Child-Directed Speech and the Developing Brain:

An Investigation of Adult Verbal Warmth and Negative Affect

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Abstract

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This dissertation examines the association between the quality of children's language experiences – as operationalized by adult verbal warmth – and their cognitive developmental outcomes. A socioeconomically diverse sample of 43 parents and their 5-to-9-year-old children participated in this study. A digital audio recording of the home environment was obtained, and children completed a high-resolution, structural MRI scan as well as direct assessments of their language and reading skills. The audio recordings were transcribed and coded using a coding scheme newly developed by the candidate in consultation with leading experts, in order to identify and quantify psycholinguistic elements of adult-child communication.

Primary hypotheses included that adult verbal warmth is associated with (1) language and reading outcomes (2) the neural regions associated with each. To date, no studies have combined a transcription-based, fine-grained analysis of naturalistic home recordings with neuroimaging data. As such, this study represents a new line of inquiry at the nexus of developmental psychology, neuroscience, and education.

The findings shed light on the impact of psychosocial language experiences on child development and on which forms of adult-child communication are most conducive to learning. Such information can inform programs that aim to teach parents ways to nurture their children's development through high quality child-directed speech. Social, educational, and clinical implications for mitigating risk factors and bolstering protective factors in order to, ultimately, foster healthy development for all children, are discussed.

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Dedication

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Chapter 1: Introduction

1.1 Socioeconomic Factors and Child Development

Human development is the product of the continuous dynamic interplay of biological factors, environmental contexts, and social relationships that an individual experiences from the beginning of life. Early childhood is a sensitive period during which children's development is malleable and especially vulnerable to environmental factors, including inequality and socioeconomic status (SES) (Shore, 1997; Zeanah, Gunnar, McCall, Kreppner, & Fox, 2011). It is well-documented that children from disadvantaged backgrounds are at a profoundly increased risk for negative physical, socioemotional, academic, and cognitive outcomes, and that these deleterious patterns emerge early, compound over time, and persist into adulthood (Anderson & Armstead, 1995; Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; Duncan, Magnuson, Kalil, & Ziol-Guest, 2011; McLoyd, 1998). The incorporation of neuroscience into topics more commonly associated with the social sciences has furthered our understanding of the link between adverse experiences and development (Greenough, Black, & Wallace, 1987).

Socioeconomic factors, including parental education and family income, exert their effects on child development via both proximal psychological, social, and environmental contexts, which presumably then impact brain regions related to cognitive, academic, and social functioning. Recent work indicates that socioeconomic background plays a role in shaping children's brain structure (Brito & Noble, 2014; Farah, 2017; Johnson, Riis, & Noble, 2016). For example, socioeconomic disadvantage is associated with reduced gray matter (Hanson et al., 2013) and, in particular, reduced gray matter in brain regions that support language comprehension and production (Noble et al., 2015). Poverty has been linked to structural differences in several areas of the brain associated with school readiness skills and memory (Hair, Hanson, Wolfe, & Pollak, 2015; Hanson, Chandra, Wolfe, & Pollak, 2011; Noble, Houston, Kan, & Sowell, 2012). In fact, recent work has estimated that socioeconomic status accounts for approximately 20% of the variance in childhood IQ (Bornstein & Bradley, 2014) and moreover, it is estimated that as much as 20% of the observed SES gap in test scores between students could be explained by maturational lags in children's neurodevelopment (Hair et al., 2015). In short, the influence of poverty on children's learning and achievement likely arises from specific downstream experiential effects on structural brain development (Hair et al., 2015). Yet, electroencephalography (EEG) studies suggest that socioeconomic disparities in brain activity are not present at birth (Brito, Fifer, Myers, Elliott, & Noble, 2016), but may be present by 6-9 months of age (Tomalski et al., 2013). This leads to the question: what are the experiential differences underlying the differences in children's brain development?

1.2 Socioeconomic Factors and Language Input Quantity

Evidence suggests a variety of possible and non-mutually-exclusive mechanisms linking SES to child well-being, including prenatal factors, access to cognitively stimulating materials and social resources or differences in the quantity of and biological response to stress-inducing conditions by both children and their parents (Bradley & Corwyn, 2002; Brito, 2017; Evans, 2004; Hackman & Farah, 2009; Noble et al., 2012). Linguistic stimulation, or the language input that children receive in their early years, is a prime candidate mechanism that may link SES with children's language-related brain structure and academic outcomes (Brito, 2017; Hoff, 2003; Pace, Luo, Hirsh-Pasek, & Golinkoff, 2017; Rowe, 2008, 2012; Weisleder & Fernald, 2013). In a pioneering observational study, Hart and Risley (1995) estimated that disadvantaged children hear 30 million fewer words than their more affluent peers by the age of four. Further, they demonstrated that these socioeconomic differences are predictive of differences in cognitive development and vocabulary scores, which then translate to gaps in later academic trajectories. Recent works shows that SES-related gaps in vocabulary are evident as early as 7 months (Betancourt, Brodsky, & Hurt, 2015) and continue to widen during preschool years (Farkas & Beron, 2004). The latter researchers found that the SES-related gap in children's vocabulary at age three remained unchanged through the age of 13. Language skills are among the best predictors of young children's school readiness and academic outcomes (Duncan et al., 2007; Hoff, 2013a, 2013b), making it important to have a full understanding of their predictors.

Findings on the SES-related stratification of oral language development have fueled national programs designed to close the "30-million-word-gap" and intervene in the learning trajectories of children from disadvantaged families, in part, by increasing the quantity and quality of early language input. Of course, the overall quality of language input is a reflection of not only the quantity and complexity of speech to children, but also the affective tone and responsiveness with which it is delivered (Ainsworth, 1979). As such, the sheer quantity of language input is insufficient to solely account for differences in language development. For example, for infants and young children, language exposure from television is not associated with beneficial effects, demonstrating that the social element of human interaction is integral to positive language development (Barr & Hayne, 1999; Kuhl, Tsao, & Liu, 2003; Liu, Kuhl, & Tsao, 2003; Lytle & Kuhl, 2017a).

1.3 Socioeconomic Factors and Language Input Quality

Indeed, recent research corroborates the notion that SES-related differences in early language environments are not limited to the quantity of input, but extend to the quality of social interactions and exchange as well (Cartmill et al., 2013; Goldin-Meadow et al., 2014; Hirsh-Pasek et al., 2015; Iverson & Goldin-Meadow, 2005; Rowe, 2012; Schwab & Lew-Williams, 2016). One recent study reported that the quality of the home language environment, but not socioeconomic status, predicted infant's early language skills (Melvin et al., 2017). Moreover, research examining both quantity and quality simultaneously suggests that quality may be the primary predictor of language outcomes (Pace et al., 2017; Rowe, 2012). One indicator of higher-quality communication is the number of conversational turns children experience, defined as reciprocal, responsive verbal interactions. Recent findings show that the number of conversational turns experienced by children is predictive of language-related brain function and verbal skill, over and above the sheer quantity of words heard (Romeo et al., 2018). Importantly, this research found significant associations across all socioeconomic levels; meaning that outcomes for children from lower-income families were associated with conversational interplay just as much as those of children from higher-income families. Furthermore, the hourly conversational turns children experience at home is significantly predictive of greater surface area in language-related brain regions, with a larger effect size than seen with the hourly adult word count (Merz, Maskus, Melvin, He & Noble, 2019). Thus, while the overall number of words children hear varies widely and may be important, the *quality* of social interactions vis-a-vis language experiences may be a more powerful predictor of developmental outcomes.

However, while the literature typically conceptualizes *quality*, in part, as conversational input, linguistic and grammatical complexity (Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Rowe, 2012) or use of questions (Aram, Fine, & Ziv, 2013), there is much evidence that sensitive interactions, defined by affective aspects of warmth and responsiveness, also predict language abilities (Hirsh-Pasek et al., 2015; Kuhl, 2007a; Leigh, Nievar, & Nathans, 2011; Tamis-LeMonda, Bornstein, & Baumwell, 2001; Tamis-LeMonda, Kuchirko, & Song, 2014). It is well-documented that responsive interactions and relationships are developmentally expected and biologically essential (Hofer, 1975, 2006; Phillips & Shonkoff, 2000; Shonkoff, Marshall, & Zigler, 2000). Literature on children who have experienced maltreatment and neglect shows that the continued absence of responsive caregiving signals a serious threat to child well-being as this diminished social interaction becomes compounded by the adverse impact of excessive stress activation, resulting in cascading physiological effects that can have deleterious lifelong consequences (National Scientific Council on the Developing Child, 2012; Nelson, 2014). In this way, caregivers play an especially formative role in promoting successful early childhood developmental outcomes. Given the empirical and theoretical notion that attuned and responsive care promotes optimal development, there is an increasing need to explore the links between caregivers' interactions with children and children's subsequent brain development.

1.4 The Current Study

Yet, the effects of the latter psycholinguistic experiences on children's brain structure have never been studied. At a time when nearly one in five children (21%; 15 million) in the United States lives below the official poverty line (National Center for Children in Poverty, 2019), more research is necessary to disentangle the mechanisms through which socioeconomic status exerts its influence on development across the lifespan. In order to maximize the impact of education programs and policies that seek to improve developmental outcomes for children from disadvantaged families, we must investigate how the quantity of linguistic input *and* the quality of caregiver-child communication interact to shape the developing brain. In my dissertation work, I broaden the consideration of the quality of communication by examining various characteristics of adult-child interactions, including verbal responsiveness, warmth, and positive regard. In so doing, I aim to elucidate the role of parental warmth and positive affect on children's language and cognitive growth. More broadly, I aim to examine how psycholinguistic patterns in adult-child communication relate to academic, socioemotional, and neurodevelopmental outcomes. It should be noted that while much of the theoretical framework and research motivation concerns populations from disadvantaged backgrounds, the current study is relevant to the entire population as insight into the association between adult verbal warmth and negative affect and children's neurocognitive development is invaluable for all families and educators.

Historically, research on children's language exposure relied on short recordings or periods of in-person observations – a form of data collection that was not only cumbersome, but also posed significant financial, methodological and time-related challenges. The present study relies on the Language Environment Analysis (LENA) system; a novel technology that combines a wearable audio recorder with automated vocal analysis software (Ganek & Eriks-Brophy, 2018). In this approach, the child wears a small digital recorder that records up to 16 hours of speech in the home. LENA software then analyzes the recording and provides automated estimates of the number of adult and child words and adult-child conversational turns. Beyond the time-saving benefit, LENA technology provides an opportunity for unseen, naturalistic observation and allows a more authentic measure of children's linguistic stimulation. The present study provides further innovation, by incorporating transcription and coding of portions of the LENA recordings, thereby building an unparalleled dataset linking extremely rich information about the naturalistic linguistic environment to state-of-the-art measurements of brain structure in children.

Chapter 2: Background

2.1 Theoretical Framework

Environmental influences in childhood, particularly the quality of the caregiver–infant relationship and emotional interactions within this context, have been purported to shape neurological, psychological and social development and have potential long-term effects on psychological and emotional functioning. Several theoretical approaches endorse the importance of positive or warm caregiver affect in the development of optimal child outcomes. The current study integrates neurodevelopmental science with social learning and attachment theories, to underscore the complex interactions between environmental and psychosocial factors and to better understand the caregiver-child qualities that impact child development. Beginning with a review of language development studies and attachment theory, the following chapter will interweave findings of how human engagement has been found as the catalyst for both changes in neural activity leading to language acquisition and in the formation of behavioral patterns in caregiver-child relationships. Following the review, the chapter will show how the social attachments created in a caregiver-child relationship impact neurological, language, and socioemotional development through communication styles.

2.1.1 Social Learning Theory

Infants begin life with neural systems that allow them to flexibly acquire any and all languages to which they are exposed, and to acquire language by eye or by ear, as either a visual-manual code or auditory-vocal, on roughly the same timetable (Petitto & Marentette, 1991). In short, infants are extraordinarily poised to "crack the speech code." An infants' transition from prelinguistic babbling to their budding ability to understand words that induce meaning in our collective minds, and, subsequently, to communicate their thoughts, is a breathtaking feat that has a long-standing history of puzzling psychology and linguistics scholars.

Historically, humans' capacity for speech and language acquisition has sparked classic debates on nature versus nurture from proponents of nativism (Chomsky, 1959) and operant conditioning (Skinner, 1957) to constructivism and sociocultural theory (Bruner, 1983; Vygotsky, 1962). Yet, new data on infants' cognitive predispositions and language learning abilities indicate that infants' computational and cognitive skills alone are insufficient for language mastery. Recent findings in cognitive science build on social learning models, which emphasize that language acquisition is a dynamic process by which children construct meaning out of interactions with caregivers (Golinkoff, Can, Soderstrom, & Hirsh-Pasek, 2015; Kuhl, 2004, 2007b; Lytle & Kuhl, 2017a; Tamis-LeMonda et al., 2014).

According to this framework, children are thought to learn how to structure thinking processes from interpersonal interactions with their caregivers and teachers, before these become internalized for independent functioning (Vygotsky, 1978). Moreover, social interactions allow children to build on their elementary cognitive processes to develop more sophisticated higher-order cognitive processes. In order to do so, children must come to recognize that language is a social tool, or one that enables them to share intentions with those around them (Bruner, 1983). Yet, infants are not inherently aware of social pragmatics, nor are they inherently equipped with the understanding that language is a communication tool (Tamis-LeMonda et al., 2014). Studies show that humans develop a sensitivity to the structure of social exchanges and an appreciation of communicative intersubjectivity, or the psycholinguistic-relation between a speaker's intention to communicate and the expectation that the listener will comprehend the meaning that was intended in early infancy (Bruner, 1983, 1984; Grice, 1968; Rochat, Querido, & Striano, 1999; Tamis-

LeMonda et al., 2014). As infants grow in their appreciation that meanings are socially shared, they engage in actions that elicit their caregiver's attention and knowledge (Bourvis et al., 2018; Stern, Jaffe, & Beebe, 1975; Tamis-LeMonda et al., 2008). They look where adults look, reference adults in ambiguous situations, and use gestures and words to share experiences (Tomasello, 1995; Tomasello & Carpenter, 2007). As such, social interactions with responsive caregivers are thought to facilitate infants' development of secondary intersubjectivity, thereby, facilitating their possibilities for and achievement of language acquisition (Landry, Smith, Swank, Assel, & Vellet, 2001; Tamis-LeMonda & Bornstein, 2001; Tamis-LeMonda & Bornstein, 2002; Tamis-LeMonda et al., 2014; Trevarthen & Marwick, 1986).

