Review Article

Socioeconomic and Experiential Influences on the Neurobiology of Language Development

Rachel R. Romeo[a,b,c,d]

Purpose: The process by which young children acquire language is an incredible feat subserved by neurobiological language circuitry. Although the foundations of brain structure and function are genetically determined, children's experiences during sensitive periods in early life have a significant influence on the development of language systems. The purpose of this review is to provide practitioners with a comprehensive summary of foundational and recent research on the ways that children's early experiences—both favorable and adverse—may influence the neuroanatomy and neurophysiology underlying language development. A specific focus is given to the burgeoning neuroimaging evidence of relationships between socioeconomic status and brain development, as well as to emerging research on proximal experiences that may serve as the direct mechanisms by which socioeconomic status influences language development.

Conclusion: Findings from the neuroscience field have direct implications for practice in speech-language pathology. Specifically, clinicians can have immense influence on crafting supportive language environments during windows of maximal neural influence, both via direct intervention and parent coaching. Practical suggestions are provided for translating research findings to practice.

The human brain is an incredibly dynamic organ. Nearly all of the brain's neurons are present at birth, yet the neonatal brain is far from complete. Over the next two decades, a child's brain undergoes an extraordinary transformation, forming trillions of synapses or connections between neurons, which in turn make up neural networks or circuits. Also during this time, frequently used neural pathways become insulated and reinforced to allow faster information transfer, whereas connections that are less frequently used get pruned away ("use it or lose it"). Both of these processes are forms of developmental neuroplasticity that allow the brain to function more efficiently and underlie all stages of children's linguistic and cognitive development.

Although the basic framework for brain development is determined by genetics, the developing brain is remarkably impressionable. Children's early experiences may have an immense impact on their brain development through a process called *biological embedding* (Fox, Levitt, & Nelson, 2010; Hertzman, 1999). Specifically, during developmental time windows called *sensitive periods*, the brain is particularly responsive to certain stimuli. After these periods pass, there is reduced plasticity of the relevant neural circuits and the successful development of the associated skill will be more difficult if not impossible (Knudsen, 2004). The sensitive period for language development is widely considered to span the first 5–12 years of life and comprises cascading periods for the development of speech perception, phonology, morphology, and syntax (Kuhl, 2010; Newport, Bavelier, & Neville, 2001; Werker & Tees, 2005). During these sensitive periods, children's early language exposure—or lack thereof—has the ability to fundamentally shape the neural circuitry that supports their language development.

In this review article, I first review the cognitive–behavioral literature that demonstrates the influence of rich early language experience on development and how these experiences may vary across socioeconomic backgrounds. I then review recent neuroscience findings that reveal the neurobiological mechanisms by which children's experiences support their language development. Finally, I discuss

[a]Laboratories of Cognitive Neuroscience, Division of Developmental Medicine, Boston Children's Hospital, MA
[b]Harvard Medical School, Boston, MA
[c]Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge
[d]McGovern Institute for Brain Research, Massachusetts Institute of Technology, Cambridge

Correspondence to Rachel R. Romeo: rromeo@mit.edu

Editor: Laura B. Green

Received September 7, 2019
Accepted October 1, 2019
https://doi.org/10.1044/2019_PERSP-19-00073

Disclosures
Financial: Rachel R. Romeo has no relevant financial interests to disclose.
Nonfinancial: Rachel R. Romeo has no relevant nonfinancial interests to disclose.

the clinical implications of this work and directions for future research.

Variation in Early Language Experience

With the exception of rare cases of extreme neglect, nearly all children receive some exposure to a linguistic system. For this reason, the language domain is often considered to be experience expectant, meaning that input is required and expected for typical development (Greenough, Black, & Wallace, 1987; McLaughlin, Sheridan, & Nelson, 2017). However, there is wide variability in the amount (quantity) as well as the content and context (quality) of language that children experience in early life, both within and across sociocultural contexts. For example, a representative study of more than 300 monolingual English-speaking American families aimed to determine the variability in experiences of 2- to 48-month-old children by using dense, automatized, naturalistic recordings (Gilkerson et al., 2017). Although some children heard just over 3,000 words spoken by adults in a 12-hr day, others heard over 30,000. Similarly, although some children experienced fewer than 60 interactive vocal "conversational turns" with adults in a day, others experienced nearly 20 times this amount (Gilkerson et al., 2017, 2018). Numerous studies have additionally documented extensive variability in various qualitative aspects of the speech children hear (for a review, see Cartmill, 2016). Qualitative variation includes linguistic features such as lexical diversity, syntactic complexity, and question use (e.g., Hoff & Naigles, 2002; Huttenlocher, Vasilyeva, Waterfall, Vevea, & Hedges, 2007; Rowe, 2012; Weizman & Snow, 2001), as well as interactional features such as response contingency and turn-taking (e.g., Hirsh-Pasek et al., 2015; Tamis-LeMonda, Kuchirko, & Song, 2014).

Importantly, variation in input quantity and quality has been linked to children's language development (for a review, see Hoff, 2006). In one of the earliest studies of these relationships, Huttenlocher, Haight, Bryk, Seltzer, and Lyons (1991) found that the number of words mothers spoke to their 16-month-old children was positively related to the rate of children's vocabulary acquisition through 26 months of age. More recent work finds that differences in the amount of language experienced by 1-year-old children predicts their language and intelligence quotient scores as much as 10 years later (Gilkerson et al., 2018). Additional research has aimed to explain the mechanisms by which experience influences language development. Eye-tracking studies, in which infants look at images or videos while listening to spoken descriptions, allow researchers to objectively assess infants' linguistic knowledge long before they can respond to most standardized assessments (Fernald, Zangl, Portllo, & Marchman, 2008; Swingley, 2012). Such studies have found that children who hear more child-directed speech at 18 months of age look to pictures of spoken words faster than children with less language experience, and this efficiency in turn predicts children's vocabulary size at 24 months of age (Hurtado, Marchman, & Fernald, 2008; Weisleder & Fernald, 2013). These differences in language processing efficiency suggest that differences in early language exposure may have cascading effects on development by affecting the children's ability to comprehend language and learn new words.

Many additional studies have demonstrated that qualitative aspects of children's language input may be even more important than input quantity in predicting children's language outcomes. These studies highlight the importance of both the content of language experience, such as different types of utterances and rare words (Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Jones & Rowland, 2017; Rowe, 2012), as well as the context of these experiences, including word referent transparency, discourse connectedness, and contingent turn-taking (Cartmill et al., 2013; Gilkerson et al., 2018; Hirsh-Pasek et al., 2015; Zimmerman et al., 2009). Furthermore, it appears that various aspects of input support language learning at different developmental stages, such that the quantity of speech matters most in early infancy, using diverse and sophisticated vocabulary best supports language development for toddlers, and use of decontextualized language about topics removed from the here and now (e.g., narrative, pretend, and explanations) best support preschool language development (Jones & Rowland, 2017; Rowe, 2012).

