Walle & Campos, 2014). Further, previous studies have found that the onset of specific motor milestones are related to the *future* development of receptive (Libertus & Violi, 2016) and expressive language (Oudgenoeg-Paz et al., 2012). There are several possible reasons why the present findings do not support previous studies. First, it is possible that the statistical relationships between motor and language development observed previously are due to underlying age-related changes affecting the two systems rather than a directional relationship between motor and language development. By accounting for age (and sex) differences, the present study may be removing shared variance between the motor and language domains that is due to general developmental changes. Second, the use of standardized assessments may obscure the impact of specific motor milestones on language development. Third, the present analytic approach only examines *concurrent* relationships. A different analytic approach (e.g., time-lagged correlations) may yield insights to directional relationships (e.g., motor predicting language outcomes).

Contrary to our hypotheses, the mediation analysis did not yield meaningful results regarding the potential impact of motor development on the relationship between household income and language development. The sample characteristics - small sample size and lack of variability – may have contributed to these null findings.

Limitations and Future Directions

The original data was collected from 2001 – 2007 as part of the NIH Study of Normal Brain Development and aimed to reflect the US demographics at the time. Although the full sample included slightly more diversity in terms of race and parental education, the exclusion criteria for the analytic approach (i.e., 3+ time points and ages birth – 3 years) resulted in a small sample (n = 50) that lacked variability in race and parental education. The results of the present study have limited generalizability to non-Caucasian or highly educated populations. Future studies are needed with racially and educationally diverse samples to parse unique effects of SES-related variables (e.g., income and parental education) and race. The study is also limited in generalizability due to the use of older version of standardized assessments. The current BSID-IV assessment, which has five subsections and splits motor development into fine and gross motor skills and language development into receptive and expressive communication, should be used. The language subtests of the BSID-IV were based on the PLS. Similarly, the current version of the PLS is the PLS-5 Again, changes across these versions in terms of content and standardization would affect the degree to which the present results are appliable to studies using newer versions of these assessments.

These limitations notwithstanding, this study still provided corroborating evidence regarding age-related trajectories in overall motor and language development from birth through 3 years. It also provided corroborating evidence regarding the positive impact of household income on expressive language for Caucasian infants and toddlers. As mentioned above, future studies are needed with larger, more diverse samples (in terms of race/ethnicity and parental education) to confirm the results from the present study and ensure generalizability of these results. More research focused on the lower end of the SES spectrum is needed to confirm these results outside our narrow ethnic sample. Although results from this study are applicable to Caucasian children from mid- to high-SES household, future studies should aim to include a more balanced sample of the full SES spectrum by equal sampling across all SES levels. This will ensure the inferences made in the exant literature are independent of what our results identify.

In addition, future studies are needed to determine how environmental and parental factors contribute to the relationships between SES, motor development, and language development. Evidence suggests that when infants are exposed to less maternal language, positive child-caregiver interactions can act as a buffer (Vernon-Feagans et al., 2013). However, prior research suggests that even within low-SES groups there are caregivers who provide a rich-linguistic environment Schwab & Lew-Williams, 2016). Therefore, environmental and parenting characteristics would be more appropriate factors that influencemotor or language outcomes. Indeed, identifying modifiable targets within and outside of the home that predict these important infant outcomes is a necessary first step to creating interventions that impact the trajectory of motor and language development and clarify the SES-gap previously observed across all domains.

Chapter 4 - General Discussion

Previous studies examining the relationship between SES and motor or language development have included small samples, cross-sectional study designs, often relied on parental report of developmental milestones, and employed different methods for evaluating SES. In this study, we critically examined the longitudinal trajectory of each domain, as well as their relationships from birth to 3 years of age. Our sample consisted of 50 participants who contributed at least three longitudinal data points. The mixed-longitudinal sampling enabled us to address knowledge gaps using a robust longitudinal analysis with standardized assessments and median household family income as a quantitative measure of SES. Although some of the hypotheses were not supported – namely the lack of influence of household income on motor or receptive language and the lack of relationship between motor and language development – the study provided confirmatory evidence regarding the developmental trajectory of motor and language skills and the influence of household income on expressive language skills.

Building upon this study, an important next step would be to address a wider income range, including a higher proportion of participants from the lower end of SES spectrum. Indeed, the studies that reported a significant negative impact of low-SES (parent education or income) on behavioral outcomes exclusively included samples from low-SES communities (Black et al., 2000; Campos et al., 2012; Wallace et al., 1998). With that said, additional information regarding environmental factors or parenting factors would be needed to parse direct and indirect effects of SES on motor and language outcomes. Furthermore, many studies relied on parental reports of milestone onset from birth to 3 years of age. Future studies should include parental reports of infant milestones in addition to the standardized performance assessments to determine if differences between the present study and previous studies are due to the assessments employed or sample characteristics. The current version of the BSID (BSID-IV) includes subtests of motor development (fine and gross motor development) as well as language development (expressive and receptive communication). It would be useful to perform analyses by subtest to determine how each domain is impacted by SES or other factors (e.g., sex, age).

The present study did not find a relationship between motor and language development, after accounting for the developmental trajectories of each domain. However, the BSID-II assesses performance on many motor skills, rather than the development of particular motor milestones. In contrast, the previous studies that observed a relationship between motor and language development focused on how the onset of a specific motor milestones impacted concurrent or later development of language skills (Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2015). It is unclear if the onset of key motor skills (e.g., sitting, crawling, walking) or other neurodevelopmental changes underlie changes in both motor and language development previously observed. If there is a true relationship between specific motor milestones and language outcomes, then future interventions that promote the development of those key motor milestones could be implemented to reduce the impact of low-SES on behavior.

SES is often confounded with other factors, such as race, ethnicity, environmental factors, and parenting factors. The inclusion of race and ethnicity in statistical analyses may help disentangle cultural differences in parenting practices and family dynamics from SES measures. However, specific questionnaires asking about cultural practices in parenting and family characteristics are also needed in future studies.