In fact, research on infants' phonetic perception in the first year of life shows that infants must combine their remarkable social skills, along with their computational and cognitive skills, to successfully acquire language; demonstrating a fundamental connection between the brain mechanisms underlying social cognition and language acquisition in its earliest stages (Kuhl, 2004; Kuhl et al., 2003). In this way, the social brain is said to "gate" language learning (Kuhl, 2007b). This assertion that social factors gate language learning may explain not only how typically developing children acquire language, but also why children on the autism spectrum exhibit twin deficits in social cognition and language, and why nonhuman animals with impressive computational abilities do not acquire language (Kuhl, 2014).

The aforementioned "social-gating hypothesis" was borne out of a series of studies on language acquisition in the infant brain (Kuhl, 2007b; Kuhl et al., 2003). In a landmark study, American infants only exposed to English were grouped into three separate groups in which they were exposed to Mandarin twelve times over a four-week period: Group 1 listened to the Mandarin tutors via audio recording; Group 2 watched videos of the Mandarin tutors; and Group 3, had live

Mandarin tutors who played, read stories, and interacted with the infants. Groups without the social engagement showed no acquisition of Mandarin phonemes; whereas both English and Mandarin phonetics were maintained in infants who received live Mandarin exposure, demonstrating that social interactions are essential for phonetic analysis and language acquisition (Kuhl et al., 2003).

Thus, responsive caregiver-child interactions are theorized to yield benefits for social cognitive skills that support language learning by allowing infants to engage in the motivating properties (such as attention and arousal) inherent in social interactions (Kuhl, 2007b). From a sociocultural perspective affect is one of a number of motivators of thought (Vygotsky, 1980). In a similar vein, (Ratner & Stettner, 1991) emphasized the role of parental affect in constructing a shared context that influences learning. Parental positive affect functions to promote learning, whether by increasing attention, fostering enthusiasm in the child; whereas negative affect functions to deter learning. This theory was confirmed in a study that found that the degree of social interaction and engagement with live tutors, as shown through shifting eye gaze from the tutor's eyes to the newly introduced toys, correlated with event-related potential (ERP) brain measures of language learning (Conboy & Kuhl, 2011; Conboy, Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2008). A more recent study found further neural evidence of enhanced learning in the presence of a peer, even when learning from screen video (Lytle, Garcia-Sierra, & Kuhl, 2018; Lytle & Kuhl, 2017b). Collectively, these findings build on the social-interactive account, by which children are motivated by, attend to, and benefit from interactions with attuned, engaging social partners (Kuhl, 2007b).

Insights into the social gating hypothesis underscore the transformational role that caregivers play in promoting successful early childhood language acquisition, suggesting that the underlying neural systems for language and psychosocial interaction mutually influence one another during development. While the social gating hypothesis powerfully argues the centrality of social interactions and relationships for language learning, it does not deeply investigate the nature and attributes of the human relationship that most facilitate learning. Our understanding of the simultaneity of language encoding with social bonding demands a closer investigation into the psychosocial and neural mechanisms that may underlie and have the power to shift neuro- and language development (Cozolino, 2014; Friederici & Wartenburger, 2010; Kuhl & Rivera-Gaxiola, 2008; Lytle et al., 2018; Lytle & Kuhl, 2017b).

2.1.2 Attachment Theory

According to the zeitgeist of the late 19th and early 20th centuries: parental affection would harm developmental outcomes. In a title chaptered "Too Much Mother Love," behaviorist John B. Watson advised:

> "When you are tempted to pet your child remember that mother love is a dangerous instrument...Never hug and kiss them, never let them sit in your lap. If you must, kiss them once on the forehead when they say goodnight. Shake hands with them in the morning" (Watson, 1928, p. 87)

Psychoanalytic developmental theorists dismantled this viewpoint by demonstrating the developmental significance the caregiver-child relationship (Ainsworth, 1969; Bowlby, 1969b). Attachment theory was borne out of studies on maternal deprivation and eventually led to an integrative framework of human development, whereby development occurs in the context of early relationships that provide security and comfort (Ainsworth, 1979; Harlow & Harlow, 1962). Studies of human attachment linked affective caregiver behaviors and interaction styles to the nature of the caregiver-child bond, demonstrating that levels of sensitivity or responsiveness and emotional withdrawal or inconsistency were primary determinants of children's secure or insecure attachment, respectively (Ainsworth et al., 1984; De Wolff & van Ijzendoorn, 1997; Harlow & Harlow, 1962; Bowlby, 1988). In other words, the key difference between the parents of securely and insecurely attached children is the degree to which the parents are sensitive to their children's needs. Parental behaviors reflecting insensitivity and misattunement to a child's cues, such as low affective communication, negative behavior or emotional withdrawal, have been found to lead to poor caregiver-child attachment (Lyons-Ruth, Bronfman, & Parsons, 1999; Parkes, Stevenson-Hinde, & Marris, 2006), while responsive parenting, which was seen as involving the capacity to sensitively attend to and provide communication to the child, was thought to regulate a child's state of anxiety or arousal (Tracy & Ainsworth, 1981).

Indeed, since then, the integration of attachment theory with neuroscience and biology has shown that the lack of parental sensitivity poses a two-fold threat for healthy development: not only does the brain not receive the positive stimulation it needs, but the body's stress response is activated, flooding the developing brain with potentially harmful stress hormones (Shonkoff & Garner, 2012). Findings have revealed the long-term devastation caused by early deprivation of responsive caregiving, leading to profound adverse effects on all developmental domains, including neurological, psychological, emotional, and physical (Harlow & Harlow, 1962; Merz & McCall, 2010; Nelson, Zeanah, & Fox, 2019; van IJzendoorn et al., 2011). Collectively, findings have demonstrated that responsive parenting is both expected and essential (Schore & Schore, 2008). Biochemical findings show that one of the neuropeptides or hormones that orchestrate human affiliation and bonding, oxytocin, is at incredibly high levels in infancy, but decreases with age (Lee, Macbeth, Pagani, & Young, 2009; Nishizato, Fujisawa, Kosaka, & Tomoda, 2017). Moreover, children's oxytocin level was found to be positively associated with parental sensitivity during interactions (Abraham, Hendler, Zagoory-Sharon, & Feldman, 2018). From birth, infants show a preference for those who are responsive to them (Bigelow & Birch, 1999) and engage in a range of 'signaling' behaviors in order to seek and maintain social contact with caregivers, including making eye contact, mimicking facial expressions, and signaling affective states, which serve to elicit responses from the caregiver (Bell & Ainsworth, 1972; Bowlby, 1969a; Paavola, Kunnari, & Moilanen, 2005). These innate capacities shape social communication and the development of early understanding of relationships with the responsive social environment. In this way, infants are neurologically primed for social communication and interaction within the context of the primary caregiving relationship (Cozolino, 2014; Schore & Schore, 2008; Strathearn, 2018)

2.1.3 Interpersonal Theory

The interactions and patterns of communication between a parent and child are initiated by the parent and largely determined by the parent's general interpersonal style (Schneider et al., 2012). Research in interpersonal theory posits that the interpersonal behavior is primarily based on two dimensions: affiliation and dominance (Leary, 1955; Sullivan, 2013). In this concept, affiliation continuously ranges from cold-hostile to warm-loving, and dominance is described by dominating versus patient behavior. Studies of parenting also posit responsiveness and demandingness as the two core elements of interpersonal behavior in caregiving relationships (Baumrind, 1991; Steinberg & Darling, 2017).

In the context of parent-child relationship, it is thought that parental behavior stems from the subjective experience of affection that a parent exhibits towards the child (Condon, 1993; Condon & Corkindale, 1998; de Cock et al., 2017). According to this theory, these parental behaviors are facilitated by parents' goal directed needs or dispositions to act in relation to the child (i.e. knowing, being with, avoiding separation and loss from, protecting, and gratifying the needs of the child). Parental attitudes toward child rearing are typically measured using four subscales: warmth, encouragement of independence, strictness, and aggravation; whereby stronger levels of warmth and encouragement and lower levels of strictness and aggravation indicate better parent-child relationships (PACR; Easterbrooks & Goldberg, 1984). It has been shown that an affectionate or warm interpersonal style is connected to secure attachment, while a cold-hostile style is related to insecure and anxious attachment (Horowitz, Rosenberg, & Bartholomew, 1993). Other studies have underscored that the effects of responsive parenting (e.g., as based on multiple dimensions of interpersonal style: engagement, sincerity, sensitivity, acceptance, emotional availability) are moderated by the level of caregiver-child attachment security (Kochanska, Aksan, Knaack, & Rhines, 2004). Indeed, intervention literature shows that children whose parents are trained in providing responsive interactions demonstrate improved attachment-related behaviors, supporting a causal role of sensitivity in shaping caregiver-child attachment (Juffer, Bakermans-Kranenburg, & van IJzendoorn, 2012; van IJzendoorn & Juffer, 1995).

The demanding or dominating dimension of parenting is characterized by highly controlling and negative behavior directed toward the child through prohibitions and restrictions. Intrusive and controlling behaviors (such as unnecessarily restraining or verbally controlling) reflect a parent's imposition of his or her own agenda onto the child and a failure to understand and recognize the child's effort to gain autonomy and self-efficacy (Egeland, Pianta, & O'Brien, 1993; Pungello, Iruka, Dotterer, Mills-Koonce, & Reznick, 2009). Thus, it is theorized that negative affect undermines children's autonomy and confidence and is subsequently linked to negative child outcomes and poor attachment (Adam, Gunnar, & Tanaka, 2004).

Nevertheless, there are critical differences between the concepts of affiliation and attachment: while attachment represents the quality of the relationship between two individuals, interpersonal affiliation relates to a person's general affection toward others. Thus, secure attachment can be seen as a result of experiencing an attachment figure as warm-loving and responsive, making parental affiliation a precursor for a child's attachment. It is suggested that a parent's own attachment and social characteristics have a fundamental role in parenting and children's subsequent attachment (Bowlby, 1969a; Fonagy, Steele, & Steele, 1991; Huth-Bocks, Levendosky, Bogat, & Von Eye, 2004) and studies investigating these links have found neural abnormalities in insecurely attached individuals (Depue & Morrone-Strupinsky, 2005; Teicher et al., 2016). As such, caregivers' interpersonal behaviors and a child's subsequent attachment are theorized to directly relate to children's neural development. Indeed, research in translational psychiatry demonstrated that childhood attachment style has been found to predict neural development (Coan, 2008; Cozolino, 2014; Leblanc, Dégeilh, Daneault, Beauchamp, & Bernier, 2017; Quirin, Gillath, Pruessner, & Eggert, 2010) and that maternal interpersonal affiliation is related to alterations in both the brain structure and function in adolescents (Schneider et al., 2012).

2.4 Children's Language Experiences at Home and their Language Development

Parental responsivity has been consistently positively associated with children's language development across early childhood (Pace et al., 2017; Tamis-LeMonda et al., 2014). Operationalized differently across studies, parental responsivity has been investigated behaviorally, verbally, and as a combination of the two modalities. Parental responsiveness, which is typically behaviorally evaluated, and verbal warmth, which concerns communication, may have overlapping or similar mechanisms related to the degree of attention and sensitivity allotted to the child (Masur, Flynn, & Eichorst, 2005), and as such, it is important to review the specific characteristics of parenting behaviors that contribute to children's development.

Parental responsiveness is characterized by the timing of a parent's response to a child (i.e. temporal contingency) and the relatedness of the parent's response (i.e. semantic contingency) and is thought to meaningfully build on the child's conversational bid thereby facilitating language development (Bornstein, Tamis-LeMonda, Hahn, & Haynes, 2008; Merz et al., 2015; Murray & Hornbaker, 1997; Tamis-LeMonda et al., 2014). Parents' responsiveness promotes and modulates infants' communicative skills before infants produce conventional words (Goldstein & Schwade, 2008; Tamis-LeMonda et al., 2014). When infants begin to babble and then produce simple phrases, responsiveness predicts the sizes of infants' vocabularies (Tamis-LeMonda & Bornstein, 1998), the diversity of infants' communications (Beckwith & Cohen, 1989), and the timing of language milestones (Tamis-LeMonda & Bornstein, 1998; Tamis-LeMonda, Bornstein, & Baumwell, 2001). In a set of studies, infants' vocabulary growth was tracked from 9 to 21 months and mothers' responsiveness was coded from video-recorded infant-mother interactions. Infants of high-responsive mothers (90th percentile) at 9 and 13 months achieved language milestones such as first words, vocabulary spurt, and combinatorial speech, four to six months earlier than infants of low-responsive mothers (10th percentile) (Tamis-LeMonda & Bornstein, 1998; Tamis-LeMonda et al., 2001).

Affective aspects of parent-child interactions and communication, including emotional tone and parental warmth, have also been found to be related to child development (Boak, 1999; Estrada, Arsenio, Hess, & Holloway, 1987; Hart & Risley, 1995; Pianta & Egeland, 1994). Positive main effects of warm, sensitive parenting on children's language abilities have been reported in infancy (Lisa Baumwell, Tamis-LeMonda, & Bornstein, 1997; Pungello et al., 2009). For instance, one study found that the children of mothers who were observed to be more sensitive at 12 and 24 months experienced faster rates of development of expressive and receptive language from 18 to 36 months (Pungello et al., 2009). In early childhood, maternal sensitivity and sensitive parenting have been found to be significantly associated with expressive and receptive language (Barnett, Gustafsson, Deng, Mills-Koonce, & Cox, 2012; Kelly, Morisset, & Barnard, 1996; Mistry, Biesanz, Taylor, Burchinal, & Cox, 2004) and to vocabulary scores (Fagot & Gauvain, 1997). It is important to note that parental sensitivity is not simply a measure of cognitive stimulation, and in fact, findings show that maternal sensitivity and cognitive stimulation are independently related to children's language outcomes at age four (Raviv, Kessenich, & Morrison, 2004). Hart & Risley (1995) found that parental feedback tone, statements of approval and other affirmations were positively correlated with measures of children's vocabulary use and growth. Positive statements, comments, praise; smiles and laughter; nurturing embraces or touches; and limited negative comments or yelling are some of the behaviors that have been related to positive child outcomes (Barnard, 1997). Similarly, studies have found that maternal warmth (Culp, Hubbs-Tait, Culp, & Starost, 2000; Hubbs-Tait, Culp, Culp, & Miller, 2002) (Culp et al., 2000) and parental positive affect (Hann, Osofsky, & Culp, 1996; Kelly et al., 1996) predicted children's receptive language.