Collectively, these studies suggest that there is extensive variability in the amount, content, and context of children's early language experience, and these variations strongly predict the course of children's language development. Since caregivers tend to be remarkably consistent in their input patterns relative to other caregivers (Huttenlocher et al., 2007), this motives one to ask whether there are any systematic environmental predictors of variation in children's early language experiences.

Socioeconomic Effects on Language Development

Perhaps the most frequently studied demographic factor in relation to children's language input is socioeconomic status (SES). SES is a multifaceted construct that refers to an individual's social and economic resources and the consequent status that arises from these resources. In effect, it is a spectrum of how "well off" a person is within a given community (Farah, 2017). Objective SES measures typically index an individual's educational attainment, income, and/or occupational prestige (Bradley & Corwyn, 2002; Duncan & Magnuson, 2012; Ensminger & Fothergill, 2003). For children, their SES background is typically indexed by these measures of their primary caregivers.

Over several decades of research, SES has been consistently strongly related to children's linguistic and cognitive development, academic achievement, and even long-term health and employment outcomes (Duncan & Brooks-Gunn, 1997). Despite these wide-reaching effects, SES appears to have a disproportionately strong impact on language and literacy skills compared to other cognitive domains

(Farah et al., 2006; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005). Disparities in both receptive and expressive language skills are visible long before children enter school (e.g., Ginsborg, 2006; Lee & Burkam, 2002; Ramey & Ramey, 2004) and, in some cases, as early as the first year of life (Halle et al., 2009). This has prompted a great deal of research into potential precursors of these disparities.

Over the last two decades, numerous studies have found that SES is associated with differences in the quantity and quality of early language experiences (for reviews, see Rowe, 2017; Rowe & Zuckerman, 2016; Schwab & Lew-Williams, 2016). In their now seminal study, Hart and Risley (1995) found that children from lower SES families heard fewer than a third of the words heard by their higher SES peers, which aggregated to a "30-million word gap" when extrapolated over the first 4 years of life. The authors further found SES differences in both linguistic and interactional quality measures, such as lexical and grammatical diversity and affirmative responsiveness. The combination of these measures explained over 60% of the variance in children's intelligence quotient scores at 3 years of age (Hart & Risley, 1995). Although this finding has been met with recent controversy concerning methodological adequacy and sociological implications (e.g., Avineri et al., 2015; Johnson, 2015; Sperry, Sperry, & Miller, 2018), the general pattern of results has been replicated numerous times with a variety of methods across many cultures (for a review, see Golinkoff, Hoff, Rowe, Tamis-LeMonda, & Hirsh-Pasek, 2019).

Further studies have revealed that these differences in early language input mediate socioeconomic disparities in children's linguistic, cognitive, and academic development, known as the achievement gap (Hoff, 2003; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Romeo, Leonard, et al., 2018; Rowe & Goldin-Meadow, 2009). For example, in one early study, the mean length of maternal utterances fully explained SES differences in the vocabulary growth of 2-year-old children and accounted for 22% of the variance in children's vocabulary after controlling for SES (Hoff, 2003). Further research suggests that these input-related differences in language skill may in turn explain the well-documented SES disparities in executive functioning (Noble et al., 2005; Sarsour et al., 2011) and academic achievement (Durham, Farkas, Hammer, Bruce Tomblin, & Catts, 2007; Morgan, Farkas, Hillemeier, Hammer, & Maczuga, 2015; Walker, Greenwood, Hart, & Carta, 1994).

These findings largely support the bioecological model of development (Bronfenbrenner & Morris, 1998) in which a child's development is shaped by a nested system of social contexts. In this model, influences furthest from the child include contexts such as culture and SES, termed *distal* influences. These distal factors likely do not directly shape child development, but rather they shape the more immediate factors of children's day-to-day experiences, such as their language input from caregivers and direct teaching in schools, called *proximal* influences. Thus, distal factors influence proximal factors, which in turn influence cognitive development.

However, there is presumably another intermediate step in this chain in which proximal environmental factors must first shape brain development, which then drives language development. In other words, any effect of experience on cognition must rely on changes to the brain or neuroplasticity. Understanding this neuroplasticity is important for learning which environmental factors are most influential and for predicting how environments will shape cognition and behavior in the long term. As the fields of cognitive development and neuroscience converge, pediatric neuroimaging research is just beginning to yield insights into the neurobiological mechanisms by which children's early experiences shape their language development. Evidence of the effects of distal environmental factors such as SES on neurodevelopment is a burgeoning field, yet evidence directly linking proximal—and malleable—experiential factors is currently at an exciting emergent point.

Socioeconomic Influences on the Neural Basis of Language Development

With the proliferation of noninvasive human neuroimaging, recent decades have seen an exponential increase in studies of how social phenomena, such as SES, manifest in the brain. Seminal early studies revealed that raising rodents in impoverished environments (i.e., lacking toys and socialization) restricted brain development, whereas enriched environments (i.e., lots of stimulating toys and maternal nurturance) caused enlargements of the cerebral cortex, the outer portion of the brain responsible for cognition (for a review of rodent studies, see Markham & Greenough, 2004). Although such controlled studies are not possible with humans, researchers have observed naturally occurring associations between children's environments and measures of their brain development and have found remarkably similar relationships as those seen in rodent studies. Several recent review articles comprehensively examine the neural footprint of poverty and SES in children and adults (Brito & Noble, 2014; Farah, 2017; Holz, Laucht, & Meyer-Lindenberg, 2015; Johnson, Riis, & Noble, 2016). Thus, the summary here is restricted to evidence relevant to language development.

SES and Brain Structure

Human neuroimaging studies can investigate two categories of measures: brain structure and brain function. Brain structure comprises the neuroanatomical properties of the brain, such as cortical gray matter volume, thickness or surface area, and/or the integrity of the white matter tracts that connect various regions to each other. Work in this area has found that higher SES is related to greater cortical volume as early as 5 weeks of age (Betancourt et al., 2016) with widening disparities throughout childhood, adolescence, and early adulthood (Hanson et al., 2013; Piccolo, Merz, He, Sowell, & Noble, 2016). Importantly, effects are typically most prominent in children from the lowest SES groups, such that small differences in income between families at or near the poverty line are associated with relatively large brain differences, but similarly small income differences between families above a certain income threshold have reduced impact on brain development (Hair, Hanson, Wolfe, & Pollak, 2015; Noble et al., 2015). There are two hypotheses of how these effects arise. First, children growing up in lower SES environments simply may not form as many synaptic connections early in development, and thus they exhibit less gray matter formation throughout childhood and adolescence. Alternatively, lower SES children may exhibit accelerated cortical maturation by speeding up the natural process of pruning away synapses that are less frequently used, which would then appear as reduced gray matter when looking at a single time point. Because young children are highly sensitive to their early environments, accelerated maturation may actually serve as a protective adaptation. In other words, by making the brain more adultlike more quickly, it becomes more resistant to change, thus reducing the negative effects of early adversity (Callaghan & Tottenham, 2016). However, reduced vulnerability may inadvertently also reduce the capacity for positive neuroplasticity, thus making it more difficult to learn in early childhood.