The present sample was limited in terms of race (mostly Caucasian) and parental education (mostly high school graduates). Therefore, the present results are limited in generalizability to Caucasian infants and toddlers, from mid-high SES households, of parents who have a high school education. Although we replicated some findings regarding the impact of household income on language development, we were unable to assess the impact of parental education and race/ethnicity on these domains. Thoughtful data collection and stratification of a sample is still necessary to disentangle SES variables (e.g., parental education, income, and parental occupation) from race/ethnicity and cultural/environmental characteristics. Indeed, environmental enrichment – the present of material supports and nurturing parental practices – have been shown to affect behavioral outcomes, but the timing, magnitude, and domain differ in the literature (Christakis et al., 2009; Hoff, 2003; Hoff & Tian, 2005; Wallace et al., 1998). Additional studies are needed to separate the influence of environmental support or parental education on behavioral domains from SES-related variables.

This project has been an intensely rich experience. I had the opportunity to investigate a significant scientific question and acquire a breadth of knowledge that will prove very useful in my future experiences as a developmentalist. I gained methodological skills in terms of data quality assurance, data management, and longitudinal data analysis. Indeed, I learned how to successfully conduct linear-mixed effects analysis in R and R-Studio, including testing assumptions and conducting sensitivity analyses. In addition, I became more familiar with the performance assessments (BSID and PLS) and was able to examine them more critically with respect to findings from previous studies. I also became accutely aware of the difficulty operationally defining SES and related variables and how different SES-related variables influence behavioral outcomes. I hope to leverage these skills in my future research, investigating motor and language development in low-SES environments. Lastly, this project has ignited my interest in infant development and has contributed to my passion for the scientific pursuit of knowledge.

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Appendix A

Auburn University Human Research Protection Program

EXEMPTION REVIEW APPLICATION

For information or help completing this form, contact: **THE OFFICE OF RESEARCH COMPLIANCE,**
Location: 115 Ramsay Hall **Phone:** 334-844-5966 **Email:** IRBAdmin@auburn.edu

Submit completed application and supporting material as one attachment to IRBsubmit@auburn.edu.

1. PROJECT IDENTIFICATION **Today's Date** June 10, 2020

a. Project Title Relationships between motor, cognitive, and language development in infants and young children

b. Principal Investigator Melissa Pangelinan Degree(s) Ph.D.
Rank/Title Assistant Professor Department/School Kinesiology
Phone Number 334-744-4142 AU Email mgp0020@auburn.edu

Faculty Principal Investigator (required if PI is a student) ____
Title ____ Department/School ____
Phone Number ____ AU Email ____

Dept Head Mary Rudisill Department/School Kinesiology
Phone Number 334-844-1458 AU Email rudisme@auburn.edu

c. Project Personnel (other PI) – Identify all individuals who will be involved with the conduct of the research and include their role on the project. Role may include design, recruitment, consent process, data collection, data analysis, and reporting. Attach a table if needed for additional personnel.

Personnel Name Julia Sassi Degree (s) M.Ed.
Rank/Title Graduate Student Department/School Kinesiology
Role Data analysis and reporting
AU affiliated? ☒ YES ☐ NO If no, name of home institution ____
Plan for IRB approval for non-AU affiliated personnel? ____

Personnel Name Davis Dyke Degree (s) M.Ed.
Rank/Title Graduate student Department/School Kinesiology
Role Data analysis and reporting
AU affiliated? ☒ YES ☐ NO If no, name of home institution ____
Plan for IRB approval for non-AU affiliated personnel? ____

Personnel Name ____ Degree (s) ____
Rank/Title ____ Department/School ____
Role ____
AU affiliated? ☐ YES ☐ NO If no, name of home institution ____
Plan for IRB approval for non-AU affiliated personnel? ____

d. Training – Have all Key Personnel completed CITI human subjects training (including elective modules related to this research) within the last 3 years? YES ☒ NO ☐

The Auburn University Institutional Review Board has approved this Document for use from
06/21/2020 to ---------
Protocol # 20-277 EX 2006

AU Exemption Form Version 05.19.2020 Version Date (date document created): ____ page __ of __

e. Funding source – Is this project funded bythe investigator(s)? ☐ YES ☒ NO

Is this project funded by AU? ☐ YES ☒ NO If YES, identify source ____________

Is this project funded by an external sponsor? ☐ YES ☒ No If YES, provide the name of the sponsor, type of sponsor (governmental, non-profit, corporate, other), and an identification number for theaward.

Name____________ Type____________ Grant #____________

f. List other IRBs associated with this research and submit a copy of their approval and/orprotocol.

____

2. Mark the category or categories below that describe the proposedresearch:

☐ 1. Research conducted in established or commonly accepted educational settings, involving normal educational practices. The research is not likely to adversely impact students' opportunity to learn or assessment of educators providing instruction. 104(d)(1)

☐ 2. Research only includes interactions involving educational tests, surveys, interviews, public observation if at least ONE of the following criteria. (The research includes data collection only; may include visual or auditory recording; may NOT include intervention and only includes interactions). **Mark the applicable sub-category below (i, ii, or iii).** 104(d)(2)

☐ (i) Recorded information cannot readily identify the participant (directlyorindirectly/linked); **OR**

- surveys and interviews: no children;
- educational tests or observation of public behavior: can only include childrenwhen investigators do not participate in activities beingobserved.