In contrast to the positive impact of parental sensitivity and positive affect, negative parenting has received less attention in studies of early language development, although several findings show that parental intrusiveness and restriction is inversely related to children's receptive vocabulary scores (Culp et al., 2000; Elardo, Bradley, & Caldwell, 1977; Hart & Risley, 1995) and children's early achievement outcomes (Boak, 1999; Culp et al., 2000; Egeland et al., 1993). Restrictive or intrusive parenting communication is typically reflected in the verbal commands that parents use to guide and control their child's behavior. Parental directive language, which is defined as the relative amount of prompting that a child experiences or how often the child is asked - rather than told - what to do, and the subsequent guidance style that parents use with their children have also been related to later language and cognitive development (Hart & Risley, 1995; Walker, Greenwood, Hart, & Carta, 1994). In caregiver-child interactions, parental language modulates the amount of autonomy allotted to the child. As such, parental guidance and directiveness refers to the various strategies by which the parent provides more control and structure through increased information and less choice (Landry, Smith, Miller-Loncar, & Swank, 1997; Landry et al., 2001) and has consistently been found to inhibit a child's vocabulary (Dodici, Draper, & Peterson, 2003; Landry et al., 1997; Tomasello & Todd, 1983). While the degree of guidance can be measured verbally (e.g., Hart & Risley, 1995) or behaviorally (e.g., Masur, Flynn, & Eichorst, 2005), it is typically based on the utterances caregivers use and can be categorized by the verbal responses their utterance prompt. For instance, directive statements demand prompt action, whereas questions or suggestive statements ask for a response, and informative statement give limited or no direction and allow children to use the information as he or she chooses (Dodici et al., 2003). Instructive language that offers children more choice predicts positive academic outcomes in children (Masur et al., 2005; Pan, Imbens-Bailey, Winner, & Snow, 1996; Pine, 1994), as does parent-child inferential language, or communication that encourages decontextualized discourse on abstract or hypothetical situations (Merz et al., 2015). In fact, one study that measured both maternal verbal responsiveness and maternal verbal intrusive directiveness found that while verbal responsiveness positively predicted children's lexical growth, verbal instructive directiveness had negative predictive effects (Masur et al., 2005). Moreover, parents who frequently use directives with their children have been found to exhibit lower levels of responsiveness (Gest, Freeman, Domitrovich, & Welsh, 2004).

While many of the aforementioned studies assessed maternal responsiveness, it is important to note that paternal responsiveness and support also predicts infants' language development (Shannon, Tamis-LeMonda, London, & Cabrera, 2002) and school readiness (Martin, Ryan, & Brooks-Gunn, 2010). Findings consistently confirm that positive parenting behaviors related to improved language development contain elements of parental responsivity, sensitivity and emotional warmth. Critically, the benefits of such parenting are not merely epiphenomena of genetic heritability, as parental sensitivity relates to the verbal skills of adopted children (Stams, Juffer, & van IJzendoorn, 2002), predicts infant learning under laboratory manipulations (Goldstein, King, & West, 2003), and enhances children's language skills in interventions that target responsiveness (Landry, Smith, Swank, & Guttentag, 2008). Collectively, it is evident that caregiving drives children's language development; moreover, it is linked with early academic achievement and as such it is necessary to investigate the pathways by which caregiving impacts child outcomes.

2.5 Children's Language Experiences at Home and the Developing Brain

Brain plasticity during childhood makes the brain particularly sensitive to environmental influence, especially the social-affective, or caregiving, environment (Belsky & de Haan, 2011; Bernier, Carlson, & Whipple, 2010; De Bellis, 2001; Rifkin-Graboi et al., 2015; Schore, 2001).

In infancy, variations in maternal care and parent-child interactions are thought to influence epigenetic programming and help shape neural structures and circuits (Perry, 2002; Roth & Sweatt, 2011; Sethna et al., 2017). Much of what is known about the variations in caregiver care and offspring brain development and behavior is based on animal research (Champagne, 2008; Di Segni, Andolina, & Ventura, 2018). For example, increased maternal licking/grooming behavior in rodents has been linked with physiological and neural changes. Evidence across species demonstrates that caregivers regulate the neurodevelopment of those in their care (Callaghan, Sullivan, Howell, & Tottenham, 2014).

In humans, the impact of parenting on brain development stems largely from clinical populations (Nelson, 2014; Nelson et al., 2019). For instance, children suffering extreme neglect and deprivation in their first years of life have reduced grey matter volumes as adolescents (Eluvathingal et al., 2006; Mehta et al., 2009; Teicher, Samson, Anderson, & Ohashi, 2016; Tottenham et al., 2010). In fact, brain volumes of maltreated children have consistently been found to correlate negatively with the duration of abuse (e.g. the longer the duration of maltreatment, the smaller the volume) (De Bellis, 2001; De Bellis & Thomas, 2003). Findings on the effect of maltreatment on the developing brain include that the corpus callosum area of abused/neglected children was 17% smaller than controls and 11% smaller than fellow psychiatric patients who had not been mistreated (Teicher et al., 2004, 2016). Children with extensive histories of harsh corporal punishment manifest grey matter volume reductions of almost 20% in the right medial frontal gyrus (Tomoda et al., 2009). Findings consistently suggest that early childhood maltreatment is associated with subsequent neurodevelopmental abnormalities (Belsky & de Haan, 2011; De Bellis, Hall, Boring, Frustaci, & Moritz, 2001; H. Hart & Rubia, 2012; Teicher & Samson, 2016).

Emerging research suggests that normative variation in parenting quality relates to children's brain structure and findings consistently demonstrate the neuroanatomical differences associated with normative variations in maternal responsiveness, specifically (Bernier et al., 2018; Frye, Malmberg, Swank, Smith, & Landry, 2010; Kok et al., 2018, 2015; Leblanc et al., 2017;

Luby, Belden, Harms, Tillman, & Barch, 2016; Luby et al., 2013; Moutsiana et al., 2015; Rao et al., 2010; Rifkin-Graboi et al., 2015; Sarah Whittle et al., 2014, 2016).

Higher levels of parental sensitivity (Kok et al., 2015) and parent-child attachment security (Leblanc et al., 2017) have been linked with larger total brain and grey matter volumes in children and have been found to predict the volume of the left hippocampus in adolescence, with better nurturance associated with smaller hippocampal volume (Rao et al., 2010). Conversely, reduced maternal sensitivity was correlated with smaller subcortical grey matter volume (Sethna et al., 2017) and larger hippocampal (Rifkin-Graboi et al., 2015) and amygdala volume (Bernier et al., 2018). In studies investigating negative caregiving practices: insecure attachment in infancy was associated with greater amygdala volumes in adulthood (Moutsiana et al., 2015) and aggressive maternal behavior was also associated with alterations in adolescent brain maturation (Sarah Whittle et al., 2016). In a socioeconomically diverse participant sample, the degree of caregiver support and hostility was found to mediate the association between poverty and hippocampal volume (Luby et al., 2016). This finding indicates that not only is variation in normal childhood experience is associated with differences in brain morphology, but further suggests that warm caregiving has a buffering effect on child development.

Literature linking environmental influence with neural development suggests that certain brain regions that are instrumental to neurocognition may be especially sensitive during childhood. Language-related brain regions are those that have been shown to be most notably sensitive to children's environmental influence (Noble et al., 2007). The development of reading and language skills in children relies on the diverse network of regions that has been implicated in this body of literature, including the supramarginal gyrus (SMG), superior temporal gyrus (STG), left inferior frontal gyrus (IFG) and left fusiform gyrus (Noble et al., 2012; Raizada, Richards, Meltzoff &

Kuhl, 2008). Similarly, the ventromedial prefrontal cortex (vmPFC) and the anterior cingulate cortex (ACC), which are heavily involved in regulating cognitive control, have been implicated in their sensitivity to environmental and psychological influence (Sheridan & McLaughlin, 2014; Gianaros et al., 2007; McEwen & Gianaros, 2010; Noble et al., 2012). The orbitofrontal cortex (OFC) and middle frontal gyrus (MFG), which are involved in orienting attention, have also been linked to in studies of SES and brain morphometry (Japee et al., 2015; Jednoróg et al., 2012; Lawson et al., 2013: Ursache & Noble, 2016). Environmentally-related reductions in these neural regions have been associated with decline in cognitive function (Bradley, Corwyn, McAdoo & Coll, 2001; Linver, Brooks-Gunn, & Kohen, 2002). Regions of interest (ROIs) for the present study were selected based on the literature to encompass regions that support critical language skills in childhood.

2.6 Caregiving, Socioeconomic Status, and the Social Buffering Hypothesis

Proximal processes in the family and home environment influence children's developmental outcomes (Bronfenbrenner, 1986; Spera, 2005), and research has shown that the level of positive versus negative affect present in parent-child interactions is associated with a family's socioeconomic status (Bee, Van Egeren, Pytkowicz Streissguth, Nyman, & Leckie, 1969; Belsky, Bell, Bradley, Stallard, & Stewart-Brown, 2007; Bradley & Corwyn, 2002; Hart & Risley, 1995; Lugo-Gil & Tamis-LeMonda, 2008) and may vary by cultural context (Baumrind, 1972; Coll et al., 1996; Deater-Deckard & Dodge, 1997; Dornbusch, Ritter, Leiderman, Roberts, & Fraleigh, 1987; Ispa et al., 2004). For instance, Hart and Risley (1995) found that children living in low-income households heard twice as many prohibitions as affirmative statements from their parents compared to children living in middle- and upper- income households. Additionally, children from higher SES families experience more gestures by their caregivers and differences in early gesture accounted for SES-disparities in children's later vocabulary knowledge (Rowe & Goldin-Meadow, 2009).

It is theorized that life stress and unsafe living environments associated with low-SES might result in more negative, punitive, and authoritarian parenting, which in turn leads to adverse language and school readiness outcomes (Hoff, Laursen, & Tardif, 2002). In addition, an environment dominated by high levels of parenting stress and household chaos may create a disorganized home situation in which children are not able to optimally develop academic skills, whereas better family organization and greater parental warmth are associated with an increase in school readiness abilities (Vernon-Feagans, Willoughby, Garrett-Peters, & Family Life Project Key Investigators, 2016). However, it is important to note that neglectful acts of parenting occur in every culture, at all income levels, and within all racial, ethnic, and religious groups (National Scientific Council on the Developing Child, 2012).

Among children living in disadvantaged environments, sensitive parenting, or the presence of a supportive caregiver, has been consistently shown to promote more resilient long-term outcomes (Afifi & Macmillan, 2011; Durbin, Darling, Steinberg, & Brown, 1993; Miller-Graff, Cater, Howell, & Graham-Bermann, 2016; VanTieghem & Tottenham, 2018; Werner & Smith, 1992) and at least partially accounts for socioeconomic disparities in children's academic skills (Conger, Ge, Elder, Lorenz, & Simons, 1994; Linver, Brooks-Gunn, & Kohen, 2002; Masten, Best, & Garmezy, 1990; McLoyd, 1998). Research has shown that parental warmth or sensitivity at least partially accounts for SES-related disparities in children's language skills and trajectories (Mistry, Biesanz, Chien, Howes, & Benner, 2008; Noble, Engelhardt, et al., 2015; Raviv et al., 2004). Recent findings further demonstrated that caregiving and certain interactive features of communication (e.g. joint engagement, conversational turns) served as a buffer against poverty (Hirsh-Pasek et al., 2015; Luby et al., 2013). Moreover, research has shown that positive caregiver-child language interactions in child care settings buffered low-SES children from poor language outcomes, and such a buffering effect is especially strong for children who received limited language input at home (Vernon-Feagans, Bratsch-Hines, & The Family Life Project Key Investigators, 2013).

Interventions facilitating positive parenting practices, such as parental sensitivity and responsiveness have also furthered understanding of the importance of high quality caregiver-child interactions (Dozier et al., 2009; Fisher, Gunnar, Dozier, Bruce, & Pears, 2006). In the Play and Learning Strategies Intervention (PALS) (Landry et al., 2006, 2008), low-income mothers of six-month-olds were trained to respond to children's communication signals in a sensitive, warm, and contingent manner. Compared with children in the control group, children in the intervention group had greater receptive vocabularies, initiated conversations more often, and produced more words during mother-child interactions (Landry et al., 2006). Together, these findings suggest that responsive and engaging caregiver-child communication modulates the effects of SES on child development; thereby, mirroring the social buffering effects observed in neuroaffective development research (Gee et al., 2014; Hennessy, Kaiser, & Sachser, 2009; Hostinar, Johnson, & Gunnar, 2015; Kikusui, Winslow, & Mori, 2006). As such, positive caregiving practices can serve as a protective factor and may ameliorate the effects of early childhood adversity via social buffering. It is important to further identify how such protective factors influence neural development. Despite robust evidence of social buffering effects during typical neuro-affective development, no evidence to date has examined the effects of warm caregiver communication on children's language-related brain regions.