SES is particularly related to the structure of brain regions supporting language and reading processes. For example, one early study revealed that 5-year-old children from higher SES backgrounds exhibited greater volume of left inferior frontal regions or Broca's area, which plays a critical role in both language processing and speech production (Raizada, Richards, Meltzoff, & Kuhl, 2008). More recent work finds that the volume of this region in 6- to 9-year-olds explains 37% of the total effect of SES on vocabulary scores (Romeo et al., 2017). Similar relationships have been found between SES and left fusiform and occipito-temporal regions, which are known to support reading and orthographic processing (Jednoróg et al., 2012). Specifically, the thickness of gray matter in these regions is associated with SES-related disparities in school achievement in 13- to 15-year-old adolescents (Mackey et al., 2015), and the surface area of these regions is also associated with language and reading scores in 3- to 20-year-old youth (Noble et al., 2015). Additionally, SES may moderate the relationship between cortical thickness and language and reading scores, such that high SES may protect against language difficulties associated with thinner cortices (Brito, Piccolo, & Noble, 2017).

SES also appears to also be related to the development of white matter tracts that connect various brain regions to each other. Pathways known to underlie language and reading development are the superior longitudinal fasciculus (SLF) and a subcomponent known as the arcuate fasciculus, which connects Broca's area to Wernicke's area in the posterior temporal lobe via a dorsal (upper) route, and the inferior longitudinal fasciculus, which connects reading and language regions via a ventral (lower) route (for a review, see Friederici, 2015). Several studies have found that higher SES is related to greater strength and organization of these fiber pathways (Dufford & Kim, 2017; Gianaros, Marsland, Sheu, Erickson, & Verstynen, 2013; Gullick, Demir-Lira, & Booth, 2016; Noble, Korgaonkar, Grieve, & Brickman, 2013; Ozernov-Palchik et al., 2019; Rosen, Sheridan, Sambrook, Meltzoff, & McLaughlin, 2018; Ursache, Noble, & PING Study, 2016). Furthermore, SES has been found to interact with the heritability of fiber integrity, such that the impact of early environmental differences has a greater impact on white matter structure in lower SES individuals who might not have access to other buffering, positive resources (Chiang et al., 2011). In aggregate, these studies have demonstrated that distal influences such as SES and poverty status are intimately related to the neuroanatomical structure of both cortical gray matter and white matter pathways that underlie language development.

SES and Brain Functioning

In addition to neuroanatomical differences, numerous studies have investigated relationships between SES and brain function, or the way the brain processes stimuli or completes tasks such as comprehending language or reading text. Studies utilizing electroencephalography have found that lower SES children exhibit resting neural activation patterns indicative of a maturational lag (Harmony, Marosi, Diaz de Leon, Becker, & Fernandez, 1990; Otero, 1994; Otero, 1997; Otero, Pliego-Rivero, Fernandez, & Ricardo, 2003). These patterns are similar to those seen in children with learning disabilities and neurodevelopmental disorders (Barry, Clarke, & Johnstone, 2003; Kinsbourne, 1973) as well as children experiencing severe deprivation due to institutionalization (Marshall, Fox, & BEIP [Bucharest Early Intervention Project] Core Group, 2004; McLaughlin et al., 2010). Functional SES disparities, specifically in frontal brain regions involved in higher cognitive functions such as language, appear to arise within the first 6–9 months of life (Tomalski et al., 2013)—a pattern that has been linked to impairments in language development (Benasich, Gou, Choudhury, & Harris, 2008; Gou, Choudhury, & Benasich, 2011).

Other research has utilized functional magnetic resonance imaging to track neural activation patterns while children perform a language or reading task. These studies have found that higher SES is related to greater brain activation in left perisylvian language regions during phonological awareness tasks, such as rhyming, in young children and adolescents (Demir, Prado, & Booth, 2015; Demir-Lira, Prado, & Booth, 2016; Raizada et al., 2008). Additionally, SES may moderate relationships between phonological skills and reading-related brain activation. An early study found that lower SES children exhibit stronger correlations between phonological awareness skills and brain activity in left fusiform and perisylvian regions during reading than their higher SES peers, who exhibited higher brain activation and higher reading scores no matter their phonological awareness scores (Noble, Farah, & McCandliss, 2006; Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006). Similar relationships have been found between SES and left prefrontal activation during phonemic discrimination (Conant, Liebenthal, Desai, & Binder, 2017) and in the structural connectivity of brain regions involved in recognizing the visual form of words (Ozernov-Palchik et al., 2019). These results suggest that certain early environmental experiences, such as increased exposure to language and literacy practices, may buffer low phonological skill levels in higher SES children, resulting in increased neural recruitment and better language and reading outcomes.

Additional work suggests that children differing in SES may even rely on alternative neural circuitry to support successful phonological and reading skills. For example, lower SES students exhibit greater reliance on right hemisphere homologues of canonical left cortical regions and pathways for reading and language (Gullick et al., 2016; Younger, Lee, Demir-Lira, & Booth, 2019). Similar bilateral patterns are often seen in the compensatory neuroplasticity of children with dyslexia who have undergone remediation (D'Mello & Gabrieli, 2018). This is further supported by evidence that children varying by SES respond in a cognitively and neurally disparate manner to specific reading intervention programs (Romeo et al., 2017). Together, these results suggest that SES may impact the neural underpinnings of both typical and disordered language and literacy development, as well as response to instruction and intervention.

In sum, the reviewed literature suggests that differences in SES may impact the development of structural neuroanatomy as well as brain functioning during language and reading processes. However, a bioecological model suggests that such a distal environmental factor must influence neurodevelopment via proximal, day-to-day influences (Bronfenbrenner & Morris, 1998). Study of the effects of proximal factors on brain development is much more complex than a surface-level exploration of SES alone. However, a detailed investigation is crucial for characterizing which components of a child's experiences might be most efficacious as a focus of early intervention programs.

Experiential Influences on the Neural Basis of Language Development

SES is associated with many factors that likely influence brain development, including cognitive stimulation, parenting behaviors, stress, nutrition, trauma, prenatal health, and exposure to toxins, among others (Johnson et al., 2016). Although many of these may have downstream effects on language development, the cognitive–behavioral literature suggests that variation in early language experience may have a particularly strong relationship with developmental neuroplasticity. Following the neurodevelopmental principle of use it or lose it, decreased language exposure during sensitive periods may allow for earlier pruning of language relevant cortical areas, less efficient white matter circuitry, and reduced activation during language function, which may in turn lead to disparities in language and reading skills.