☐ (ii) Any disclosures of responses outside would not reasonably place participant at risk; **OR**

☐ (iii) Information is recorded with identifiers or code linked to identifiers and IRB conducts limited review; no children. **Requires limited review by the IRB.***

☐ 3. Research involving Benign Behavioral Interventions (BBI)** through verbal, written responses (including data entry or audiovisual recording) from adult subjects who prospectively agree and ONE of the following criteria is met. (This research does not include children and does not include medical interventions. Research cannot have deception unless the participant prospectively agrees that they will be unaware of or misled regarding the nature and purpose of the research)
Mark the applicable sub-category below (A, B, or C). 104(d)(3)(i)

☐ **(A)** Recorded information cannot readily identify the subject (directly or indirectly/linked); **OR**

☐ **(B)** Any disclosure of responses outside of the research would not reasonably placesubject at risk; **OR**

☐ **(C)** Information is recorded with identifiers and cannot have deception unless participant prospectively agrees. **Requires limited review by the IRB.***

☒ 4. Secondary research for which consent is not required: use of identifiable information or identifiable bio-specimen that have been or will be collected for some other 'primary' or 'initial' activity, if one of the following criteria is met. Allows retrospective and prospective secondary use. **Mark the applicable sub-category below (I, ii, iii, or iv).** 104(d)(4)

☒ (i) Biospecimens or information are publically available;

☒ (ii) Information recorded so subject cannot readily be identified, directlyorindirectly/linked; investigator does not contact subjects and will not re-identify thesubjects;OR

☐ (iii) Collection and analysis involving investigators use of identifiable health information when use is regulated by HIPAA "health care operations" or "research or "public health activities and purposes" (does not include biospecimens (only PHI and requires federal guidance on how to apply); OR

☐ (iv) Research information collected by or on behalf of federal government usinggovernment generated or collected information obtained for non-researchactivities.

☐ 5. Research and demonstration projects which are supported by a federal agency/department AND designed to study and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs;(iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs. (must be posted on a federal web site). 104(d)(5) (must be posted on a federal web site)

☐ 6. Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture. The research does not involve prisoners as participants. 104(d)(6)

New exemption categories 7 and 8: Both categories 7 and 8 require Broad Consent. (Broad consent is a new type of informed consent provided under the Revised Common Rule pertaining to storage, maintenance, and secondary research with identifiable private information or identifiable biospecimens. Secondary research refers to research use of materials that are collected for either research studies distinct from the current secondary research proposal, or for materials that are collected for non-research purposes, such as materials that are left over from routine clinical diagnosis or treatments. Broad consent does not apply to research that collects information or biospecimens from individuals through direct interaction or intervention specifically for the purpose of the research.) **The Auburn University IRB has determined that as currently interpreted, Broad Consent is not feasible at Auburn and these 2 categories WILL NOT BE IMPLEMENTED at this time.**

***Limited IRB review* – the IRB Chairs or designated IRB reviewer reviews the protocol to ensure adequate provisions are in place to protect privacy and confidentiality.**

****Category 3 – Benign Behavioral Interventions (BBI)* must be brief in duration, painless/harmless, not physically invasive, not likely to have a significant adverse lasting impact on participants, and it is unlikely participants will find the interventions offensive or embarrassing.**

3. PROJECT SUMMARY

a. Does the study target any special populations? (Mark applicable)

Minors (under 18 years of age)	■ YES ☐ NO
Pregnant women, fetuses, or any products of conception	☐ YES ■ NO
Prisoners or wards (unless incidental, not allowed for Exempt research)	☐ YES ■ NO
Temporarily or permanently impaired	☐ YES ■ NO

b. Does the research pose more than minimal risk to participants? ☐ YES ■ NO

Minimal risk means that the probability and magnitude of harm or discomfort anticipated in the research are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or test. 42 CFR 46.102(i)

c. Does the study involve any of the following?

Procedures subject to FDA regulations (drugs, devices, etc.)	☐ YES ■ NO
Use of school records of identifiable students or information from instructors about specific students.	☐ YES ☐ NO
Protected health or medical information when there is a direct or Indirect link which could identify the participant.	☐ YES ■ NO
Collection of sensitive aspects of the participant's own behavior, such as illegal conduct, drug use, sexual behavior or alcohol use.	☐ YES ■ NO
Deception of participants	☐ YES ■ NO

4. Briefly describe the proposed research, including purpose, participant population, recruitment process, consent process, research procedures and methodology.

We are requesting access to the National Institutes of Mental Health Data Archive, which is a repository of data funded by the NIH. All parents of participants provided consent during the initial data collection by the NIH. All data available in the repository have been de-identified and there is no way to link subject data to participants. We will request the following data from the Pediatric MRI dataset: Bayley Scales of Infant Development - II, Preschool Language Scale - 3, demographics (family income, race, maternal education, sex, age, etc.), anatomical MRI, and diffusion MRI. We are interested examining the development of motor, cognitive, and language skills in infants and young children (birth - 4 years) and whether relationships between these variables are mediated by changes in the brain. To this end, we will conduct mediation analysis and other multivariate statistics.

5. Waivers

Check any waivers that apply and describe how the project meets the criteria for the waiver. Provide the rationale for the waiver request.

- ☐ **Waiver of Consent (Including existing de-identified data)**
- ☐ **Waiver of Documentation of Consent (Use of Information Letter)**
- ☐ **Waiver of Parental Permission (for college students)**

All retrospective information will be de-identified.

6. **Describe how participants/data/specimens will be selected. If applicable, include gender, race, and ethnicity of the participant population.**

We are conducting a secondary data analysis of data that have already been collected. For the purpose of our analyses, we are interested in data from birth to age 4 years for all participants in the database.

7. **Does the research involve deception? ☐ YES ☒ NO If YES, please provide the rationale for deception and describe the debriefing process.**

8. **Describe why none of the research procedures would cause a participant either physical or psychological discomfort or be perceived as discomfort above and beyond what the person would experience in daily life.**

All data have already been collected. So this is not applicable.

9. **Describe the provisions to maintain confidentiality of data, including collection, transmission, and storage.**

All data downloaded from the data repository have been de-identified. These data will be analyzed using password-protected spreadsheets on password protected computers. Only the researchers identified above will have access to these data. In addition, a data use agreement will be signed ensuring appropriate/approved use of these data.

10. **Describe the provisions included in the research to project the privacy interests of participants (e.g., others will not overhear conversations with potential participants, individuals will not be publicly identified or embarrassed).**

All data have already been collected. So this is not applicable.