2.7 Summary

The integration of neuroscientific findings with psycholinguistic and attachment theories has contributed to greater understanding of the significance of early caregiver relationships. Findings support a social relational approach by which the most pervasive and potent relational experiences of childhood, caregiver-child interactions, can be seen as a primary mechanism to account for experience-driven differences in children's neural development and academic readiness. In short: how caregivers communicate with children affects children's developmental outcomes. Although there is a growing literature pertaining to caregiving interactions and brain morphology, there are no studies that focus directly on the affective features and quality of caregiver communication. If an effective parent-child relationship is one that includes high levels of emotional warmth and encouragement and low levels of strictness and aggravation, then it is necessary to review the psycholinguistic relationship of positive, warm communication (i.e. sensitive, affectionate, responsive) and negative communication (i.e. demanding, controlling, and punitive) on children's neural development. As such, the proposed study will investigate how the quantity and the quality of communication interact to shape the architecture of the developing brain. Moreover, because the deleterious relationship between poverty and children's neural structure has been found to be most prominent in regions supporting language, reading, executive function skills (Merz, Wiltshire, & Noble, 2018; Noble, Houston, et al., 2015); the current study further investigates whether the brain regions associated with these abilities are most vulnerable to differences in the home language environment and caregiver communication.

Chapter 3: The Current Study

3.1 The Problem

Extensive research points towards the protective and bolstering effect of nurturing, responsive, and reliable caregiving on cognitive development, and a growing body of recent work has demonstrated associations between caregiving quality and children's brain structure and function. Conversely, findings repeatedly confirm that repeated or persistent periods of prolonged unresponsiveness or hostile caregiving lead to detrimental physiological, neurological and psychological outcomes in children. Yet, there are several gaps in the literature:

(1) Transcription & neural variables: Some studies conduct rich micro-coding of parental speech and link these findings to different aspects of language development (e.g., Rowe et al., 2004). Other studies have looked broadly at children's language experiences and brain outcomes (e.g. Zangl & Mills, 2007). Recent research has further linked automated measures of the home language environment to neural outcomes (e.g., Merz et al., 2019, Romeo et al., 2018). Yet, no work has combined rich psycholinguistic micro-coding with detailed information about neural structure of function that state-of-the-art brain imaging provides.

(2) Naturalistic home environment: Most research on child-directed speech has relied on rough approximation measures of children's language experiences from laboratory settings, whereas the current study offers insight into the naturalistic, fine-grained language interactions children experience.

(3) Typically-developing sample: Much of the existing neurodevelopmental literature on the role of the caregiver documents children's outcomes following extreme childhood adver-

sity (i.e. institutionalization, child maltreatment). Thus, less is understood about how normative variations in caregiver-child interactions, specifically communication, are associated with the development of the brain in typical, naturalistic settings among children with a more typical range of experiences (Belsky & de Haan, 2010).

(4) Concomitant development: While the reviewed neuroscientific investigations of caregiver quality in normative pediatric populations are an important first step, some are retrospective in design, or had lengthy periods between caregiving measures and MRI acquisition (Frye et al., 2010; Kok et al., 2015; Leblanc et al., 2017; Moutsiana et al., 2015). Others used infant (de Cock et al., 2017; Sethna et al., 2017) or adolescent samples (Whittle et al., 2014). Yet, because child development is embedded in the family context, it is valuable to investigate the home environment and brain structure concomitantly.

(5) Independent effects of communication style: There are few studies that have examined both sensitive and intrusive caregiver communication in relation to early language development, and moreover, these studies have yielded mixed findings (Baumwell & Tamis-LeMonda, 1997; Kelly et al., 1996; Shannon et al., 2002). Others have found that both sensitivity and negativity had independent (Keown, Woodward, & Field, 2001) and polarizing relations with children's outcomes (Hubbs-Tait et al., 2002). For instance, children whose parents provided the highest proportions of emotional support and the lowest proportions of intrusive behavior demonstrated the highest language scores (Hubbs-Tait et al., 2002). These findings suggest that the proportion of caregiver verbal warmth and negativity may contribute independently to development and their contributions may differ depending on environmental context. As such, it is necessary to examine the separate links of caregiver verbal warmth and verbal negative affect with neurodevelopment.

While the link between caregiver-child interactions and language skills is well-established, the relationship between caregiver communication and children's language-related neural development has never been studied. In short, no work has examined whether, in natural environments, among normative populations, child-directed speech content and delivery impacts children's neurodevelopmental outcomes.

3.2 Overview of the Current Study

The goal of this dissertation is to examine the association between the quality of children's linguistic experiences – as operationalized by adult verbal warmth – and their cognitive developmental outcomes. A socioeconomically diverse sample of 94 parents and their 5-to-9-year-old children participated in this study. A digital audio recording of the home environment was obtained, and children completed a high-resolution, structural MRI scan as well as direct assessments of their language, cognitive and reading skills. The audio recordings were transcribed and coded using a coding scheme newly developed by the candidate in consultation with leading experts, in order to identify and quantify psycholinguistic elements of adult-child communication. Linking these rich linguistic data to children's MRI data enabled an in-depth analysis of the neural pathways through which psychosocial language experiences impact developmental and academic outcomes. Primary hypotheses included that adult verbal warmth is associated with (1) language skills outcomes (2) reading outcomes and (3) the neural regions associated with these domains. To date, no studies have combined a transcription-based, fine-grained analysis of naturalistic home recordings with neuroimaging data. As such, this study represents a new line of inquiry at the nexus of developmental psychology, neuroscience, and education. The findings aim to shed light on the neural mechanisms linking adult verbal warmth to children's cognitive, linguistic and reading outcomes, and on which forms of adult-child communication are most conducive to learning. Such information can inform programs that aim to teach parents ways to nurture their children's growth through the quality of language input. This study also provides evidence on how to mitigate risk factors and bolster protective factors in order to, ultimately, foster healthy development for all children.

3.3 Research Aims and Hypotheses

The present study is designed to examine how psycholinguistic patterns in the quality of parental speech to children, specifically verbal warmth and verbal negative affect, relate to children's cognitive development. It was hypothesized that caregiver verbal warmth would explain unique variance in children's language and reading skills beyond that explained by the quantity of language input alone. The first goal was simply a descriptive one: to help provide a fuller picture of *how* caregivers speak to children in the naturalistic, home environment setting. A second goal was to examine whether verbal warmth has a positive, or supportive, effect for child development outcomes, and conversely, whether verbal negative affect confers a negative impact on child development outcomes. A third goal was to investigate the extent to which children's brain structure accounted for any links between caregiver verbal warmth/negative affect and children's developmental outcomes. These goals are reflected in 4 specific aims and sets of hypotheses, below.

Specific Aim 1: Examine the association between caregiver verbal warmth/negative affect and children's language outcomes.

Hypothesis 1a: Higher levels of verbal warmth will be associated with improved language skills, when controlling for automated counts of the total number of words heard.

Hypothesis 1b: Higher levels of verbal negative affect will be associated with worse language skills, when controlling for automated counts of the total number of words heard.

Specific Aim 2: Examine the association between caregiver verbal warmth/negative affect and children's reading outcomes.

Hypothesis 2a: Higher levels of verbal warmth will be associated with improved reading skills, when controlling for automated counts of the total number of words heard.

Hypothesis 2b: Higher levels of verbal negative affect will be associated with worse reading skills, when controlling for automated counts of the total number of words heard.

Specific Aim 3: Investigate the association between caregiver verbal warmth/negative affect and children's language-related brain structure.

Hypothesis 3a: Higher levels of verbal warmth will be associated with greater surface area in language-supporting brain regions, and these associations will hold when controlling for socioeconomic factors.

Hypothesis 3b: Higher levels of verbal negative affect will be associated with lower surface area in language-supporting brain regions, and these associations will hold when controlling for socioeconomic factors.

Exploratory Aim 4: Examine mediational models accounting for links among SES, caregiver verbal affect, brain structure, and children's reading and language outcomes.

Hypothesis 4a: The associations between adult verbal affect and children's reading and language skills will be mediated by language-related brain structure.

Hypothesis 4b: The association between family SES and children's reading and language skills will be jointly mediated by caregiver verbal affect and language-related brain structure.

3.4 Methods

3.4.1 Participants

Recruitment: Participants were recruited from community events and posting flyers in local neighborhoods in New York, NY. A socioeconomically diverse sample was recruited by ensuring that families in the study represented a wide range of parental educational attainment. Interested families were contacted by phone and screened for eligibility. Inclusionary criteria were as follows: 1) between 5 and 9 years of age, 2) born after 37 weeks of gestation, 3) born from a singleton pregnancy, 4) no history of medical or psychiatric problems, 5) the primary caregiver and child were proficient in English, and English was the language spoken most often in the home. Children with contraindications for MRI scanning were excluded.

Sample characteristics: Children ranged from 5.06 to 9.87 years of age (61% female), family income ranged from \$2,880 to \$350,000 (income-to-needs ratio range: .17 - 15.21), and parental education ranged from 6.50 to 20.00 years. Children were 50% Hispanic/Latino, 31% African American, non-Hispanic/Latino, and 14% White, non-Hispanic/Latino.

Sample sizes: There were 94 total families who completed questionnaires and the child testing battery. Of those, 80 provided LENA data. LENA data were missing for families that declined to schedule the LENA recording days (n = 3), did not return the LENA recorder (n = 8), or returned the recorder without recorded data (n = 3). Of the 94 total families, 85 were enrolled in the MRI portion of the study and participated in a mock scan. Out of that group, MRI data were acquired for 66 children. MRI data were missing because the family or child chose not to participate in the MRI scanning session following the mock scan (n = 12) or because the child was fidgety, afraid, or uninterested during the mock scan and the MRI scan was therefore not scheduled (n = 7). There were no significant differences between participants who had both MRI and LENA data and those who did not in terms of child sex, $\chi^2(1) = .02$, $p = .90$, child race/ethnicity, $\chi^2(2) = 3.73$, $p = .16$, family income-to-needs ratio, $t(92) = -.39$, $p = .70$, or parental education, $t(92) = -1.37$, $p = .17$. However, the subsample with both MRI and LENA data was older on average (7.38 vs. 6.67 years) than those without these data, $t(92) = -2.79$, $p = .01$, due to older children being more likely to complete the mock scan and MRI scan.

3.4.2 Procedure

Families participated in two campus visits within a month. During the first visit, informed consent/assent was obtained from parents and children. Children then completed a neurocognitive task battery, while parents completed questionnaires and were given a LENA recorder with instructions (detailed below). Finally, a mock MRI session was performed to familiarize children with scanning and to gauge child interest in scanning. During the second visit, children completed the MRI scan. All procedures were approved by the Institutional Review Boards at New York State Psychiatric Institute.

Image Acquisition and Processing:

MRI data were acquired on a 3-Tesla General Electric MR750 scanner with a 32-channel head coil. During scanning, children watched a movie of their choice. Children completed a high-resolution, T1-weighted fast spoiled gradient echo scan with the following parameters: sagittal acquisition; TR=7.1ms; TE=min full; inversion time (TI)=500 ms; flip angle=11 degrees; 176 slices; 1.0 mm slice thickness; FOV 25 cm; in plane resolution= 1x1 mm. All images were visually inspected for motion artifacts and ghosting, leading to exclusion of 15 participants, and a final sample of 51 usable scans. There was no manual editing of data that were deemed eligible for inclusion. Images were processed using standard automated procedures in the FreeSurfer software suite (http://surfer.nmr.mgh.harvard.edu/) (version 6.0). These included removal of non-brain tissue, image intensity normalization, and construction of white/gray matter and gray matter/cerebrospinal fluid boundaries (Dale, Fischl, & Sereno, 1999; Fischl & Dale, 2000). Following cortical surface reconstruction, automated procedures parcellate the cerebral cortex into regions based on gyral and sulcal structure (Desikan et al., 2006; Fischl et al., 2004), based on the Desikan-Killiany atlas (Desikan et al., 2006).

Home Language Activity:

Parents were given a 2-ounce LENA Pro digital language processor (DLP), which fits in a child's shirt pocket and stores up to 16 hours of digitally recorded audio (Xu, Yapanel, & Gray, 2009). They were also given two child-sized t-shirts with specially designed pockets to hold the DLP securely. Parents were instructed to record 8 continuous hours each day for two days (weekend days or days when children were primarily at home), amounting to 16 recorded hours. The average number of days between LENA recording and the MRI scan was 5.80 (SD = 15.10), with a maximum of 65 days. Upon return of the DLPs, audio data were transferred and analyzed using the LENA software, which employs advanced speech-identification algorithms that automatically analyze audio files and produce reports of language activity (Oller et al., 2010; Xu, Yapanel, & Gray, 2009).

Audio Data Preparation:

The LENA software was used to prepare each participant's large dataset of recorded audio for further coding of linguistic complexity and adult verbal warmth following previously used procedures (Ramírez-Esparza, García-Sierra, & Kuhl, 2014). The audio files were processed using the LENA Advanced Data Extractor Tool (ADEX) in order to efficiently identify intervals with the language activity of interest (i.e., adult speech), eliminate intervals that did not qualify for analysis as described below, and segment each participant's large audio file into 30-s intervals. Intervals for coding were identified based on adult word count in order to ensure that there was appropriate language activity to allow for coding of psycholinguistic factors of child-directed speech. Each hour of recording yielded approximately 75-120 intervals with adult word counts after the data were segmented into 30-s intervals. Intervals with zero adult words were removed and intervals that were at least 3-min apart were selected from the remaining intervals across the entire day. Of these, 60 intervals were chosen from those with the highest adult word counts. This was done to ensure that there would be sufficient language activity to produce variability in warmth and negative affect. This approach further ensured that there was no coding of intervals containing only silence or non-speech noise.

Sixty 30-s intervals were identified for each participant, yielding a total of 30 minutes of audio per participant. Past work has suggested that at least ten minutes of audio recording per participant are required to obtain accurate results when coding linguistic complexity (Rowe, 2011).

The majority of participants provided 16 hours of audio (8 hours on two days), and for those participants, thirty 30-s segments were chosen from each day. For participants whose recordings were unevenly distributed across days, or when participants provided one or three days' worth of recording, the proportion of each day's recording was used to calculate the number of intervals to include from the given day (e.g., if one day of recording yielded 4 of the 16 total hours, then 25% of the intervals, or 15 intervals, would be used from the 4-hour recorded day).