Several recent studies find evidence to support these hypotheses. Utilizing wearable recording technology, researchers are able to quantify the amount of real-world language exposure children experience in a given day (Gilkerson et al., 2017) and calculate relationships with neuroimaging measures. In one study, Romeo, Leonard, et al. (2018) found that the sheer number of words spoken to 4- to 6-year-old children was less strongly related to brain development than the frequency of interactive adult–child conversational turns, in which either an adult speaks and the child responds or vice versa. Children who experienced more conversational turns exhibited greater brain activation in Broca's area while listening to spoken stories (Romeo, Leonard, et al., 2018) and also exhibited stronger white matter connectivity in the left SLF and arcuate fasciculus tracts (Romeo, Segaran, et al., 2018). These neural measures independently mediated the relationship between children's language exposure and their language skills, and also explained 23%–30% of the effect of SES on children's language skills. Further work finds that the language experience of 5- to 7-year-old children additionally relates to the surface area of left perisylvian cortex, which mediates the relationship between SES and their reading skills (Merz, Maskus, Melvin, He, & Noble, 2019). Although correlational, these studies suggest that children's early language experience and especially interactive conversation may influence the development of brain structure and function supporting language and reading skills.

Additional studies find relationships between language input and neural responses to both sublexical and supralexical stimuli. For example, a study with 11- to 14-month-old infants found that the amount of words infants heard related to their brain responses in prefrontal regions while listening to native language phonetic contrasts (Garcia-Sierra, Ramírez-Esparza, & Kuhl, 2016). Specifically, infants who were exposed to more words exhibited more mature neural patterns, in which the brain comes to preferentially respond to phonetic contrasts that are meaningful in the child's native language versus those that are only meaningful in a nonnative language. Additionally, the lexical and morphosyntactic complexity of input experienced by 8- to 12-year-old children correlated with activation in right frontal brain regions during a rule-learning task that did not depend on language skills at all, suggesting that language input may also impact other high-level cognitive functions (Sheridan, Sarsour, Jutte, D'Esposito, & Boyce, 2012). Together, these studies complement findings from the behavioral literature of a developmental progression, suggesting that input quantity may be most supportive for young infants, whereas input quality and complexity may be most important for older children and adolescents. However, longitudinal research is necessary to fully understand the relative impact of various aspects of language exposure at different developmental time points.

Similarly, several studies have found positive relationships between the home literacy environment and language-related brain activation. Specifically, more frequent reading exposure with 3- to 5-year-olds is associated with greater activation while listening to stories in the left parietal–temporal–occipital association cortex, a region involved in mental imagery and narrative comprehension (Hutton et al., 2015). Additionally, the dialogic quality of shared story book reading and child engagement during reading are related to activation in and connectivity with frontal language processing regions during story listening (Hutton et al., 2017a, 2017b). Furthermore, relationships between the home literacy environment and activation in the frontal lobe during a phonological task differ between prereading children with and without a genetic risk for dyslexia (Powers, Wang, Beach, Sideridis, & Gaab, 2016), suggesting that early reading experience may influence language-related brain development for children both with typical and atypical language and literacy developmental trajectories.

Finally, several other proximal aspects of children's early learning environments have been linked to developmental brain measures. Deprivation of positive caregiving experiences and cognitive stimulation, as is often the case in early institutionalization, leads to long-lasting deleterious effects on the neural development underlying many cognitive and emotional domains (for a review, see Nelson, Zeanah, & Fox, 2019). Relatedly, a few studies have shown that frequent supportive caregiving experiences, such as providing emotional support and accolades during difficult tasks, may protect against the deleterious effects of poverty on brain structure and functioning (Brody et al., 2017, 2019; Luby et al., 2013). Additionally, children and adolescents with greater cognitive stimulation and variety of learning experiences at home exhibit thicker cortex in fronto-parietal networks and stronger white matter connectivity in the SLF, which mediates SES disparities in academic achievement (Rosen et al., 2018). These studies suggest that extralinguistic aspects of children's early environments may also impact neurodevelopmental mechanisms important for language development and lifelong learning.

In summary, these studies complement earlier behavioral work and reveal both structural and functional neural mechanisms by which children's early experiences shape their language and reading development while also identifying which specific experiences have the greatest neurocognitive impact. Importantly though, the vast majority of reviewed neuroimaging studies employ a cross-sectional design, providing a snapshot of the brain at a single time point. Because brain development is an incredibly complex, dynamic process, with bidirectional influences between children and their environments, future longitudinal research is imperative to determine how early experiences may exert differential influences on neuroplasticity at different developmental stages. Findings from such research may have invaluable translational impact for assisting children at both genetic and environmental risk for language and literacy disorders.

Translating Research to Practice

Initially, findings of neurocognitive disparities linked to early experiential differences may sound discouraging. However, these findings also identify multiple influential and potentially malleable targets for modification, thus providing a foundation of evidence that speech-language pathologists and other providers may apply within several areas of practice. Perhaps the most direct translation is parent coaching, primarily within the domain of early intervention, but also relevant for families of older children who might benefit from extra support.

Clear from both the cognitive and neural research is the fact that, no matter a family's resources, access to a rich early language environment promotes children's language development. Many parent coaching models already emphasize increasing the quantity of child-directed speech, but perhaps even more important is the quality or content of verbal interactions. Beyond educating parents about the importance of turn-taking, clinicians may need to model optimal turn-taking behaviors. This includes teaching parents about maximizing opportunities for conversation, following the child's lead and waiting for a response, establishing joint attention to a referent or topic, continuing conversation through questions and other cues, and in some cases, educating parents of both verbal and nonverbal forms of a child's "turn." The latter is especially important in light of the developmental progression of turn-taking; although a question and answer discourse is appropriate for older children, exchange of facial expressions, gestures, and nonlinguistic sounds may be best suited for infants, thus keeping adult input within the child's zone of proximal development (Zimmerman et al., 2009). Indeed, some research suggests that direct parental instruction on turn-taking may increase children's language skills and neural functioning (Ferjan Ramírez, Lytle, Fish, & Kuhl, 2019; Neville et al., 2013). Many parents may also benefit from learning about the developmental progression of input, with findings suggesting that the sheer quantity of input is most important earlier in infancy, whereas at older ages, the most impactful factor is the diversity of language, including the use of a variety of different words as well as decontextualized language such as narrative, pretend, and explanations (Jones & Rowland, 2017; Rowe, 2012).

The neurobiological research further suggests that promoting high-quality language environments might be even more important for the most vulnerable children, potentially mitigating negative outcomes for children with genetic risk factors for language and literacy disorders, as well as for children in low resource environments. Specifically, increased early exposure to language and literacy may buffer low phonological skill levels and weaker neural reading circuitry in early readers and lead to better reading outcomes than would be expected otherwise (Noble, Farah, & McCandliss, 2006; Noble, Wolmetz, et al., 2006; Ozernov-Palchik et al., 2019). Additionally, frequent cognitive stimulation and emotional support, both of which can be accomplished through language input, may help to protect against some of the socioeconomic disparities in cognitive and neural development (Luby et al., 2013; Rosen et al., 2018). Some longitudinal research even suggests that parent coaching might be most effective for lower SES families (McGillion, Pine, Herbert, & Matthews, 2017). By identifying at risk families, providers may be able to help dispel certain developmental disparities before they take root, and an exciting area of future research will be to explore how clinician- and caregiver-implemented interventions may induce language-related neuroplasticity in at-risk children.