11. **Will the research involve interacting (communication or direct involvement) with participants?**
☐ **YES** ☒ **NO If YES, describe the consent process and information to be presented to subjects. This includes identifying that the activities involve research; that participation is voluntary; describing the procedures to be performed; and the PI name and contact information.**

12. Additional Information and/or attachments.

In the space below, provide any additional information you believe may help the IRB review of the proposed research. If attachments are included, list the attachments below. Attachments may include recruitment materials, consent documents, site permissions, IRB approvals from other institutions, etc.

We have attached the data use agreement, which needs to be signed by an authorized representative of the university.

Principal Investigator's Signature member: 815EF6A7-0053-469C-990F-D3DABBA1C7DF DD641838-B63C-469C-B287-E2D445D6280A Digitally signed by member: 815EF6A7-0053-469C-990F-D3DABBA1C7DF DD641838-B63C-469C-B287-E2D445D6280A Date: 2020.07.24 11:25:54 -04'00' **Date** June 10, 2020

If PI is a student,
Faculty Principal Investigator's Signature member: 815EF6A7-0053-469C-990F-D3DABBA1C7DF DD641838-B63C-469C-B287-E2D445D6280A Digitally signed by member: 815EF6A7-0053-469C-990F-D3DABBA1C7DF DD641838-B63C-469C-B287-E2D445D6280A Date: 2020.08.05 10:22:42 -05'00' **Date** June 10, 2020

Department Head's Signature Mary Rudisill Digitally signed by Mary Rudisill Date: 2020.07.24 12:52:46 -05'00' **Date** June 10, 2020

AU Exemption Form Version 05.19.2020

Version Date (date document created): ____________

page __ of __

OMB Control Number: 0925-0667
Expiration Date: 11/30/2020

NIMH Data Archive

Data Use Certification

Last updated: August 2019

OMB Control Number: 0925-0667
Expiration Date: 11/30/2020

NIMH Data Archive Data Use Certification

Introduction

The National Institute of Mental Health (NIMH) Data Archive (NDA) is an NIH-funded collaborative resource that contains human subjects research data from multiple research data repositories.

The NIMH Data Archive Data Use Certification (DUC) is used to request access to shared research data in a data repository within the NIMH Data Archive. Shared data are available with either an Institutional sponsorship or an Individual sponsorship. All data access requests require acceptance of the Data Use Terms and Conditions contained in this DUC. (See the *NIMH Data Archive Recipient Information and Certifications* form in this document for available data and associated sponsorship types.)

- Institutional sponsorship requires Recipients to be affiliated with an NIH recognized institution (foreign or domestic), based upon registration in the NIH's eRA Commons system, with an active Federal Wide Assurance (FWA) issued by the Department of Health and Human Services, Office for Human Research Protections (OHRP). The signature of an Authorized Institutional Business Official is also required on this DUC.
- Individual sponsorship may be requested by a Recipient without the need for sponsorship by or affiliation with an NIH recognized institution and, therefore, the signature of an Authorized Institutional Business Official or an active institutional FWA is not required.

A Data Access Committee(s) (DAC) will objectively review a data access request sponsored by an Institution. Individual sponsorships do not require DAC review. To submit data to the NIMH Data Archive, the NIMH Data Archive Data Submission Agreement (DSA) must be completed, which is a separate document.

The NIMH Data Archive (NDA)

The National Institutes of Health (NIH) and NIMH have developed a data infrastructure to store the collection of data from participants in research studies, regardless of the source of funding. The extensive information collected by these studies is harmonized and subsequently stored in one of several data repositories within the NIMH Data Archive (NDA) data infrastructure, providing a rare and valuable scientific resource. A current list of all NDA data repositories and links to their websites is available at https://nda.nih.gov/about/about-us.html.

The NIH and NIMH seek to encourage the use of these resources to achieve rapid scientific progress. Moreover, NIMH has made data sharing a requirement for all clinical research it funds (see NOT-MH-19-033). In order to take full advantage of such resources and maximize their research value, it is important that data are made **broadly available**, on appropriate terms and conditions, to the largest possible number of qualified investigators in a timely manner.

Data collected by the Submitters have been stripped of all individual identifiers, but the unique and intrinsically personal nature of genomics data, brain imaging, and other derivative data of which are included in these repositories, combined with the recent increase in the accessibility of conducting genotype and other sequence analyses (in terms of technological capacity and cost), has altered the framework through which "identify-ability" can be defined. To protect and assure the confidentiality and privacy of all participants, the Recipient who is granted access to these data is expected to adhere to the specifications of this DUC. Failure to do so could result in denial of further access to data.

Data Use Terms and Conditions

I request access to shared data from the NIMH Data Archive for the purpose of scientific investigation, scholarship or teaching, or other forms of research and research development as described in the following NIMH Data Archive Data Use Certification (DUC). I, and any Other Recipients listed in this DUC, agree to the following terms:

1. Research Data Use Statement

Generally, these data will be used by the Recipient in connection with the purpose indicated and described in the *Research Data Use Statement* on the DUC. Recipients are encouraged to explore shared data in the NIMH Data Archive for a variety of purposes including secondary analysis, hypothesis generation, and replication regardless of whether said exploration leads to analysis in support of a question beyond the scope of the originally identified purpose described in the *Research Data Use Statement*.

2. Non-transferability of Agreement

This DUC is not transferable. If a Recipient changes institution and wishes to retain access to the NIMH Data Archive, a new DUC is required.

3. Non-Identification of Subjects

Recipients agree that data will not be used to establish the individual identities of any of the study participants from whom data were obtained (or their relatives) and/or contact the individual study participant, except as permitted by law (e.g., in connection with a separately negotiated collaboration with the original research team or the enrollment of the consented subject in the Recipient's study). Recipients agree to not publish or disseminate any derived data that could aid in the re-identification of any of the study participants (or their relatives). Recipients agree to notify the NIH at NDAHelp@mail.nih.gov as soon as possible if, upon use of NIMH Data Archive data, identifying information is discovered.