Home Language Activity Transcription:

All utterances by adults and children in the selected LENA audio recordings were transcribed verbatim by research assistants trained to transcribe reliably using the CHAT conventions of the Child Language Data Exchange System (CHILDES; MacWhinney, 2000). Transcribing software (Transcriber 1.5.1) played the specific 30-s interval for coding based on the time stamp entered in a participant's transcription template, and transcripts were subsequently divided using the GEM command in the CLAN program to yield corresponding transcript blocks for pre-selected recording intervals. The unit of transcription was the utterance, which is defined as speech by one speaker bounded by transition in speaker, grammatical closure, and/or a pause of more than two seconds. In transcription, we were liberal in what counted as a word. All dictionary words, as well as onomatopoeic sounds (e.g. woof) and evaluative sounds (e.g. uh-oh), were counted as words and transcribed (Rowe, 2008). Transcripts were then coded for communicative intent using the pragmatic coding system. Transcription procedures were developed in consultation with Dr. Meredith Rowe's Lab and a review of prior transcription protocol (MacWhinney & Wagner, 2010).

A team of five research assistants were trained on the CHAT conventions during the Spring 2019 semester. On average, it took approximately 10 hours to transcribe each 30-minute audio recording, not including transcription verification procedures. A doctoral researcher verified each transcript to ensure accuracy. Transcription reliability was established by having research assistants transcribe with a reliability criterion of 95% (Rowe, 2008). Reliability was based on accuracy of both utterance boundaries and word transcription and was achieved when the second coder agreed with the first on 95% of the transcription decisions. Once the transcriber and reliability coder agreed on the accuracy of 95% of the utterances, the transcriber's data was used. In addition to having the verifier listen to the audio and read over the transcript to ensure that nothing was missing, a frequency and check analysis were conducted (FREQ and CHECK in CLAN) to get a list of the words spoken in the transcript and check the accuracy of the transcription. All discrepancies were resolved through discussion During the course of the study, transcribers participated in weekly reliability meetings to ensure reliability maintenance..

Transcripts that contained any Spanish were transcribed, translated, and coded by native Spanish speakers. All instances of bilingual code-switching was transcribed into English to ensure that utterances could be coded and verified by the doctoral researcher using the same procedure. It should also be noted that transcripts that included Spanish were not different in any meaningful way (demographic: age, SES; home language input quantity: adult word count, conversational turn count, child vocalization count) from the transcripts that did not.

Coding Child-Directed Speech:

Identified intervals were coded for each participant by trained coders. Coders were provided with basic information about each interval (date, day of the week, time of day, and the time stamp on the audio recording) to supplement audio recordings and transcripts. A set of abbreviated codes was created for the proposed pragmatic speech codes. A new dependent tier was created in the CLAN program to accommodate the aforementioned codes (%prg). Subsequent analyses relied on a frequency count of the codes of interest in the pragmatic speech tier. Five research assistants independently coded 15% of the transcripts (Rowe et al., 2015). Kappa coefficients for five coders ranged from .90 to .97 (Bakeman & Gottman, 1997).

3.4.3 Measures

SES indices: Parents reported their annual household income and the number of adults and children in the household. The income-to-needs ratio was calculated by dividing household income by the poverty threshold for the size of the family. Family income-to-needs ratio was log-transformed to correct for positive skew. In addition, parents reported on their years of educational attainment, which were averaged across the number of parents in the household.

Language input quantity: LENA software provided estimates of the total number of adult words spoken in the recording, the total number of child vocalizations, and the total number of adult-child conversational turns, defined as an adult utterance followed by a child utterance within five seconds or vice versa. These totals were then divided by the amount of recording time in hours to generate hourly adult words, conversational turns, and child vocalizations (Merz et al., 2019).

Audio recording time: The majority of families (66%) had 16 hours of recording time. Three families with < 5 hours of recording time and one family that used the recorder incorrectly were excluded from analyses, for a final total of 76 families with usable LENA data. Recording time ranged from 5.18 to 16.00 hours (M = 14.22, SD = 3.24, skew = -1.73, kurtosis = 1.64). Out of the sample of 43 children with both LENA and imaging data, there were 8 recordings that were < 10 hours. Audio recording time was not associated with hourly adult word count (r = -.07, p = .55), but was significantly associated with hourly conversational turn count (r = -.32, p = .005) and child vocalization count (r = -.29, p = .01).

Reliability check: LENA speech identification algorithms have demonstrated strong reliability, with approximately 82% accuracy for adult speech and 76% accuracy for the speech of children up to 3 years of age (Gilkerson et al., 2017). The LENA system has been formally validated up to 4 years of age, and recent work has successfully used LENA algorithms with older children (Romeo et al., 2018; Vohr, Topol, Watson, St Pierre, & Tucker, 2014; Wang, Pan, Miller, & Cortina, 2014). As an additional check, we examined the reliability of child vocalization counts in our sample following previously used procedures (Weisleder & Fernald, 2013). Twelve 5-minute chunks were transcribed from ten randomly chosen home audio recordings, generating 60 minutes of transcribed speech for each of these ten participants. To include chunks that were representative of the entire recording, four 5-minute chunks were selected randomly from the top, middle-, and bottom-third of the distribution of child vocalization counts for each participant, totaling 20 minutes of transcribed speech in each bin for each participant. Analysis of these transcriptions revealed a strong correlation between automated estimates of child vocalizations and transcriber-based child vocalization counts ($r = .74$, $p < .001$), confirming that the LENA system's estimates of child vocalizations in recordings of 5- to 9-year-old children are as reliable as those used in younger children (Merz et al., 2019).

Language skills: Children's language skills were measured using the Comprehensive Test of Phonological Processing, Second Edition CTOPP-II (Wagner, Torgesen, Rashotte, & Pearson, 1999) Elision, Blending Words, and Sound Matching subtests. Scores on these subtests were standardized and averaged to create a phonological processing composite.

Reading skills: Children's reading skills were measured using the Woodcock-Johnson Tests of Achievement III (Woodcock, McGrew, & Mather, 2001) Letter-Word Identification, Word Attack, and Passage Comprehension subtests. Raw scores on these subtests were strongly correlated (r=.89-.95, $p < .0001$) and thus were standardized and averaged to create a reading composite.

Brain Regions of Interest: Regional surface area analyses were conducted with the Query, Design, Estimate, Contrast (QDEC) surface-based analysis tool, using a 10mm smoothing kernel and cluster-wise correction for multiple comparisons. Based on past literature linking the following regions to language skills and socioeconomic difference, the following areas were selected as *a priori* language related regions of interest: inferior frontal gyrus (IFG), superior temporal gyrus (STG), and fusiform gyrus. Additionally, QDEC was used to estimate total cortical surface area across the entire cortical surface.

Measuring Adult Verbal Warmth

Based on a review of the literature and extant measures, as well as consultations with leading researchers, I conducted the exploratory and conceptualization phases of developing an adult verbal warmth/ negative affect coding scheme. I drafted the coding template in collaboration with experts in fields whose expertise ranged from maternal responsiveness to social interaction coding. Iterative versions of the coding template were created following feedback from these experts. I then pre-piloted the coding scheme by sampling its utility with LENA audio recordings.

The majority of parent-child communication coding schemes rely on video-recorded interactions (Merz et al., 2017; Rowe, Coker, & Pan, 2004; Snow, Pan, Imbens-Bailey, & Herman, 1996; Tamis-LeMonda & Bornstein, 2001) While caregiver responsiveness to a child's cues is defined as prompt (occurring within a 5-s window of the onset of child behavior); contingent (depending conceptually on the preceding child behavior); and appropriate (mother responds in a positive and meaningful way), much of these responsive behaviors include nonverbal communication, gestures, and attention directing and orienting (Bornstein et al., 2008). Similarly, assessments that focus on parental warmth typically emphasize in-person observations of physical affection (e.g., Home Observation for Measurement of the Environment Parental Warmth subscale, Caldwell & Bradley, 1984). Due to the audio recordings used in the present study, we were unable to capture nonverbal promptness and appropriateness of a caregiver's response to a child nor the amount of physical affection. As such, a new coding scheme was developed to capture the pragmatic and affective features of caregiver speech that are of interest and that were captured via audio. Such fine-grained coding of parent behavior – whether by audio or video – has rarely if ever been used in conjunction with measures of children's brain development to date.

Pragmatic features examined in caregiver speech included the following mutually-exclusive categories: positive and negative expressions, prohibitions, and affirmations (see Table 1) (in part, adapted from Karasik, Tamis-LeMonda, & Adolph, 2014; Landry et al., 2008; Rowe et al., 2004).

In an analysis of maternal behaviors, Landry et al. (1997) determined that various observed maternal behaviors were significantly intercorrelated, and as such, scores were averaged to obtain a single composite measure that was labeled “warm responsiveness.” Similarly, Dodici and Draper (2003) found that a high level of multicollinearity existed between parent-child interaction scores and overall parenting scores, concluding that an overall parenting-child interaction score is a better predictor than the score of any one behavior. Yet, Landry et al. (2008) found independence among maternal response types, lending support to a multidimensional and modular account of parental responsiveness (Bornstein et al., 2008). As such, all coded adult communication data will be assessed through factor analysis to determine whether an aggregated caregiving rating of “warmth” and “negative affect” would be more appropriate than examining the psycholinguistic categories independently.

It is important to note that research demonstrates that parental directive behaviors do not necessarily connote negative parenting, especially in non-European-American mothers who are not from the majority group in the United States (Halgunseth, Ispa, & Rudy, 2006; Ispa et al., 2004; Lugo-Gil & Tamis-LeMonda, 2008). As such, and in order to more aptly capture and distinguish between negative parenting and directiveness, a fifth category was included in the developed coding scheme: “imperatives.” Doing so insured that parental directives or commands would not be classified under “negative affect.” Imperatives were not included in the final analyses, but were coded nonetheless. In contrast to caregiver discipline, which is focused on control, the focus of the present study is on negative affect, which encompasses negative, hostile or critical verbal behavior, including speaking negatively to and blaming the child, as well as putting the child down.

Table 1. Pragmatic Speech Coding Scheme

Type of Speech Act	Definition	Examples
Affirmation	Verbal encouragements of a child's behavior or efforts, whereby the adult is recognizing and praising a child's behavior or agreeing with child	"Yes" "Good job" "You did it!" "Thank you"
Prohibition	Utterances that prohibit or stop a child's behavior, including interrupting a child activity to get the child to do something else	"No" "Stop" "Don't do that"
Positive Expression	Utterances conveying sensitivity, enthusiasm, affection, guidance, or empathy directed at the child	"I love you" "honey" Terms of endearment
Negative Expression	Expressions include insensitive, inflammatory, disrespectful or hostile language directed at the child	"You're being bad" "Stop bothering me"

3.5 Preliminary Data

Preliminary data (Merz et al., 2019) demonstrates that among this sample:

(1) Socioeconomic factors are associated with automated measures of language input. Specifically, higher parental education and higher family income-to-needs ratio were each associated with higher hourly conversational turns and hourly adult words, as measured by LENA.

(2) Greater language input is associated with greater left perisylvian cortical surface area. Specifically, children who experienced more conversational turns and/or more adult words had significantly greater surface area in the left perisylvian cortex, with a larger effect size for conversational turns; remaining significant after controlling for socioeconomic factors.

(3) Home language input mediated the association between parental education and children's left perisylvian cortical surface area.

(4) Home language input was indirectly associated with children's reading skills via left perisylvian cortical surface area, and left perisylvian cortical surface area significantly mediated the association between parental education and children's reading skills.

As outlined above, it was hypothesized that the warmth and negative affect of language input, as based on the aforementioned coding scheme, would account for variance in children's cognitive and neural outcomes, above and beyond the variance accounted for by these automated measures of language input quantity.

3.6 Analytic Approach

All analyses were conducted using SPSS software (version 26.0) and FreeSurfer software (https://surfer.nmr.mgh.harvard.edu/). First, factor analysis of the pragmatic speech codes was used to inform data reduction and variable creation. Next, bivariate correlations between speech code factors and child outcomes were examined. In analyses of the links between verbal affect and child brain morphometry, surface area was examined using whole-brain-corrected, vertex wise analyses. Monte Carlo null-Z simulations were conducted with the cluster-wise *p*-value threshold set to 0.05 and the vertex-wise threshold set to 0.01. Surface area data for significant cluster(s) identified in the vertex-wise analyses were extracted for each participant and imported into SPSS for further analyses.

Subsequently, hierarchical multiple regression models were run to test Hypotheses 1-5 as follows, with *a priori* plans to control for child age and hourly adult word count, as well as sex and race if these demographic factors were associated with adult verbal warmth or negative affect. To test Hypotheses 4-7, surface area and cortical thickness were considered independently for each ROI.

Specifically, to test **Hypothesis 1a**, language skills, as measured by (i) the phonological composite (ii) the linguistic complexity composite), were regressed onto verbal warmth, adjusting for covariates. To test **Hypothesis 1b**, the two language composites were regressed onto verbal negative affect, adjusting for covariates.

To test **Hypothesis 2a**, the reading skills composite was regressed onto verbal warmth, adjusting for covariates. To test **Hypothesis 2b**, the reading skills composite was regressed onto verbal negative affect, adjusting for covariates.

To test **Hypothesis 3a,** surface area was extracted for the following *a priori* language-related regions of interest (ROIs): inferior frontal gyrus (IFG), superior temporal gyrus (STG), supramarginal gyrus (SMG), and fusiform gyrus. ROIs were then regressed onto adult verbal warmth, adjusting for covariates. To test **Hypothesis 3b**, surface area of each of the language-related ROIs was regressed onto adult verbal negative affect, adjusting for covariates.

To test Hypotheses 4 , mediation analyses were planned, provided that significant associations occurred at every level. To test the significance of the mediated (*ab* path), bias-corrected boot-strapping via the PROCESS macro were planned, with a 95% confidence interval (Hayes, 2013).

Specifically, if any significant links exist between adult verbal warmth and/or negative affect and children's reading and language skills, then **Hypothesis 4a** will be tested by exploring whether such links are statistically mediated by surface area in any of the language-related *a priori* ROIs: inferior frontal gyrus (IFG), superior temporal gyrus (STG), supramarginal gyrus (SMG), and fusiform gyrus.