Finally, research on the diversity of language neurobiology may provide critical information for increasing the efficacy of targeted, adaptive interventions. Differences in previous experiences and in linguistic neural circuitry may predispose both parents and children from varying backgrounds to respond better to different forms of interventions (Romeo et al., 2017). One frequent finding is that summer breaks may be a particularly efficacious time for working with less advantaged children, who are more prone to summer learning loss due to reduced access to language and literacy resources when not at school (Cooper, Charlton, & Valentine, 2000); thus, interventions during this time period may be highly effective for diminishing achievement gaps. However, this line of inquiry is too new to responsibly recommend specific treatment protocols entirely based on a child's experience without additionally considering the myriad other social, cognitive, and developmental factors. One exciting area of future research will be to explore whether additionally using individual neural measures may help identify for each child both the most efficacious strategies as well as the time windows in which to provide interventions that stimulate optimal neurodevelopmental trajectories and language outcomes (Gabrieli, Ghosh, & Whitfield-Gabrieli, 2015).

Conclusions

Children's incredible potential for acquiring language is built upon neurobiological foundations, yet the brain's development is also highly dependent on early environments and experiences during sensitive periods. During these windows of time, children's exposure to distal sociocultural influences such as SES, as well as proximal experiences such as frequent linguistic stimulation and contingent turn-taking, shape the neural structure and function underlying the development of language and literacy. So important are these early language experiences that they are termed *experience-expectant* processes and are essential for typical linguistic and neurocognitive development (McLaughlin et al., 2017).

Knowledge of the neurobiological effects of proximal and distal environments provides us with a better understanding of the brain's preferred input for optimal language development, as well as which specific types of input are most influential at which developmental stages. As clinicians, we have a responsibility to educate caregivers, clinicians, and policy makers about the developmental importance of rich early language environments for all children and assist in providing evidence-based, developmentally appropriate input during the sensitive periods for language. In doing so, we have the power to change periods of neural vulnerability to ones of vast neural opportunity.

Acknowledgments

Rachel Romeo is supported by National Institutes of Health Grant T32MH112510. The author would like to thank Melissa Giebler for her helpful comments on an earlier version of this review article and Denise Fournier Eng for many thoughtful discussions on this topic.

References

Avineri, N., Johnson, E., Brice-Heath, S., McCarty, T., Ochs, E., Kremer-Sadlik, T., . . . Paris, D. (2015). Invited forum: Bridging the "language gap." *Journal of Linguistic Anthropology, 25*(1), 66–86.

Barry, R. J., Clarke, A. R., & Johnstone, S. J. (2003). A review of electrophysiology in attention-deficit/hyperactivity disorder: I. Qualitative and quantitative electroencephalography. *Clinical Neurophysiology, 114*(2), 171–183.

Benasich, A. A., Gou, Z., Choudhury, N., & Harris, K. D. (2008). Early cognitive and language skills are linked to resting frontal gamma power across the first 3 years. *Behavioural Brain Research, 195*(2), 215–222.

Betancourt, L. M., Avants, B., Farah, M. J., Brodsky, N. L., Wu, J., Ashtari, M., & Hurt, H. (2016). Effect of socioeconomic status (SES) disparity on neural development in female African-American infants at age 1 month. *Developmental Science, 19*(6), 947–956.

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Reviews in Psychology, 53,* 371–399.

Brito, N. H., & Noble, K. G. (2014). Socioeconomic status and structural brain development. *Frontiers in Neuroscience, 8,* 276.

Brito, N. H., Piccolo, L. R., & Noble, K. G. (2017). Associations between cortical thickness and neurocognitive skills during childhood vary by family socioeconomic factors. *Brain and Cognition, 116,* 54–62.

Brody, G. H., Gray, J. C., Yu, T., Barton, A. W., Beach, S. R., Galván, A., . . . Sweet, L. H. (2017). Protective prevention effects on the association of poverty with brain development. *JAMA Pediatrics, 171*(1), 46–52.

Brody, G. H., Yu, T., Nusslock, R., Barton, A. W., Miller, G. E., Chen, E., . . . Sweet, L. H. (2019). The Protective effects of supportive parenting on the relationship between adolescent poverty and resting-state functional brain connectivity during adulthood. *Psychological Science, 30,* 1040–1049.

Bronfenbrenner, U., & Morris, P. A. (1998). The ecology of developmental processes. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology: Theoretical models of human development* (5th ed., Vol. 1, pp. 993–1028). Hoboken, NJ: Wiley.

Callaghan, B. L., & Tottenham, N. (2016). The Stress Acceleration Hypothesis: Effects of early-life adversity on emotion circuits and behavior. *Current Opinion in Behavioral Sciences, 7,* 76–81.

Cartmill, E. A. (2016). Mind the gap. *Policy Insights from the Behavioral and Brain Sciences, 3*(2), 185–193.

Cartmill, E. A., Armstrong, B. F., Gleitman, L. R., Goldin-Meadow, S., Medina, T. N., & Trueswell, J. C. (2013). Quality of early parent input predicts child vocabulary 3 years later. *Proceedings of the National Academy of Sciences of the United States of America, 110*(28), 11278–11283.

Chiang, M. C., McMahon, K. L., de Zubicaray, G. I., Martin, N. G., Hickie, I., Toga, A. W., . . . Thompson, P. M. (2011). Genetics of white matter development: A DTI study of 705 twins and their siblings aged 12 to 29. *NeuroImage, 54*(3), 2308–2317.

Conant, L. L., Liebenthal, E., Desai, A., & Binder, J. R. (2017). The relationship between maternal education and the neural substrates of phoneme perception in children: Interactions between socioeconomic status and proficiency level. *Brain and Language, 171,* 14–22.

Cooper, H. M., Charlton, K., & Valentine, J. C. (2000). Making the most of summer school: A meta-analytic and narrative review. *Monographs of the Society for Research in Child Development, 65*(1), 1–118.

Demir, Ö. E., Prado, J., & Booth, J. R. (2015). Parental socioeconomic status and the neural basis of arithmetic: Differential relations to verbal and visuo-spatial representations. *Developmental Science, 18*(5), 799–814.

Demir-Lira, Ö. E., Prado, J., & Booth, J. R. (2016). Neural correlates of math gains vary depending on parental socioeconomic status (SES). *Frontiers in Psychology, 7,* 892.

D'Mello, A. M., & Gabrieli, J. D. E. (2018). Cognitive Neuroscience of Dyslexia. *Language, Speech, and Hearing Services in Schools, 49*(4), 798–809.

Dufford, A. J., & Kim, P. (2017). Family income, cumulative risk exposure, and white matter structure in middle childhood. *Frontiers in Human Neuroscience, 11,* 547.