4. Use of the NIH Global Unique Identifier (GUID)

The Global Unique Identifier (GUID) is a computer-generated alphanumeric code that is unique to each research participant. The GUID allows the NIMH Data Archive to link together all submitted information on a single participant, giving researchers access to information even if the data were collected at different locations or through different studies. If Recipients access data on individuals for whom they, themselves, have previously submitted data to the NIMH Data Archive, Recipients may gain access to more data about an individual participant than they, themselves, collected. Consequently, these research activities may be considered "human subjects research" within the scope of 45 C.F.R. 46. Recipients must comply with the requirements contained in 45 C.F.R. 46, as applicable, which may require Institutional Review Board (IRB) approval of the Research Data Use Statement.

5. Data Disclaimers

Recipients acknowledge that the NIH does not and cannot warrant the results that may be obtained by using any data or data analysis tools included in the NIMH Data Archive. The NIH disclaims all warranties as to the accuracy of the data in the NIMH Data Archive or the performance or fitness of the data or data analysis tools for any particular purpose.

6. Data Access for Research

Data and Supporting Documentation in the NIMH Data Archive are eligible for access by qualified researchers, pursuant to the terms set forth in this DUC. Recipients acknowledge that other researchers have access to the data and that downloading, and duplication of research is a distinct possibility, thereby decreasing subject data protections. Raw or nearly raw research data files (e.g. fastq, bam, MRI, and EEG recordings) are made available for just in time computation, regardless of where the computational resources may reside. Therefore, data copied shall not be persisted (i.e., stored) beyond the time necessary for computation and shall be expunged once computation has been completed. Recipients are encouraged to utilize the NIMH Data Archive computational capabilities described at https://nda.nih.gov/tools/nda-tools.html#cloud.

7. Supporting Documentation

Recipients agree to review the supporting information, materials, and documentation ("Supporting Documentation") for the data accessed in the NIMH Data Archive to enable efficient use of the submitted data by Recipients unfamiliar with the data or the research project. Examples of supporting documentation include:

- Research protocol(s)
- Questionnaire(s)
- Study manuals

8. Sharing of a NIMH Data Archive Study/Acknowledgements

Recipients agree to create and share an NIMH Data Archive Study (https://nda.nih.gov/get/manuscript-preparation.html) for each publication, computational pipeline, or other public disclosure of results from the analysis of data accessed in the NIMH Data Archive, whether reporting positive or negative results, thereby linking it to the underlying data. Recipients agree to create the NIMH Data Archive Study when a manuscript is submitted for review and share the Study when the publication is released. Recipients agree to acknowledge the appropriate NIMH Data Archive data repository and the relevant Digital Object Identifier(s) (DOI), which will be created by NIMH Data Archive staff, in any and all oral and written presentations, disclosures, and publications (including abstracts, as space allows) resulting from any and all analyses of data, whether or not the Recipient is collaborating with Submitter(s). The oral or written presentation, disclosure, or publication should include an acknowledgement statement, which includes a disclaimer of NIH endorsement, as appropriate. Acknowledgements specific to each NDA data repository are maintained at https://nda.nih.gov/get/manuscript-preparation.html.

If the Research Project involves collaboration with Submitters or NIH staff (as indicated in the DUC), then Recipient will acknowledge Submitters or NIH staff as co-authors, if appropriate, on any presentation, disclosure, or publication.

9. No Distribution of Data

Recipients agree to retain control over data from the NIMH Data Archive, and further agree not to transfer or sell data, with or without charge, in any form, to any other entity or any individual or to distribute the data to anyone other than the Other Recipients listed on this DUC who also agree to the terms in this DUC. This includes any data derived from the data in the NIMH Data Archive if the associated GUID is distributed with that derived data or if the derived data can aid in the re-identification of a research participant.

10. Non-Governmental Endorsement; Liability

Recipients agree not to claim, infer, or imply endorsement of the research project described in the *Research Data Use Statement*, the entity, or personnel conducting the research project or any resulting commercial product(s) by the United States Government, the Department of Health & Human Services, the National Institutes of Health, or the National Institute of Mental Health. The United States Government assumes no liability except to the extent provided under the Federal Tort Claims Act (28

U.S.C. § 2671-2680).

11. Recipient's Compliance with Institutional Requirements

Recipients with Institutional sponsorship acknowledge that access, if provided, is for research that is approved by the Institution with which they are affiliated, which must be operating under an active Federal Wide Assurance (FWA) issued by the Department of Health & Human Services, Office for Human Research Protections (OHRP). Furthermore, Recipients agree to comply with all applicable rules for the protection of human subjects, which may include Department of Health and Human Services regulations at 45 C.F.R. Part 46, and other federal and state laws for the use of this data. Recipients agree to report promptly to the NIH any unanticipated problems involving risks to subjects or others. This DUC is made in addition to, and does not supersede, any of Recipient's institutional policies or any local, State, and/or Federal laws and regulations that provide additional protections for human subjects.

12. Recipient's Permission to Post Information Publicly

Recipient agrees to permit the NIMH Data Archive to publicly summarize the Recipient's research use of data along with the Recipient's name and organizational/institutional affiliation.

13. Privacy Act Notification

Recipients agree that information collected by the NIH from a Recipient, as part of the DUC, may be made public in part or in whole for tracking and reporting purposes. This Privacy Act Notification is provided pursuant to Public Law 93-579, Privacy Act of 1974, 5 U.S.C. Section 552a. Authority for the collection of the information requested below from Recipients comes from the authorities regarding the establishment of the National Institutes of Health, its general authority to conduct and fund research and to provide training assistance, and its general authority to maintain records in connection with these and its other functions (42 U.S.C. 203, 241, 289l-1 and 44 U.S.C. 3101), and Sections 301 and 493 of the Public Health Service Act. These records will be maintained in accordance with the Privacy Act System of Record Notice 09-25-0156 (https://oma.od.nih.gov/forms/Privacy%20Documents/Documents/Privacy%20Act%20Systems%20of%20Records%20Notices%20(SORNs)%205-1-15.pdf) covering "Records of Participants in Programs and Respondents in Surveys Used to Evaluate Programs of the Public Health Service, HHS/PHS/NIH/OD." The primary uses of this information are to document, track, monitor, and evaluate the use of NIMH Data Archive datasets, as well as to notify interested Recipients of updates, corrections or other changes to the database.