Finally, if any significant links exist between family SES (parental education / family income-to-needs ratio) and children's reading and language skills, then **Hypothesis 4b** will be tested by exploring whether such links are jointly mediated by caregiver verbal warmth or negative affect as well as by surface area in any of the above *a priori* language-related ROIs.

Chapter 4: Results

4.1 Data Reduction of Adult Verbal Affect Codes

Data were cleaned, processed and transformed to normalize values. Principal component analysis was used to identify and compute the factors underlying the pragmatic speech codes (adult affirmations, adult prohibitions, adult negative expressions, and adult positive expressions). Initial eigenvalue examination demonstrated that two factors had an eigenvalue greater than 1. Solutions for two factors were examined using varimax rotations of the factor loading matrix with Kaiser Normalization. Minimum criteria of having a primary factor loading of .4 or above was enforced and all other coefficients were suppressed. The rotated component matrix, or structure matrix, yielded correlations of 0.85-0.94 between factors and the respective variables and indicated that there were two clear patterns of adult child-directed speech and that these patterns are independent of one another. As such, this rotation provided the best-defined factor structure. Factor loadings revealed that the first principal component corresponded to adult verbal negative affect (with adult prohibitions and adult negative expressions having factor loadings of .845 and .884, respectively). The second principal component corresponded to adult verbal warmth (with adult affirmations and adult positive expressions having factor loadings of 0.940 and 0.849, respectively). Together, these two principal components accounted for 81% of the variance in pragmatic speech codes.

Composite scores were created for adult verbal warmth by taking the mean of hourly adult affirmations and hourly adult positive expressions. Composite scores were created for adult verbal negative affect by taking the mean of hourly adult prohibitions and hourly adult negative expressions. Higher scores indicated higher hourly frequencies of adult verbal warmth or adult verbal negative affect. The skewness and kurtosis were well within a tolerable range for assuming a normal distribution and examination of the histograms suggested that the distributions looked approximately normal. Overall, analyses indicated that two distinct factors were, in fact, underlying the pragmatic speech codes in transcribed adult-child conversations and thus the data were well suited for subsequent statistical analyses.

4.2 Data Analysis

Bivariate Correlations: Verbal Affect, Language Input Quantity, and Socioeconomic Factors

Table 2 shows the mean, standard deviation, and range of adult verbal affect scores (warmth/ negative affect), the quantitative home language environment (hourly conversational turns, hourly child vocalizations, and hourly adult words as provided by LENA), and socioeconomic factors (parental education, family income-to-needs ratio). We first examined the association between adult verbal affect and (1) home language input (quantity) (Table 2) and (2) socioeconomic factors (Table 3). Adult verbal warmth was significantly positively associated with hourly adult words (r = 0.451, p = 0.002), but was not associated with hourly conversational turns or hourly child vocalizations. Parental negative affect was not significantly associated with any measures of quantitative home language input (see Table 2).

Table 2. Descriptive Statistics for Verbal Affect and Home Language Environment

	M	*SD*	Min.	Max.
Adult verbal warmth	0.00	1.00	-1.28	3.05
Adult verbal negative affect	0.00	1.00	-1.40	3.21
Hourly conversational turns	50.37	25.75	5	115
Hourly child vocalizations	202.30	109.44	13	453
Hourly adult words	1,222.53	558.80	166	2622
Family income-to-needs ratio	2.62	2.77	-1	1
Parental education (years)	14.64	2.60	10	20

Table 3. Zero-Order Correlations for Verbal Affect and Home Language Input

	1	2	3	4	5
1. Adult verbal warmth	-				
2. Adult verbal negative affect	.000	-			
3. Hourly conversational turns	.199	-.175	-		
4. Hourly child vocalizations	.081	-.143	.865**	-	
5. Hourly adult words	.451**	-.194	.776**	.532**	-

*$p < .05$. **$p < .01$. ***$p < .001$.

Socioeconomic Factors Are Associated with Adult Verbal Warmth but not Negative Affect

Family income-to-needs ratio and parental education were significantly positively associated with adult verbal warmth (r = 0.390, p = 0.010; r = 0.485, p = 0.001, respectively). Neither socioeconomic factor was significantly associated with adult verbal negative affect (see Table 4, Figure 1).

Table 4. Zero-Order Correlations for Verbal Affect and Family SES Factors

	1	2	3	4
1. Adult verbal warmth	-			
2. Adult verbal negative affect	.000	-		
3. Family income-to-needs ratio	.390*	-.110	-	
4. Parental education (years)	.485**	-.193	.625**	-

*$p < .05$. **$p < .01$. ***$p < .001$.

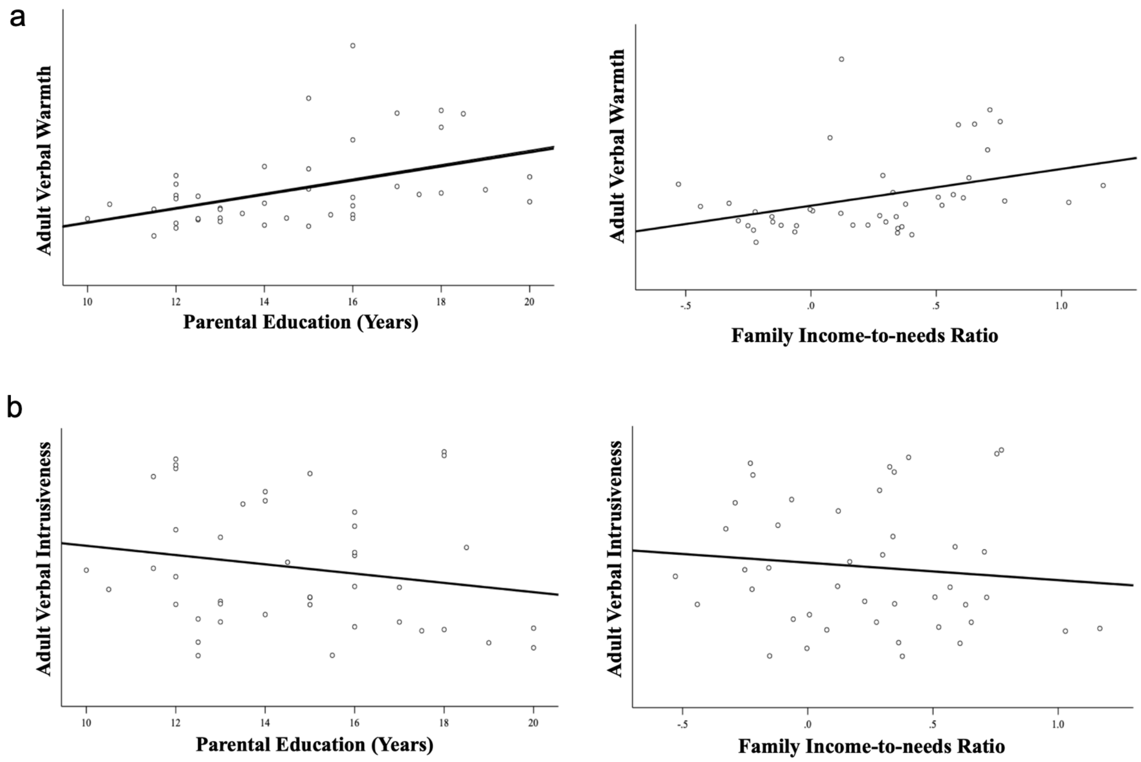

Figure 1. Scatterplots of (a) adult verbal warmth and (b) adult verbal negative affect as functions of parental education and family income-to-needs ratio (N = 43). Regression analyses controlled for child age and hourly adult words.

Multiple regression analysis was used to test whether home learning environment variables predicted adult verbal affect. Sex and race were not significantly associated with adult verbal warmth or negative affect, and therefore these factors were not included in regression models. When controlling for family income-to-needs ratio and age, language input quantity predicted adult verbal warmth (β = .0.394, *SE* = 0.141, *p* = 0.008) (see Table 5, Model 3). In other words, hourly adult word count predicted adult verbal warmth over and above family income-to-needs (Table 5). Conversely, regression results indicated that neither language input quantity nor socioeconomic factors significantly explained unique variance in adult verbal negative affect, after adjusting for control variables (see Table 6).

Table 5. Associations Between SES Factors and Adult Verbal Warmth

Independent variable	Adult verbal warmth						
	Zero-order correlation coefficients	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Socioeconomic factors:							
Family income-to-needs ratio	0.390**	0.390**	0.282+	0.254			
		(0.144)	(0.141)	(0.141)			
Parental education	0.485**				0.485***	0.357*	0.351*
					(0.137)	(0.146)	(0.144)
Home language environment:							
Hourly adult words	0.451**		0.368*	0.394**		0.295+	0.318*
			(0.141)	(0.141)		(0.146)	(0.145)
Controls:							
Child age	-0.167			-0.177			-0.207
				(0.136)			(0.130)
R^2		0.152	0.276	0.306	.236	.306	.348
$F\Delta$		7.335**	6.867*	1.701	12.643***	4.044+	2.526
Observations	43	43	43	43	43	43	43

Note. Standard errors are in parentheses. All continuous variables are standardized. Column 1 shows the zero-order correlation between the given measure and the respective independent variable.

+ approaching significance, p = 0.05 - 0.06.

*p < .05. **p < .01. ***p < .00

Table 6. Associations Between SES Factors and Adult Verbal Negative Affect

Independent variable	Adult verbal negative affect						
	Zero-order correlation coefficients	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Socioeconomic factors:							
Family income-to-needs ratio	0.012	0.012	0.075	0.036			
		(0.156)	(0.162)	(0.161)			
Parental education	-0.120				-0.120	-0.043	-0.050
					(0.155)	(0.172)	(0.169)
Home language environment:							
Hourly adult words	-0.194		-0.216	-0.180		-0.175	-0.147
			(0.162)	(0.160)		(0.172)	(0.170)
Controls:							
Child age	-0.265			-0.243			-0.249
				(0.155)			(0.153)
R^2		0.000	0.043	0.100	0.014	0.039	0.101
$F\Delta$		0.006	1.778	2.473	0.595	1.031	2.669
Observations	43	43	43	43	43	43	43

Note. Standard errors are in parentheses. All continuous variables are standardized so that coefficients could be interpreted as effect sizes and can be compared with Cohen's d. Column 1 shows the zero-order correlation between the given measure and the respective independent variable.

$^{+}$ approaching significance, p = 0.05 - 0.06.
*p < .05. **p < .01. ***p < .00

Hypothesis 1a-b: Adult Verbal Warmth Predicts Children's Phonological Processing

Adult verbal warmth, but not adult verbal negative affect, was significantly positively associated with the phonological processing composite (r = 0.342, $p = 0.025$) (see Table 7). Multiple regression analysis indicated that adult verbal warmth significantly predicted children's phonological processing scores, when controlling for language input quantity ($\beta = 0.347$, $SE = 0.166$, $p = 0.044$) (Table 8, Model 2). This association remained marginally significant after adjusting for family income and age ($\beta = 0.344$, $SE = 0.179$, p = 0.0.062) (Table 8, Model 3). The association was no longer significant after adjusting for parent education, as parent education significantly predicted children's language skills. In summary, with no controls included, a 1-SD increase in adult verbal warmth predicted a 0.34 SD increase in children's language ability ($SE = 0.015$, $p < 0.05$). This effect held after controlling for hourly adult words and family income to needs ratio ($\beta = 0.35$, $SE = 0.18$, $p = 0.06$). However, after including the control for parent education, the effect dropped by approximately 30% to 0.25, and fell from statistical significance as a result ($SE = 0.18$, $p = 0.16$).

Adult verbal negative affect was not significantly associated with child phonological processing skills (see Table 8, Model 5-8).

Table 7. Zero-Order Correlations for Verbal Affect and Children's Academic Outcomes

	1	2	3	4
1. Adult verbal warmth	-			
2. Adult verbal negative affect	.000	-		
3. Phonological processing composite	.342*	-.110	-	
4. Reading skills composite	.041	-.204	.437**	-

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 8. OLS Regression Models Predicting Children's Language Skills

Independent variable	Language Outcomes								
	Zero-order correlation coefficients	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Adult verbal affect:									
Adult verbal warmth	0.342*	0.342*	0.347*	0.344^{+}	0.253				
		(0.147)	(0.166)	(0.179)	(0.176)				
Adult verbal negative affect	-0.110					-0.110	-0.085	-0.079	-0.050
						(0.155)	(0.159)	(0.164)	(0.154)
Home language environment:			-0.011	-0.071	-0.141		0.128	0.050	-0.067
Hourly adult words	0.145		(0.166)	(0.172)	(0.169)		(0.159)	(0.167)	(0.165)
Socioeconomic factors:				0.151				-0.241	-
Family income-to-needs ratio	0.244			(0.164)				(0.164)	
					0.359*				0.446**
Parental education	0.424**				(0.170)			-	(0.162)
Controls:									
Child age	0.090			0.172	0.139			0.092	0.074
				(0.155)	(0.148)			(0.163)	(0.152)
R^2		0.117	0.117	0.159	0.231	0.012	0.028	0.083	0.192
$F\Delta$		5.414*	0.005	1.241	0.882	0.501	0.653	0.321	0.237
Observations	43	43	43	43	43	43	43	43	43

Note. Standard errors are in parentheses. All continuous variables are standardized so that coefficients could be interpreted as effect sizes and can be compared with Cohen's d. Column 1 shows the zero-order correlation between the given measure and the respective independent variable.

$^{+}$ approaching significance, p = 0.05 - 0.06.
*p < .05. **p < .01. ***p < .00

Hypothesis 2a-b: Adult Verbal Affect Does Not Predict Children's Reading Outcomes

Neither adult verbal negative affect nor adult verbal warmth were significantly correlated with children's reading outcomes, as measured by the reading composite (see Table 7). Multiple regression analysis indicated that adult verbal negative affect and adult verbal warmth did not significantly explain unique variance in children's reading scores, after controlling for age (Table 9).