Duncan, G. J., & Brooks-Gunn, J. (1997). *The consequences of growing up poor*. New York, NY: Russell Sage Foundation.

Duncan, G. J., & Magnuson, K. (2012). Socioeconomic status and cognitive functioning: Moving from correlation to causation. *Wiley Interdisciplinary Reviews: Cognitive Science, 3*(3), 377–386.

Durham, R. E., Farkas, G., Hammer, C. S., Bruce Tomblin, J., & Catts, H. W. (2007). Kindergarten oral language skill: A key variable in the intergenerational transmission of socioeconomic status. *Research in Social Stratification and Mobility, 25*(4), 294–305.

Ensminger, M. E., & Fothergill, K. (2003). A decade of measuring SES: What it tells us and where to go from here. In M. H. Bornstein & R. H. Bradley (Eds.), *Socioeconomic status, parenting, and child development* (pp. 13–27). Mahwah, NJ: Erlbaum.

Farah, M. J. (2017). The neuroscience of socioeconomic status: Correlates, causes, and consequences. *Neuron, 96*(1), 56–71.

Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., . . . Hurt, H. (2006). Childhood poverty: Specific associations with neurocognitive development. *Brain Research, 1110*(1), 166–174.

Ferjan Ramírez, N., Lytle, S. R., Fish, M., & Kuhl, P. K. (2019). Parent coaching at 6 and 10 months improves language outcomes at 14 months: A randomized controlled trial. *Developmental Science, 22*(3), e12762.

Fernald, A., Zangl, R., Portllo, A. L., & Marchman, V. A. (2008). Looking while listening: Using eye movements to monitor spoken language comprehension by infants and young children. In I. A. Sekerina, E. M. Fernández, & H. Clahsen (Eds.), *Developmental psycholinguistics: On-line methods in children's language processing* (pp. 97–135). Amsterdam, the Netherlands: John Benjamins.

Fox, S. E., Levitt, P., & Nelson, C. A. (2010). How the timing and quality of early experiences influence the development of brain architecture. *Child Development, 81*(1), 28–40.

Friederici, A. D. (2015). White-matter pathways for speech and language processing. In M. J. Aminoff, F. Boller, & D. F. Swaab (Eds.), *Handbook of clinical neurology: The human auditory system fundamental organization and clinical disorders* (Vol. 128, pp. 177–186). Amsterdam, the Netherlands: Elsevier.

Gabrieli, J. D. E., Ghosh, S. S., & Whitfield-Gabrieli, S. (2015). Prediction as a humanitarian and pragmatic contribution from human cognitive neuroscience. *Neuron, 85*(1), 11–26.

Garcia-Sierra, A., Ramírez-Esparza, N., & Kuhl, P. K. (2016). Relationships between quantity of language input and brain responses in bilingual and monolingual infants. *International Journal of Psychophysiology, 110,* 1–17.

Gianaros, P. J., Marsland, A. L., Sheu, L. K., Erickson, K. I., & Verstynen, T. D. (2013). Inflammatory pathways link socioeconomic inequalities to white matter architecture. *Cerebral Cortex, 23*(9), 2058–2071.

Gilkerson, J., Richards, J. A., Warren, S. F., Montgomery, J. K., Greenwood, C. R., Kimbrough Oller, D., . . . Paul, T. D. (2017). Mapping the early language environment using all-day recordings and automated analysis. *American Journal of Speech-Language Pathology, 26*(2), 248–265.

Gilkerson, J., Richards, J. A., Warren, S. F., Oller, D. K., Russo, R., & Vohr, B. (2018). Language experience in the second year of life and language outcomes in late childhood. *Pediatrics, 142*(4), e20174276.

Ginsborg, J. (2006). The effects of socio-economic status on children's language acquisition and use. In J. Clegg & J. Ginsborg (Eds.), *Language and social disadvantage: Theory into practice* (pp. 9–27). Chichester, United Kingdom: Wiley.

Golinkoff, R. M., Hoff, E., Rowe, M. L., Tamis-LeMonda, C. S., & Hirsh-Pasek, K. (2019). Language matters: Denying the existence of the 30-million-word gap has serious consequences. *Child Development, 90*(3), 985–992.

Gou, Z., Choudhury, N., & Benasich, A. A. (2011). Resting frontal gamma power at 16, 24 and 36 months predicts individual differences in language and cognition at 4 and 5 years. *Behavioural Brain Research, 220*(2), 263–270.

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and Brain Development. *Child Development, 58*(3), 539–559.

Gullick, M. M., Demir-Lira, Ö. E., & Booth, J. R. (2016). Reading skill-fractional anisotropy relationships in visuospatial tracts diverge depending on socioeconomic status. *Developmental Science, 19*(4), 673–685.

Hair, N. L., Hanson, J. L., Wolfe, B. L., & Pollak, S. D. (2015). Association of child poverty, brain development, and academic achievement. *JAMA Pediatrics, 169*(9), 822–829.

Halle, T., Forry, N., Hair, E., Perper, K., Wandner, L., Wessel, J., & Vick, J. (2009). *Disparities in early learning and development: Lessons from the Early Childhood Longitudinal Study–Birth cohort (ECLS-B)*. Washington, DC: Child Trends.

Hanson, J. L., Hair, N., Shen, D. G., Shi, F., Gilmore, J. H., Wolfe, B. L., & Pollak, S. D. (2013). Family poverty affects the rate of human infant brain growth. *PLOS ONE, 8*(12), e80954.

Harmony, T., Marosi, E., Diaz de Leon, A. E., Becker, J., & Fernandez, T. (1990). Effect of sex, psychosocial disadvantages and biological risk factors on EEG maturation. *Electroencephalography and Clinical Neurophysiology, 75*(6), 482–491.

Hart, B., & Risley, T. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore, MD: Brookes.

Hertzman, C. (1999). The biological embedding of early experience and its effects on health in adulthood. *Annals of the New York Academy of Sciences, 896,* 85–95.

Hirsh-Pasek, K., Adamson, L. B., Bakeman, R., Owen, M. T., Golinkoff, R. M., Pace, A., . . . Suma, K. (2015). The contribution of early communication quality to low-income children's language success. *Psychological Science, 26*(7), 1071–1083.

Hoff, E. (2003). The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development, 74*(5), 1368–1378.

Hoff, E. (2006). How social contexts support and shape language development. *Developmental Review, 26*(1), 55–88.

Hoff, E., & Naigles, L. (2002). How children use input to acquire a lexicon. *Child Development, 73*(2), 418–433.

Holz, N. E., Laucht, M., & Meyer-Lindenberg, A. (2015). Recent advances in understanding the neurobiology of childhood socioeconomic disadvantage. *Current Opinion in Psychiatry, 28*(5), 365–370.

Hurtado, N., Marchman, V. A., & Fernald, A. (2008). Does input influence uptake? Links between maternal talk, processing speed and vocabulary size in Spanish-learning children. *Developmental Science, 11*(6), F31–F39.