The Federal Privacy Act protects the confidentiality of some NIH records. The NIH will use the information collected for the purposes described above. In addition, the Act allows the release of some information in the Recipient's records without the Recipient's permission; for example, if it is requested by members of Congress or other authorized individuals. The information requested in this DUC is voluntary, but necessary for obtaining access to data in the NIMH Data Archive.

14. Security

Recipients acknowledge that the data being made available were made available for researcher use with the expectation that the data will be protected in a manner consistent with security best practices. Such practices include, but are not limited to, the following:

- Accounts and passwords will not be shared.
- Data are protected from anonymous access. Any data transferred or stored outside of the NIMH Data Archive will be protected using standard encryption protocols and/or strong password protection.
- When finished using the data, the data will be expunged, as permitted by law.

15. Annual Update/Research Use Reporting

Recipients will provide to NDAHelp@mail.nih.gov an annual summary of research accomplishments from using the NIMH Data Archive and agree to create and share an NIMH Data Archive Study for each public disclosure of results pursuant to the Sharing of an NIMH Data Archive Study/Acknowledgements term in this DUC. The NIH encourages Recipients who publish manuscripts based on a combination of data from the NIMH Data Archive data, data derived from NDA data, and data collected independent of the NIMH Data Archive to consider submitting the complete analyzed dataset to the NIMH Data Archive.

16. Amendments

Amendments to this DUC must be in writing and signed by authorized representatives of all parties.

17. Termination

Either party may terminate this DUC, without cause, provided 30 days' advanced written notice to the other party. Recipients agree to immediately report violations of this agreement to the appropriate NIMH Data Archive Data Access Committee. Additionally, the NIH may terminate this agreement with 5 days' advanced written notice if the NIH determines, in its sole discretion, that a Recipient has committed a material breach of this DUC. The NIH may, in its sole discretion, provide a Recipient with 30 days' advanced written notice to remedy a breach before termination.

18. Term and Access Period

Recipients are granted permission to access requested and approved data from the NIMH Data Archive for a period of one year and this DUC will automatically terminate at that time. Data access may be renewed upon certification of a new DUC.

19. Accurate Representations

Recipients expressly certify that the contents of any statements made or reflected in this document are truthful and accurate.

OMB Control Number: 0925-0667
Expiration Date: 11/30/2020

Burden Disclosure Statement

Public reporting burden for this collection of information is estimated to vary from 15 min to 1.5 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. **An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number.** Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to: NIH, Project Clearance Branch, 6705 Rockledge Drive, MSC 7974, Bethesda, MD 20892-7974, ATTN: PRA (0925-0667). Do not return the completed form to this address.

OMB Control Number: 0925-0667
Expiration Date: 11/30/2020

NIMH Data Archive Recipient Information and Certifications

1. Access Request:

Application Type		Data Requested	Recipient Sponsor*
NEW ☐	RENEWAL ☑	NIMH Data Archive (NDA)	Institutional
NEW ☐	RENEWAL ☐	Adolescent Brain Cognitive Development Study (ABCD)	Institutional
NEW ☐	RENEWAL ☐	Connectome Coordination Facility (CCF)	Institutional
NEW ☐	RENEWAL ☐	Osteoarthritis Initiative (OAI)	Individual
NEW ☐	RENEWAL ☐	NIAAA Data Archive ($NIAAA_{DA}$)	Institutional
NEW ☐	RENEWAL ☐		

**Institutional sponsorship requires the signature of an Authorized Institutional Business Official and an active Federal Wide Assurance (FWA) number in the Signatures section below. See the "Introduction" section on page 1 for more information.*
See https://nda.nih.gov/about/about-us.html for a current list of all NDA Data Repositories.

2. Lead Recipient:

First Name: Melissa Last Name: Pangelinan Degree:

Institution: Auburn University- School of Kinesiology

City: Auburn State/Province: AL - Alabama Country: UNITED STATES

Phone: 3347444142 E-mail Address: mgp0020@auburn.edu

3. Research Data Use Statement: Describe the purpose of the scientific investigation, scholarship or teaching, or other form of research and research development for which you are requesting access to the NIMH Data Archive.

The purpose of this secondary data analysis is to determine the relationships between motor, cognitive, and language development in infants and young children and whether brain volume changes mediate these relationships. This study will serve as a component of the dissertation for two students (Julia Sassi and Davis Dyke). Behavioral (BSID, PLS-3), aMRI, DTI and demographic data from Objective 2 of the Pediatric MRI data set are requested.

August 2019

4. Renewal Applicants Only:

Has a publication, computational pipeline, or other public disclosure of results from the analysis of data accessed in the NIMH Data Archive resulted from a Recipient's previous access period? ☐ Yes ☐ No

If Yes, has an NDA Study been created? ☐ Yes List the NDA Study number(s): ______
☐ No* List the PubMed ID(s) or citation(s): ______

** See 8. Sharing of a NIMH Data Archive Study/Acknowledgements above. Contact the NDA Help Desk (NDAHelp@mail.nih.gov) to create an NDA Study.*

5. Other Recipient(s): List all individuals who will access, use, or analyze the data regardless of position title or data use role. Use additional sheets as needed.