Table 9. OLS Regression Models Predicting Children's Reading Skills

Independent variable	Reading Outcomes								
	Zero-order correlation coefficients	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Adult verbal affect:									
Adult verbal warmth	0.041	0.041	0.041	0.135	0.092				
		(0.156)	(0.175)	(0.121)	(0.122)				
Adult verbal negative affect	-0.204					-0.204	-0.179	0.009	0.024
						(0.153)	(0.156)	(0.108)	(0.104)
Home language environment:									
Hourly adult words	0.164		0.182	-0.010	-0.044		0.129	0.045	-0.011
			(0.175)	(0.116)	(0.116)		(0.156)	(0.110)	(0.112)
Socioeconomic factors:									
Family income-to-needs ratio	0.069			0.111				0.145	
				(0.111)				(0.108)	
Parental education	0.244				0.201				0.235
					(0.117)				(0.110)
Controls:									
Child age	0.759**			0.796***	0.775***			0.774***	0.762***
				(0.104)	(0.102)			(0.107)	(0.103)
R^2		0.002	0.028	0.616	0.634	0.042	0.057	0.603	0.629
$F\Delta$		0.069	1.086	58.018***	57.891***	1.775	0.678	52.167***	55.009***
Observations	43	43	43	43	43	43	43	43	43

Note. Standard errors are in parentheses. All continuous variables are standardized so that coefficients could be interpreted as effect sizes and can be compared with Cohen's d. Column 1 shows the zero-order correlation between the given measure and the respective independent variable.

$^{+}$ approaching significance, p = 0.05 - 0.06.

*p < .05. **p < .01. ***p < .00

Hypotheses 3: Adult Verbal Affect is Not Associated with Children's Brain Structure

Analyses of children's brain structure were conducted using FreeSurfer software and subsequently using extracted surface area data using SPSS. Neither adult verbal warmth nor adult verbal negative affect were significantly associated with either cortical surface area or cortical thickness of any of the *a priori* regions of interest within language-related brain regions, nor with total cortical surface area or average cortical thickness. (See Tables 10-12 for models).

Hypothesis 4: Exploratory Mediation Models

Mediation hypotheses were not supported because there was no link between verbal affect and *a priori* brain regions of interest.

Table 10. All OLS Regression Models for Language-Related ROIs (STG)

Independent variable	Superior temporal gyrus (STG) surface area														
	Zero-order correlation co-efficients	Controls only (a)	Controls only (b)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Adult verbal affect:															
Adult verbal warmth	-0.029			-0.086	-0.232	-0.194	-0.296					-0.093	-0.204		
				(0.167)	(0.176)	(0.171)	(0.177)					(0.169)	(0.173)		
Adult verbal negative affect	-0.132							-0.077	-0.034	-0.045	-0.020			-0.069	-0.037
								(0.158)	(0.158)	(0.155)	(0.156)			(0.161)	(0.158)
Home language environment:															
Hourly adult words	0.312*				0.345*		0.292		0.247		0.195				
					(0.170)		(0.169)		(0.161)		(0.167)				
Adult mean length of utterance (MLU)	0.094											0.076	0.084	0.060	0.063
												(0.156)	(0.149)	(0.157)	(0.152)
Controls:															
Child age	0.214	0.238	0.207	0.227	0.162	0.172	0.128	0.217	0.195	0.195	0.184	0.225	0.171	0.219	0.197
		(0.152)	(0.147)	(0.155)	(0.152)	(0.149)	(0.148)	(0.159)	(0.157)	(0.154)	(0.154)	(0.156)	(0.151)	(0.161)	(0.156)
Family income-to-needs ratio	0.183	0.210		0.243	0.192			0.209	0.134			0.235		0.201	
		(0.152)		(0.166)	(0.161)			(0.153)	(0.158)			(0.168)		(0.156)	
Parental education	0.309*		0.304*			0.399*	0.322^{+}			0.299^{+}	0.217		0.396*		0.294
			(0.147)			(0.168)	(0.170)			(0.150)	(0.165)		(0.170)		(0.152)
R^2		0.089	0.138	0.095	0.184	0.166	0.226	0.095	0.148	0.140	0.170	0.101	0.173	0.098	0.144
$F\Delta$		1.961	3.207^{+}	0.264	4.132*	1.294	2.977	0.237	2.364	0.083	1.365	0.238	0.320	0.149	0.175
Observations	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43

Note. Standard errors are in parentheses. All continuous variables are standardized so that coefficients could be interpreted as effect sizes and can be compared with Cohen's d. Column 1 shows the zero-order correlation between the given measure and the respective independent variable.
$^{+}$ approaching significance, p = 0.05 - 0.06.
*p < .05. **p < .01. ***p < .00

Table 11. All OLS Regression Models for Language-Related ROIs (IFG)

Independent variable	Inferior frontal gyrus (IFG) surface area														
	Zero-order correlation coefficients	Controls only (a)	Controls only (b)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Adult verbal affect:															
Adult verbal warmth	-0.138			-0.225	-0.353	-0.397	-0.469					-0.228	-0.402		
				(0.161)	(0.171)	(0.153)	(0.161)					(0.163)	(0.156)		
Adult verbal negative affect	-0.047							0.023	0.053	0.067	0.076			0.025	0.070
								(0.156)	(0.158)	(0.148)	(0.151)			(0.159)	(0.151)
Home language environment:															
Hourly adult words	0.243				0.300		0.207		0.170		0.069				
					(0.165)		(0.154)		(0.161)		(0.161)				
Adult mean length of utterance (MLU)	0.046											0.033	0.044	0.018	0.018
												(0.150)	(0.134)	(0.155)	(0.145)
Controls:															
Child age	0.242	0.270	0.233	0.242	0.186	0.162	0.131	0.276	0.261	0.250	0.247	0.241	0.161	0.276	0.251
		(0.150)	(0.140)	(0.149)	(0.148)	(0.134)	(0.135)	(0.157)	(0.158)	(0.147)	(0.149)	(0.151)	(0.135)	(0.159)	(0.149)
Family income-to-needs ratio	0.213	0.244		0.329*	0.285			0.245	0.193			0.326^{+}		0.242	
		(0.150)		(0.160)	(0.157)			(0.151)	(0.159)			(0.162)		(0.155)	
Parental education	0.401**		0.395**			0.590***	0.535***			0.403**	0.374*		0.588***		0.402**
			(0.140)			(0.151)	(0.155)			(0.143)	(0.159)		(0.153)		(0.145)
R^2		0.117	0.215	0.159	0.227	0.330	0.360	0.118	0.143	0.219	0.222	0.161	0.332	0.118	0.219
$F\Delta$		2.655	5.464**	1.963	3.303	6.716**	1.805	0.022	1.118	0.208	0.182	0.001	0.107	0.014	0.016
Observations	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43

Note. Standard errors are in parentheses. All continuous variables are standardized so that coefficients could be interpreted as effect sizes and can be compared with Cohen's d. Column 1 shows the zero-order correlation between the given measure and the respective independent variable.

$^{+}$ approaching significance, p = 0.05 - 0.06.

*p < .05. **p < .01. ***p < .00

Table 12. All OLS Regression Models For Language-Related ROIs (Fusiform Gyrus)

Independent variable	Fusiform Gyrus														
	Zero-order correlation coefficients	Controls only (a)	Controls only (b)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Adult verbal affect:															
Adult verbal warmth	-0.007			-0.042	-0.123	-0.101	-0.156					-0.053	-0.115		
				(0.163)	(0.178)	(0.172)	(0.183)					(0.164)	(0.173)		
Adult verbal negative affect	-0.096							-0.013	0.012	0.012	0.026			0.001	0.026
								(0.155)	(0.157)	(0.154)	(0.157)			(0.157)	(0.156)
Home language environment:															
Hourly adult words	0.222				0.191		0.159		0.145		0.113				
					(0.172)		(0.175)		(0.160)		(0.168)				
Adult mean length of utterance (MLU)	0.139											0.118	0.127	0.114	0.121
												(0.151)	(0.149)	(0.152)	(0.150)
Controls:															
Child age	0.301*	0.326*	0.296*	0.320*	0.284	0.278	0.253	0.322*	0.309^{+}	0.299^{+}	0.292^{+}	0.317*	0.275	0.324*	0.303^{+}
		(0.148)	(0.146)	(0.151)	(0.154)	(0.150)	(0.153)	(0.156)	(0.157)	(0.153)	(0.155)	(0.152)	(0.151)	(0.156)	(0.154)
Family income-to-needs ratio	0.173	0.211		0.227	0.199			0.211	0.167			0.216		0.196	
		(0.148)		(0.162)	(0.163)			(0.150)	(0.158)			(0.163)		(0.152)	
Parental education	0.247		0.240			0.290	0.247			0.241	0.194		0.285		0.232
			(0.146)			(0.170)	(0.176)			(0.149)	(0.166)		(0.170)		(0.150)
R^2		0.135	0.148	0.136	0.163	0.156	0.174	0.135	0.153	0.148	0.158	0.150	0.172	0.147	0.163
$F\Delta$		3.109^{+}	3.480*	0.066	1.241	0.347	0.827	0.008	0.818	0.006	0.454	0.604	0.732	0.557	0.649
Observations	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43

Note. Standard errors are in parentheses. All continuous variables are standardized so that coefficients could be interpreted as effect sizes and can be compared with Cohen's d. Column 1 shows the zero-order correlation between the given measure and the respective independent variable.

$^{+}$ approaching significance, p = 0.05 - 0.06.
*p < .05. **p < .01. ***p < .00

4.3 Post-Hoc Analysis

In order to more closely evaluate and disentangle the association between pragmatic speech codes and children's home language environment, analyses were conducted on non-factored verbal affect data as well. Results show that family income-to-needs ratio and parental education were significantly positively associated with the number of adult affirmations (r = 0.390, p = 0.010; r = 0.463, p = 0.002, respectively) and adult positive expressions (r = 0.309, p = 0.043; r = 0.372, p = 0.014, respectively) (see Table 13). The number of adult affirmations was furthermore significantly positively associated with home language input quantity (hourly conversational turns: r = 0.373, p = 0.014; hourly adult words: r = 0.536, p = 0.000) (see Table 14).

Table 13. Zero-Order Correlations for Pragmatic Speech Codes and SES Factors

	1	2	3	4	5	6
1. Number of adult affirmations	-					
2. Number of adult positive expressions	.646**	-				
3. Number of adult negative expressions	.030	.422**	-			
4. Number of adult prohibitions	.111	.287	.532**	-		
5. Family income-to-needs ratio	.390**	.309*	-.112	.229	-	
6. Parental education (years)	.463**	.372*	-.116	.007	.625**	-

*p < .05. **p < .01. ***p < .001.

Table 14. Zero-Order Correlations for Pragmatic Speech Codes and Language Input

	1	2	3	4	5	6	7
1. Number of adult affirmations	-						
2. Number of adult positive expressions	.646**	-					
3. Number of adult negative expressions	.030	.422**	-				
4. Number of adult prohibitions	.111	.287	.532**	-			
5. Hourly conversational turns	.373*	-.097	-.108	-.057	-		
6. Hourly child vocalizations	.275	-.205	-.034	-.094	.865**	-	
7. Hourly adult words	.536**	.198	-.162	-.027	.776**	.532**	-

*p < .05. **p < .01. ***p < .001.

Multiple regression analysis indicated that the number of adult positive expressions, but no other individual pragmatic speech code, was significantly associated with children's phonological processing, but not reading, scores, when controlling for age and hourly adult words ($\beta = 0.329$, $SE = 0.151$, $p = 0.035$) (Table 15, Model 2). This association was no longer significant after adjusting for family income-to-needs ratio ($\beta = 0.293$, $SE = 0.157$, $p = 0.070$) (Table 15, Model 3), nor after adjusting for parental education ($\beta = 0.369$, $SE = 0.166$, $p = 0.032$) (Table 15, Model 5).

Table 15. Post-Hoc OLS Regression Models Predicting Language Skills

Independent variable	Language Outcomes						
	Zero-order correlation coefficients	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Non-factored adult verbal affect:							
Number of positive expressions	0.345*	0.345	0.329*	0.293	0.305	0.220	0.234
		(0.147)	(0.151)	(0.157)	(0.158)	(0.152)	(0.154)
Home language environment:							
Hourly adult words	0.145		0.080	0.046	0.025	-0.060	-0.073
			(0.151)	(0.156)	(0.158)	(0.157)	(0.159)
Socioeconomic factors:							
Family income-to-needs ratio	0.244			0.140	0.158		
				(0.161)	(0.163)		
Parental education	0.424**					0.369*	0.366*
						(0.166)	(0.167)
Child age	0.09				0.137		0.113
					(0.152)		(0.144)
R^2		0.119	0.125	0.142	0.160	0.233	0.236
$F\Delta$		5.542*	0.280	0.753	0.809	4.937*	0.617
Observations	43	43	43	43	43	43	43

Note. Standard errors are in parentheses. All continuous variables are standardized. Column 1 shows the zero-order correlation between the given measure and the respective independent variable.

$^{+}$ approaching significance, p = 0.05 - 0.06.

*p < .05. **p < .01. ***p < .00

Chapter 5: Discussion

5.1 Findings & Implications

The goal of the present study was to examine associations among caregiver verbal affect, family socioeconomic background, home language input, and children's developmental outcomes. Recent studies that linked the quantity of conversational turns to children's neural development implied the existence of a more pertinent category of early language experience, such as social interactions, that actually drive language and brain development, over and above sheer quantity (Romeo et al., 2018; Merz et al., 2018). Specifically, the present study aimed to uncover whether caregiver affect drove the link between early language experiences and brain development. Results supported the primary hypothesis that adult verbal warmth predicted children's language skills. However, there was insufficient evidence to further link adult verbal warmth to children's neuro-anatomy.

The present study yielded several new insights about the relations between socioeconomic status, caregiver verbal affect and children's developmental outcomes. First, among a socioeconomically diverse sample, higher socioeconomic status was associated with greater adult verbal warmth in naturalistic settings. Specifically, results show that socioeconomic factors explain approximately 15-25% of parental verbal affect. Prior studies have reported similar relations between SES and parenting behavior (Bornstein & Bradley, 2014; Hoff et al., 2002; Pungello et al., 2009). This extends, for the first time, the well-documented SES-parenting behavior relationship to naturalistic, unseen settings, using LENA technology. Moreover, adult verbal warmth was associated with higher hourly adult word count, demonstrating a mechanism that may underlie the relationship between SES and home language input (Hoff, 2003; Pace, Luo, Hirsch-Pasek, & Golinkoff, 2017; Rowe, 2012; Schwab & Lew-Williams, 2016).