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: Relation to language input and gender. *Developmental Psychology, 27*(2), 236–248.

Huttenlocher, J., Vasilyeva, M., Cymerman, E., & Levine, S. (2002). Language input and child syntax. *Cognitive Psychology, 45,* 337–374.

Huttenlocher, J., Vasilyeva, M., Waterfall, H. R., Vevea, J. L., & Hedges, L. V. (2007). The varieties of speech to young children. *Developmental Psychology, 43*(5), 1062–1083.

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology, 61*(4), 343–365.

Hutton, J. S., Horowitz-Kraus, T., Mendelsohn, A. L., DeWitt, T., Holland, S. K., & C-MIND Authorship Consortium. (2015). Home reading environment and brain activation in preschool children listening to stories. *Pediatrics, 136*(3), 466–478.

Hutton, J. S., Phelan, K., Horowitz-Kraus, T., Dudley, J., Altaye, M., DeWitt, T., & Holland, S. K. (2017a). Shared reading quality and brain activation during story listening in preschool-age children. *Journal of Pediatrics, 191,* 204.e1–211.e1.

Hutton, J. S., Phelan, K., Horowitz-Kraus, T., Dudley, J., Altaye, M., DeWitt, T., & Holland, S. K. (2017b). Story time turbocharger? Child engagement during shared reading and cerebellar activation and connectivity in preschool-age children listening to stories. *PLOS ONE, 12*(5), e0177398.

Jednoróg, K., Altarelli, I., Monzalvo, K., Fluss, J., Dubois, J., Billard, C., . . . Ramus, F. (2012). The influence of socioeconomic status on children's brain structure. *PLOS ONE, 7*(8), e42486.

Johnson, E. J. (2015). Debunking the "language gap". *Journal for Multicultural Education, 9*(1), 42–50.

Johnson, S. B., Riis, J. L., & Noble, K. G. (2016). State of the art review: Poverty and the developing brain. *Pediatrics, 137*(4), e20153075.

Jones, G., & Rowland, C. F. (2017). Diversity not quantity in caregiver speech: Using computational modeling to isolate the effects of the quantity and the diversity of the input on vocabulary growth. *Cognitive Psychology, 98,* 1–21.

Kinsbourne, M. (1973). Minimal brain dysfunction as a neurodevelopmental lag. *Annals of the New York Academy of Sciences, 205*(1), 268–273.

Knudsen, E. I. (2004). Sensitive periods in the development of the brain and behavior. *Journal of Cognitive Neuroscience, 16*(8), 1412–1425.

Kuhl, P. K. (2010). Brain mechanisms in early language acquisition. *Neuron, 67*(5), 713–727.

Lee, V. E., & Burkam, D. T. (2002). *Inequality at the starting gate: Social background differences in achievement as children begin school*. Washington, DC: Economic Policy Institute.

Luby, J., Belden, A., Botteron, K., Marrus, N., Harms, M. P., Babb, C., . . . Barch, D. (2013). The effects of poverty on childhood brain development: The mediating effect of caregiving and stressful life events. *JAMA Pediatrics, 167*(12), 1135–1142.

Mackey, A. P., Finn, A. S., Leonard, J. A., Jacoby-Senghor, D. S., West, M. R., Gabrieli, C. F., & Gabrieli, J. D. (2015). Neuroanatomical correlates of the income–achievement gap. *Psychological Science, 26*(6), 925–933.

Markham, J. A., & Greenough, W. T. (2004). Experience-driven brain plasticity: Beyond the synapse. *Neuron Glia Biology, 1*(4), 351–363.

Marshall, P. J., Fox, N. A., & BEIP (Bucharest Early Intervention Project) Core Group. (2004). A comparison of the electroencephalogram between institutionalized and community children in Romania. *Journal of Cognitive Neuroscience, 16*(8), 1327–1338.

McGillion, M., Pine, J. M., Herbert, J. S., & Matthews, D. (2017). A randomised controlled trial to test the effect of promoting caregiver contingent talk on language development in infants from diverse socioeconomic status backgrounds. *The Journal of Child Psychology and Psychiatry, 58*(10), 1122–1131.

McLaughlin, K. A., Fox, N. A., Zeanah, C. H., Sheridan, M. A., Marshall, P., & Nelson, C. A. (2010). Delayed maturation in brain electrical activity partially explains the association between early environmental deprivation and symptoms of attention-deficit/hyperactivity disorder. *Biological Psychiatry, 68*(4), 329–336.

McLaughlin, K. A., Sheridan, M. A., & Nelson, C. A. (2017). Neglect as a violation of species-expectant experience: Neurodevelopmental consequences. *Biological Psychiatry, 82,* 462–471.

Merz, E. C., Maskus, E. A., Melvin, S. A., He, X., & Noble, K. G. (2019). Socioeconomic disparities in language input are associated with children's language-related brain structure and reading skills. *Child Development*. Advanced online publication. https://doi.org/10.1111/cdev.13239

Morgan, P. L., Farkas, G., Hillemeier, M. M., Hammer, C. S., & Maczuga, S. (2015). 24-month-old children with larger oral vocabularies display greater academic and behavioral functioning at kindergarten entry. *Child Development, 86*(5), 1351–1370.

Nelson, C. A., Zeanah, C. H., & Fox, N. A. (2019). How early experience shapes human development: The case of psychosocial deprivation. *Neural Plasticity, 2019,* 1676285.

Neville, H. J., Stevens, C., Pakulak, E., Bell, T. A., Fanning, J., Klein, S., & Isbell, E. (2013). Family-based training program improves brain function, cognition, and behavior in lower socioeconomic status preschoolers. *Proceedings of the National Academy of Sciences of the United States of America, 110*(29), 12138–12143.

Newport, E. L., Bavelier, D., & Neville, H. J. (2001). Critical thinking about critical periods: Perspectives on a critical period for language acquisition. In E. Dupoux & J. Mehler (Eds.), *Language, brain, and cognitive development: Essays in honor of Jacques Mehler* (pp. 481–502). Cambridge, MA: MIT Press.

Noble, K. G., Farah, M. J., & McCandliss, B. D. (2006). Socioeconomic background modulates cognition–achievement relationships in reading. *Cognitive Development, 21*(3), 349–368.

Noble, K. G., Houston, S. M., Brito, N. H., Bartsch, H., Kan, E., Kuperman, J. M., . . . Sowell, E. R. (2015). Family income, parental education and brain structure in children and adolescents. *Nature Neuroscience, 18*(5), 773–778.

Noble, K. G., Korgaonkar, M. S., Grieve, S. M., & Brickman, A. M. (2013). Higher education is an age-independent predictor of white matter integrity and cognitive control in late adolescence. *Developmental Science, 16*(5), 653–664.

Noble, K. G., McCandliss, B. D., & Farah, M. J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science, 10*(4), 464–480.

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science, 8*(1), 74–87.