First Name: Davis Last Name: Dyke Degree: ______
Institution: Auburn University
City: Auburn State/Province: AL - Alabama Country: UNITED STATES
Phone: 561-339-0754 E-mail Address: dzd0040@auburn.edu

First Name: Julia Last Name: Sassi Degree: ______
Institution: Auburn University
City: Auburn State/Province: AL - Alabama Country: UNITED STATES
Phone: 334-524-7177 E-mail Address: jzm0082@auburn.edu

First Name: ______ Last Name: ______ Degree: ______
Institution: ______
City: ______ State/Province: ______ Country: ______
Phone: ______ E-mail Address: ______

First Name: ______ Last Name: ______ Degree: ______
Institution: ______
City: ______ State/Province: ______ Country: ______
Phone: ______ E-mail Address: ______

First Name: ______ Last Name: ______ Degree: ______
Institution: ______
City: ______ State/Province: ______ Country: ______
Phone: ______ E-mail Address: ______

6. **Authorized Institutional Business Official**: Requests to access data requiring an Institutional sponsorship must list an individual with an "SO" role as defined in the NIH eRA Commons - *https://commons.era.nih.gov/commons*

Name: Anthony Ventimiglia Email Address: ventiaf@auburn.edu

7. Signatures: By signing and dating this DUC to request access to data in the NIMH Data Archive, I and my Institutional Official *(if required)* certify that we will abide by the Data Use Terms and Conditions defined in this DUC. I further acknowledge that I have shared this document with any Other Recipients who will participate in the use of data from the NIMH Data Archive. My Institutional Business Official *(if required)* also acknowledges that they have shared this document with appropriate institutional organizations.

Lead Recipient Signature	June 10, 2020 Date
Anthony Ventimiglia, Acting Executive Director of Research Administration Services — Digitally signed by Anthony Ventimiglia, Acting Executive Director of Research Administration Services Date: 2020.07.28 08:51:18 -05'00' Authorized Institutional Business Official Signature *(if required)*	June 10, 2020 Date

Inquiries and requests to access data in the NIMH Data Archive should be sent to:
Office of Technology Development and Coordination (OTDC), Program Director
National Institute of Mental Health | National Institutes of Health
6001 Executive Boulevard, Room 8125, MSC 9640 Bethesda, MD 20892-9640
Telephone: 301-443-3265 | Email**:** NDAHelp@mail.nih.gov

Appendix B

Normality of Residuals

To check this assumption, we examined the q-q-plots for the best fit model for each dependent variable.

Figure 11

Normality for the Best Fit Model for BSID-II Motor Scale scores

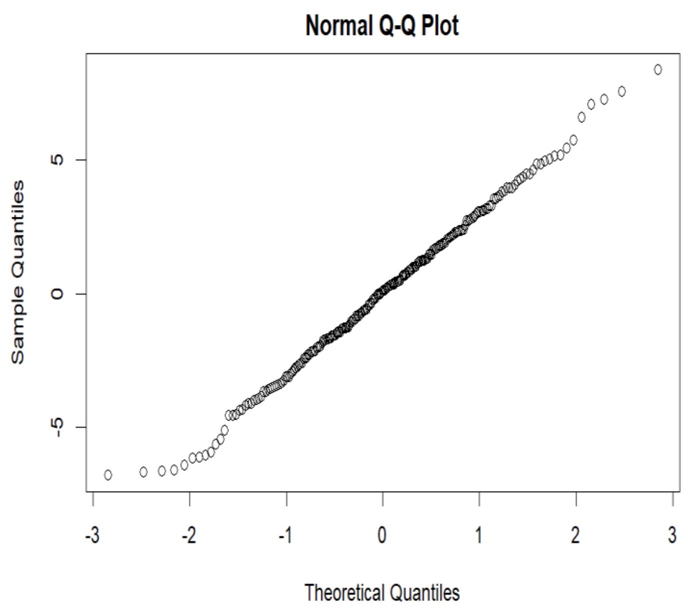


Figure 12

Normality for the Best Fit Model for PLS-3 Auditory Comprehension Scale scores

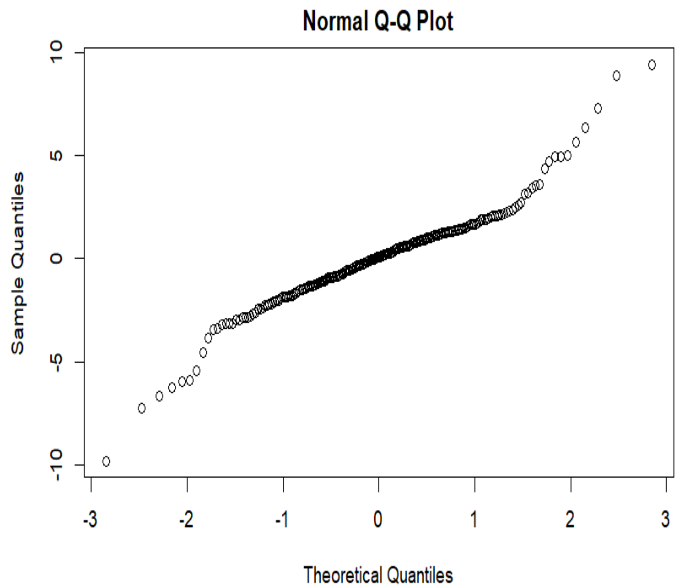
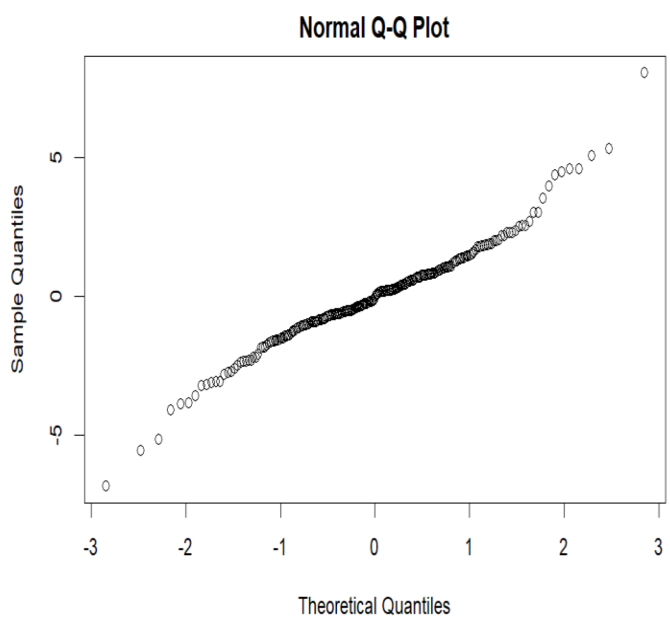


Figure 13

Normality for the Best Fit Model for PLS-3 Expressive Communication Scale scores



Homoscedasticity

To check this assumption, we examined the plots of the residuals versus the predicted/fitted values for the best fit model for each dependent variable.