Second, consistent with studies assessing the impact of parental responsivity on children's language outcomes, adult verbal warmth predicted children's language skills, even when controlling for language input quantity, further substantiating the supposition that quality of child-directed speech has demonstrable effects, over and above sheer language input (Landry, Smith, Swank, & Guttentag, 2008; Tamis-LeMonda, 2001). Although the effect of adult verbal warmth on children's language skills was modest, the results were consistent with the effect size found in similar studies ($R^2 = .117$; $\beta = 0.347$, $SE = 0.166$, $p = 0.044$, adjusting for language input quantity). For instance, Hirsh-Pasek and colleagues (2015) found that that sensitive parenting accounted for 12% of the variance in children's expressive language scores. As discussed, parental education drove down the effect of parental warmth on children's language ability, but this likely a function of the low power in the current study. Other studies have found effect sizes ranging from 0.08-0.14 of maternal sensitivity on children's language outcomes (e.g. Leigh, Nievar, and Nathans, 2011). These findings, moreover, suggest that the present study comparably captured parental behaviors using a new methodology, though lacking sufficient power.

Contrary to our hypotheses, higher verbal negative affectivity was not independently associated with worse academic outcomes, as was expected based on studies of parental intrusiveness and negative affect (e.g. Pungello et al., 2009). However, maternal verbal sensitivity has been found to have differential prediction of children's outcomes and intrusiveness, specifically, has been found to not yield predictive effect of children's language abilities (Baumwell, Tamis-LeMonda, & Bornstein, 1997).

Additionally, the null findings regarding the impact of adult verbal affect on reading skills suggests that language and literacy outcomes should, in fact, be assessed individually and not aggregated. As mentioned, adult verbal warmth had a modest, statistically significant effect on language skills (β = 0.342, $SE = 0.147$, $p = 0.025$), but not reading skills (β = 0.041, $SE = 0.156$, $p = 0.794$) (Cohen, 1997). Differences in reading skills may be more closely associated with domain-general cognitive knowledge, thereby impacting reading comprehension abilities (included in the reading composite). Moreover, it is also theorized that emergent literacy skills, and reading more generally, require specific, explicit instruction and thus may be more closely related to targeted parental scaffolding of children's cognitive abilities, as opposed to sheer affect, which is more closely related to language development. Overall, the present study offers insight into a psycholinguistic mechanism that may be underlying the relation of childhood SES to language skills.

Most notably, the present study yielded a methodological innovation that now allows for micro-coding and analysis of adult verbal warmth from transcribed data. Most research on child-directed speech has relied on approximation measures of child-parent communication from laboratory settings, whereas the current study offers insight into the naturalistic, fine-grained language interactions children experience in non-laboratory settings and every-day life.

5.2 Limitations

Several limitations of the present study should be noted. The primary limitation of the current study concerns the small sample size, which both limits the ability to interpret the findings and underpowered results, while raising concerns regarding multiple comparisons. While the study provides some evidence into the relationship between adult verbal warmth, socioeconomic status and children's language outcomes; the sample is insufficient to inform conclusions on the brain-behavior hypothesis. As such, the current study can be viewed upon as a pilot study to launch further large scale, longitudinal investigations of caregiver affect.

Given the underpowered nature of the results, there are thus additional limitations in the ability to analyze non-linear effects among the variables of interest, as well as to more thoroughly explore mediation and moderation models, without raising multiple comparisons concerns. Specifically, it is worth questioning if there are threshold effects for verbal warmth; in other words: whether the return to increasing warmth diminishes after reaching a certain minimum threshold of positive affect. Additionally, while the positive association between language input quality, as measured by adult verbal warmth, and quantity, as measured by adult word count, was noted in the current study, it is expected that there is an interactive effect of language input quantity and quality whereby the effects of high warmth coupled with low language input quantity could be compared to those of children exposed to low warmth coupled with high language input quantity. While it is hypothesized that high language quantity and high warmth would be related to the best language outcomes, analyses on the other combinations of child-directed speech characteristics would allow for more precise insight into the nuanced mechanisms underlying language development.

An additional limitation of the current study is the operationalization and coding of verbal warmth. Although parental warmth is operationalized differently across studies, most studies have investigated the construct of interest by assessing both verbal and non-verbal cues. Due to the nature of this investigation as relying on transcribed LENA recordings, we were unable to incorporate non-verbal behaviors or modes. As such, this study is narrowly focused on "verbal" warmth and likely misses many instances of caregivers displaying warm behaviors (e.g. facial expressions, gestures, attentive gaze etc.) that have been previously included in measures of responsivity and have been found to critically relate to children's language abilities (Hirsh-Pasek et al, 2015). Furthermore, this operationalization of verbal warmth and the exclusion of non-verbal cues and behaviors likely introduced cultural biases into the current study. Families of different cultural or ethnic backgrounds bring with them unique cultural values and overall models of the world, family, and self. As such, differences in parenting patterns as a function of culture and ethnicity are expected and well-documented (Bornstein et al., 1992; Bornstein, 2012; D'Andrade, 1995; Tamis-LeMonda and Song, 2012). For instance Euro-American mothers displayed facial expressions and vocalizations in response to infants' smile and vocalization, whereas mothers of Japanese-descent responded to infants through movement and touch (Fogel, Toda, & Kawai, 1988) and Mexican mothers have been found to respond with higher rates of non-verbal communication, such as gesturing (Tamis-LeMonda et al., 2012) . Other sociocultural-oriented studies note that families that value emotional restraint, such as is common of Asian culture, may be more likely to express affection through supportive behaviors, rather than verbal and physical affection (Kim, Atkinson, and Umemoto, 2001; Park, Vo, and Tsong, 2009). While this is methodological limitation exists, it is important to note that it is somewhat tempered by the fact that the present operationalization and coding of verbal warmth can be very useful and replicated in future studies assessing naturalistic, child-directed speech.

As far as the operationalization and coding of negative affect: other studies categorizing parental behavior and affect sometimes use more than two dimensions and are thus able to draw more nuanced conclusions from parental behavior. For instance, in one study, researchers distinguished between "detached," "directive" and "harsh" mothering, where "harsh" was characterized by high levels of negativity (Brady-Smith et al., 2013). The findings demonstrated that harsh parenting had the strongest and most pervasive negative associations with children's cognitive and emotional regulation development, among other outcomes. In the present study, however, the fact that all negative affect was grouped together may have contributed to a diluted effect of negative affect on child outcomes. Specifically, while the coding scheme distinguished between imperatives and negative affect, it did not quantify the degree of negative affect, or categorize instances of extreme negative affect.

An additional limitation of the study is the inability to isolate and evaluate the effect of specific speakers. Due to the use of LENA technology, child-directed speech was aggregated from all adult speakers (i.e. grandparents, neighbors, uncles etc.). As such, the current study evaluated all child-directed communication in a naturalistic setting, as opposed to a majority of comparable studies that specifically evaluate parent-child communication. Research from anthropology and sociolinguistics suggests that it is important to take a broader view of language learning contexts and include studies of participants that engage with the child (De Leon, 2011). However, this both runs the risk of inaccurately capturing the affective environment in which the child spends most time and makes it difficult to compare the current study with much of the developmental psychology literature that focuses on mother- or father-child interactions.

Another limitation of the present study is the timing of evaluation. The benefits of sensitive parenting and nurturance are especially documented in early childhood and infancy, and have been found to relate to subsequent attachment security, emotion regulation, and cognitive outcomes. For instance, in a longitudinal investigation of verbal affect on infant's language outcomes, Baumwell, Tamis-LeMonda, and Bornstein (1997) found that maternal responsiveness had a strong effect on language skills ($q = 0.52$), especially among infants who were initially lower in language comprehension. With this in mind, analyses of adult verbal warmth would likely yield larger effects when investigated longitudinally and with younger populations. Children aged 5-9, as in the present study, have already begun formal schooling and spend a large portion of their time with caretakers outside the home and as such, it becomes difficult to control for the likely effects of school or instruction quality that are critical to school-age language and reading skills. Moreover, it is important to note that due to the cross-sectional nature of the current study, the adult verbal warmth measure provided a *snapshot* of the verbal affect in the home, and due to both caregivers' own development in caregiving behavior and children's oscillating developmental needs, it would be inaccurate to claim that the current data captures, or serves as a proxy, for the verbal affect of the home language environment earlier or later in the child's life. Future studies should incorporate longitudinal measures, begin prenatally, and explore a variety of in-depth measures of linguistic and cognitive stimulation to better assess the developmental significance of verbal warmth and the role of parental warmth in early language experiences.

5.3 Future Directions

As reviewed in Chapter 1, in accord with the social-interactive account of language acquisition, the brain mechanisms underlying social cognition and language acquisition are facilitated by engaging caregivers. Specifically, caregivers are thought to promote cognitive development by increasing a child's attention, arousal and engagement in social interactions (Kuhl, 2007b; Tamis-LeMonda et. Al., 2014). This increased attention, then encourages the child to focus on language input, thereby resulting in cascading effects including increasing a child's understanding and familiarity with language. For example, among infants, maternal responsiveness has been found to explain 8% of the variance in infant's language comprehension, yet 21% of the variance in infant's attention abilities (Bornstein & Tamis-LeMonda, 1997). In another study maternal affect accounted for 30% of the variance in children's total engagement scores (Kim & Mahoney, 2004). This perceptual-attentional effect of child-directed speech necessitates the incorporation of attention measures in studies of adult verbal warmth, so as to attain further insight into this mechanism.

In order to more closely understand if attention is, in fact, the mechanism that is most affected by adult verbal warmth in early childhood, future studies assessing caregiver affect and child-directed speech should also include longitudinal measures of sustained or selective attention and use electroencephalography (EEG) to more directly measure attentional processes in the developing brain.

Additionally, bidirectional pathways should be considered. Although the present study hypothesized that parental verbal may shape children's cognitive and verbal abilities, it is also plausible that children's cognitive and verbal abilities may influence parental responsiveness. More specifically, receptive and expressive language skills may both be facilitated by sensitive parenting, and help facilitate such parenting behavior. Transactional models of parenting and child development put forth that associations are bidirectional, meaning that parents and children respond to each other's cues and influence one another's behavior (Bornstein, 2009; Sameroff, 2009; Barnett et al 2012). Multiple studies underscore evidence for transactional, or bidirectional, associations among sensitive parenting and language outcomes. For instance, one study found that children's language skills at age two uniquely contributed to increases in mothers' observed sensitive parenting in the subsequent year (Barnett et al., 2012). Bornstein et al. (2007) reported that children with larger expressive vocabularies were more sensitive to their mothers during parent–child interactions, and these children's mothers were rated as more sensitive than the mothers of children with smaller expressive vocabularies. Similarly, mothers of infants who perceived that their children had better receptive language skills have been found to use more verbal and non-verbal communication with their children (Rowe 2000). Such transactional models suggest that children's unique abilities at actively recruiting their parents' capacity for sensitivity likely lead parents to interact differently with each child as they respond to the individual's characteristics, including social behaviors and language ability (Siefer & Schiller, 1995). In short, parents may display more warmth and positivity towards children who themselves are more sensitive and engaged, and in turn, those children may be warmer to their mothers, eliciting escalated warmth while further advancing their language and social skills. It therefore may be social competence that facilitates language development, because children with advanced social abilities have more opportunities to participate in language-based exchanges (Gallagher, 1999). Conversely, poor social competence or introverted personality styles may limit social interactions and opportunities to practice and improve language skills, in turn leading to less optimal language development. In regards to the current study: while it was found that children's own rate of vocalization was not related to parental language input quantity or quality, it is theoretically plausible that children's own phonological awareness can instead promote caregiver warmth and as such, future studies investigating aspects of parent-child social interactions should include measures of children's conversational language abilities, as well as temperamental and behavioral dispositions through social competence and personality inventories, while also measuring the change of adult verbal warmth over time. In doing so, future directions of this research will be better equipped to investigate reciprocal associations and unique contributions of these variables over time.

Most evident by the current study is that parental socioeconomic status has a clear association with both the quality of parents' child-directed speech and child outcomes. As such, when considering how these results might inform intervention development, it is important to note that models with controls for concurrent measures of socioeconomic factors reduced the association between adult verbal warmth and children's language outcomes. This implies that an intervention that altered adult verbal warmth behaviors in the short-term but failed to change more substantive social-economic capital, either global knowledge of child development or family income would likely have limited effects on later outcomes. So, while this study highlights the strong link between socioeconomic factors and caregiver verbal warmth, future studies should investigate the precise factors underlying this link. A range of risk factors including caregiver depression, social or geographic isolation, the stresses of discrimination, or the stress of making ends meet may all play roles in mediating this association. Environmental factors such as home literacy, access to reading material, and school quality may be further responsible for systematic heterogeneity among socioeconomic strata. Other studies have demonstrated that the lack of warm engagement can be the result of limited understanding of the developmental needs of young children (Rowe, 2008). If knowledge of child development is consistently a primary factor underlying the link between child outcomes and socioeconomic status, then this holds potential policy implications. If intervention developers hope to generate program impacts that reduce the achievement gap, targeting the broader socioeconomic environment might yield more fruitful and long-lasting effects, and as such, understanding the precipitating socioeconomic factors and employing appropriate strategies to address identified needs can produce strong returns on targeted interventions: from voluntary parenting education to the provision of enriched learning experiences through high-quality child care or early education programs.

Conclusion

This thesis puts forth a new methodology that allows for in-depth analysis of child-directed speech and adult verbal affect. It is the first study of its kind to combine rich psycholinguistic micro-coding with detailed information about neural structure of function that state-of-the-art brain imaging provides. In summary, this thesis demonstrated that adult verbal warmth is linked to children's developmental outcomes, and that the influence of socioeconomic status on these factors seems to be driven by the children's interactive language experiences with their caregivers. While future longitudinal and large-scale research is necessary to elucidate the precise nature of these relationships and long-term intervention effects, the present results may be used to inform educational and clinical practices and policies.

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