Noble, K. G., Wolmetz, M. E., Ochs, L. G., Farah, M. J., & McCandliss, B. D. (2006). Brain–behavior relationships in reading acquisition are modulated by socioeconomic factors. *Developmental Science, 9*(6), 642–654.

Otero, G. A. (1994). EEG spectral analysis in children with sociocultural handicaps. *International Journal of Neuroscience, 79*(3–4), 213–220.

Otero, G. A. (1997). Poverty, cultural disadvantage and brain development: A study of pre-school children in Mexico. *Electroencephalography and Clinical Neurophysiology, 102*(6), 512–516.

Otero, G. A., Pliego-Rivero, F. B., Fernandez, T., & Ricardo, J. (2003). EEG development in children with sociocultural disadvantages: A follow-up study. *Clinical Neurophysiology, 114*(10), 1918–1925.

Ozernov-Palchik, O., Norton, E. S., Wang, Y., Beach, S. D., Zuk, J., Wolf, M., . . . Gaab, N. (2019). The relationship between socioeconomic status and white matter microstructure in pre-reading children: A longitudinal investigation. *Human Brain Mapping, 40*(3), 741–754.

Piccolo, L. R., Merz, E. C., He, X., Sowell, E. R., & Noble, K. G. (2016). Age-related differences in cortical thickness vary by socioeconomic status. *PLOS ONE, 11*(9), e0162511.

Powers, S. J., Wang, Y., Beach, S. D., Sideridis, G. D., & Gaab, N. (2016). Examining the relationship between home literacy environment and neural correlates of phonological processing in beginning readers with and without a familial risk for dyslexia: An fMRI study. *Annals of Dyslexia, 66,* 337–360.

Raizada, R. D., Richards, T. L., Meltzoff, A., & Kuhl, P. K. (2008). Socioeconomic status predicts hemispheric specialisation of the left inferior frontal gyrus in young children. *NeuroImage, 40*(3), 1392–1401.

Ramey, C. T., & Ramey, S. L. (2004). Early learning and school readiness: Can early intervention make a difference. *Merrill-Palmer Quarterly, 50*(4), 471–491.

Romeo, R. R., Christodoulou, J. A., Halverson, K. K., Murtagh, J., Cyr, A. B., Schimmel, C., . . . Gabrieli, J. D. E. (2017). Socioeconomic status and reading disability: Neuroanatomy and plasticity in response to intervention. *Cerebral Cortex, 28*(7), 2297–2312.

Romeo, R. R., Leonard, J. A., Robinson, S. T., West, M. R., Mackey, A. P., Rowe, M. L., & Gabrieli, J. D. E. (2018). Beyond the "30 million word gap:" Children's conversational exposure is associated with language-related brain function. *Psychological Science, 29*(5), 700–710.

Romeo, R. R., Segaran, J., Leonard, J. A., Robinson, S. T., West, M. R., Mackey, A. P., . . . Gabrieli, J. D. E. (2018). Language exposure relates to structural neural connectivity in childhood. *Journal of Neuroscience, 38*(36), 7870–7877.

Rosen, M. L., Sheridan, M. A., Sambrook, K. A., Meltzoff, A. N., & McLaughlin, K. A. (2018). Socioeconomic disparities in academic achievement: A multi-modal investigation of neural mechanisms in children and adolescents. *NeuroImage, 173,* 298–310.

Rowe, M. L. (2012). A longitudinal investigation of the role of quantity and quality of child-directed speech in vocabulary development. *Child Development, 83*(5), 1762–1774.

Rowe, M. L. (2017). Understanding socioeconomic differences in parents' speech to children. *Child Development Perspectives, 12,* 122–127.

Rowe, M. L., & Goldin-Meadow, S. (2009). Differences in early gesture explain SES disparities in child vocabulary size at school entry. *Science, 323*(5916), 951–953.

Rowe, M. L., & Zuckerman, B. (2016). Word gap redux: Developmental sequence and quality. *JAMA Pediatrics, 170*(9), 827–828.

Sarsour, K., Sheridan, M., Jutte, D., Nuru-Jeter, A., Hinshaw, S., & Boyce, W. T. (2011). Family socioeconomic status and child executive functions: The roles of language, home environment, and single parenthood. *Journal of the International Neuropsychological Society, 17*(1), 120–132.

Schwab, J. F., & Lew-Williams, C. (2016). Language learning, socioeconomic status, and child-directed speech. *Wiley Interdisciplinary Reviews: Cognitive Science, 7*(4), 264–275.

Sheridan, M. A., Sarsour, K., Jutte, D., D'Esposito, M., & Boyce, W. T. (2012). The impact of social disparity on prefrontal function in childhood. *PLOS ONE, 7*(4), e35744.

Sperry, D. E., Sperry, L. L., & Miller, P. J. (2018). Reexamining the verbal environments of children from different socioeconomic backgrounds. *Child Development, 90*(4), 1303–1318.

Swingley, D. (2012). The looking-while-listening procedure. In E. Hoff (Ed.), *Research methods in child language* (pp. 29–42). West Sussex, United Kingdom: Wiley-Blackwell.

Tamis-LeMonda, C. S., Kuchirko, Y., & Song, L. (2014). Why is infant language learning facilitated by parental responsiveness. *Current Directions in Psychological Science, 23*(2), 121–126.

Tomalski, P., Moore, D. G., Ribeiro, H., Axelsson, E. L., Murphy, E., Karmiloff-Smith, A., . . . Kushnerenko, E. (2013). Socioeconomic status and functional brain development—Associations in early infancy. *Developmental Science, 16*(5), 676–687.

Ursache, A., Noble, K. G., & PING Study. (2016). Socioeconomic status, white matter, and executive function in children. *Brain and Behavior, 6*(10), e00531.

Walker, D., Greenwood, C., Hart, B., & Carta, J. (1994). Prediction of school outcomes based on early language production and socioeconomic factors. *Child Development, 65,* 606–621.

Weisleder, A., & Fernald, A. (2013). Talking to children matters: Early language experience strengthens processing and builds vocabulary. *Psychological Science, 24*(11), 2143–2152.

Weizman, Z. O., & Snow, C. E. (2001). Lexical input as related to children's vocabulary acquisition: Effects of sophisticated exposure and support for meaning. *Developmental Psychology, 37*(2), 265–279.

Werker, J. F., & Tees, R. C. (2005). Speech perception as a window for understanding plasticity and commitment in language systems of the brain. *Developmental Psychobiology, 46*(3), 233–251.

Younger, J. W., Lee, K. W., Demir-Lira, O. E., & Booth, J. R. (2019). Brain lateralization of phonological awareness varies by maternal education. *Developmental Science, 22*(6), e12807.

Zimmerman, F. J., Gilkerson, J., Richards, J. A., Christakis, D. A., Xu, D., Gray, S., & Yapanel, U. (2009). Teaching by listening: The importance of adult–child conversations to language development. *Pediatrics, 124*(1), 342–349.