Figure 14

Homogeneity of Variance for the Best Fit Model for BSID-II Motor Scale scores

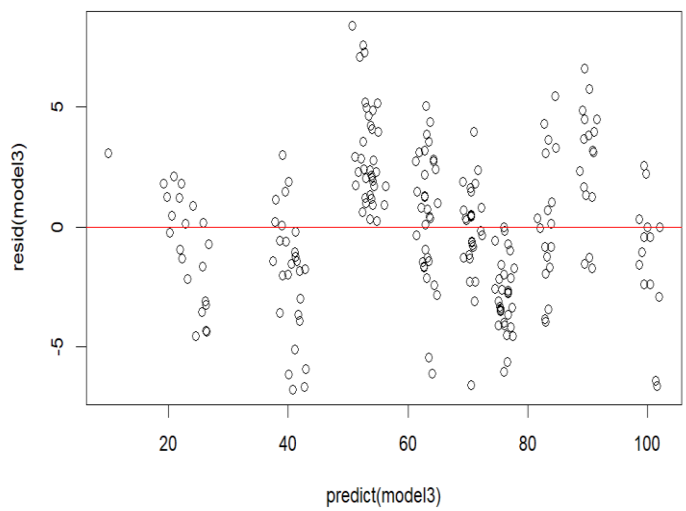


Figure 15

Homogeneity of Variance for the Best Fit Model for PLS-3 Auditory Comprehension Scale scores

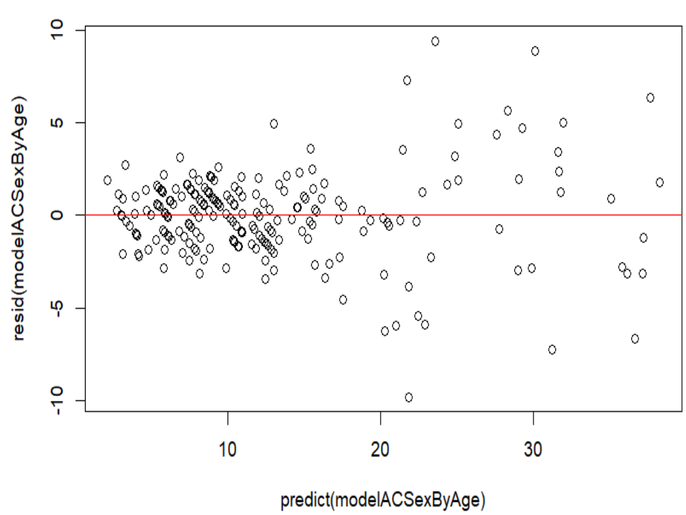
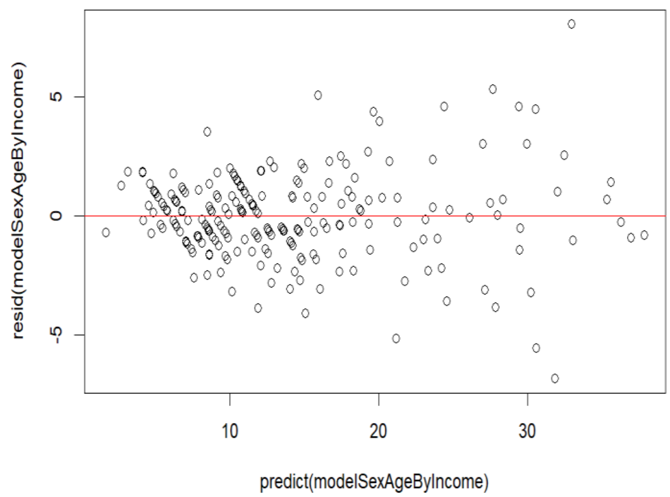


Figure 16

Homogeneity of Variance for the Best Fit Model for PLS-3 Expressive Communication Scale scores



Appendix C

Sensitivity Analyses

Sensitivity analyses were conducted based on the best fit model used for Specific Aim 2, & 3. The effect sizes are reported in units of slope.

Specific Aim 2 - Hypothesis 2

BSID-II Motor ~ Median Household Income. The study had 80% power to detect effects as small as *ß* = 2.459e-05. However, in our model, the estimate for BSID-II Motor Scores was smaller (*ß* = -1.269e-05). Therefore, we were underpowered to detect the relationship between Median Household Income and BSID-II Motor Scores.

PLS-3 AC ~ Median Household Income. The study had 80% power to detect effects as small as *ß* = 2.157e-05. However, in our model, the estimate for Median Income was smaller (*ß* = 1.040e-05). Therefore, we were underpowered to detect the relationship between Median Household Income and PLS-3 AC Scores.

PLS-3 EC ~ Median Household Income. The study had 80% power to detect the main effect of Median Income as small as *ß* = 3.401e-05. However, in our model, the estimate for Median Income was very small (*ß* = -3.112e-05). Therefore, we were not powered to detect the relationship between a fixed effect of Median Income and PLS-3 EC Scores. However, the study also had 80% power to detect a main effect of interaction between Age and Median Income as small as *ß* = 2.167e-05. The estimate for this interactive term in our model was *ß* = 4.143e-05 — therefore we were powered to detect this relationship.

Specific Aim 3 - Hypothesis 3

PLS-3 AC ~ BSID-II Motor. The study had 80% power to detect effects as small as ß = 0.154. However, in our model, the estimate for BSID-II Motor Scores was smaller (ß = 0.093). Therefore, we were underpowered to detect the relationship between PLS-3 AC scores and BSID-II Motor Scores.

PLS-3 EC ~ BSID-II Motor. The study had 80% power to detect effects as small as ß = 4.204. In our model, the estimate for BSID-II Motor Scores was (ß = 5.679), which indicates that we achieved 80% statistical power to detect the effects of BSID-II Motor Scale Scores on PLS-3 EC Scores.