

Socioeconomic Inequality and the Developing Brain: Spotlight on Language and Executive Function

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ABSTRACT—*Robust evidence of the deleterious effects of poverty on children’s academic achievement has generated considerable interest in the neural mechanisms underlying these associations. In studies of specific neurocognitive skills, researchers have found pronounced socioeconomic disparities in children’s language and executive function (EF) skills. In this article, we review research linking socioeconomic factors (e.g., family income, parental education) with children’s brain structure and function, focusing on the neural systems involved in language and EF. Then, we cover the potential mediators of these associations, developmental timing, and strategies for prevention and intervention. To complement research at the behavioral level, we conclude with recommendations for integrating measures of the developing brain into this ongoing work.*

KEYWORDS—*socioeconomic status; brain structure; brain function; language; executive function*

Nearly 16 million American children live below the poverty line (Semega, Fontenot, & Kollar, 2017), and socioeconomic disparities in children’s educational outcomes have been well documented (Sirin, 2005). Differences in school-readiness skills

emerge in early childhood, preceding differences in academic achievement that tend to widen over time. Empirical evidence suggests that socioeconomic disadvantage may hinder cognitive development and prevent children from reaching their educational potential (Duncan, Magnuson, & Votruba-Drzal, 2017). Identifying ways to reduce this socioeconomic status (SES)-achievement gap is crucial to improving the academic trajectories of many children in the United States and globally.

Recent research has shed light on correlations between SES (family income, parental educational attainment, parental occupational prestige) and the developing brain, including the neural mechanisms underlying disparities in academic achievement, with the goal of identifying targets for effective prevention and intervention strategies. Initial investigations examined associations between socioeconomic background and children’s performance on batteries of neurocognitive tasks. These studies revealed variation in the magnitude of associations across tasks, with stronger associations for language and executive function (EF) than for other neurocognitive skills (Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005). In line with these results, evidence points to large socioeconomic differences in language comprehension and production (e.g., expressive and receptive vocabulary, grammar, phonological awareness), along with moderate to large differences in EF skills, including inhibitory control, working memory, and cognitive flexibility (Lawson, Hook, & Farah, 2017; Pace, Luo, Hirsh-Pasek, & Golinkoff, 2017).

In this article, we review studies examining associations between family SES and children’s brain structure and function, emphasizing the neural regions that support language and EF. Then, we address the proximal factors through which SES may affect language and EF development, the developmental timing of socioeconomic disparities in language and EF, and programs and policies that may mitigate the effects of socioeconomic disadvantage on language and EF. Because few studies have tackled these latter questions with regard to the brain, we summarize evidence from behavioral studies of language and EF, and use this research to suggest directions for ongoing work.

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SOCIOECONOMIC INEQUALITY AND BRAIN STRUCTURE IN YOUTH

Family SES has been associated repeatedly with differences in children's brain structure, particularly in regions responsible for language and EF. Socioeconomic disadvantage has been associated with reduced cortical gray matter, as measured in terms of volume (Hair, Hanson, Wolfe, & Pollak, 2015; Jednoróg et al., 2012), thickness (Lawson, Duda, Avants, Wu, & Farah, 2013; Mackey et al., 2015; Romeo et al., 2017), and surface area (Noble et al., 2015). For example, in a study of 3- to 20-year-olds, higher family income and parental education were associated significantly with greater cortical surface area, independent of age, sex, and genetic ancestry (Noble et al., 2015). The strongest effects were seen in the left perisylvian cortical regions underlying language processing, as well as in the regions of the prefrontal cortex (PFC) underlying EF. These neuroanatomical differences partially explained socioeconomic disparities in vocabulary (Romeo et al., 2017), EF (Noble et al., 2015), and standardized tests of academic achievement (Hair et al., 2015; Mackey et al., 2015).

Studies examining these associations have also used diffusion tensor imaging, a structural magnetic resonance imaging (MRI) technique that measures the diffusion of water molecules in the brain. In these studies, socioeconomic disadvantage was linked with reduced integrity of white matter tracts, which may indicate less efficient connections between brain regions (Ursache & Noble, 2016). For example, in 8- to 10-year-olds, lower family income was associated with lower integrity of white matter in the left uncinate fasciculus, cingulum bundle, and superior longitudinal fasciculus (Dufford & Kim, 2017). Lower integrity of the superior longitudinal fasciculus, which connects the frontal lobe with parietotemporal regions, may relate to difficulties with language processing and working memory in children from disadvantaged families. However, in another study, SES was not associated with whole-brain white matter microstructure in 10-year-olds, possibly because of the small sample size (Jednoróg et al., 2012). Thus, while growing evidence points to socioeconomic differences in the structure of both gray and white matter in areas of the brain responsible for language and EF, more research is needed to delineate these differences and tie them to academic achievement.

SOCIOECONOMIC INEQUALITY AND BRAIN FUNCTION IN YOUTH

Socioeconomic differences in brain function in children and adolescents have been observed using functional MRI (fMRI) and electrophysiological methods. Disparities have been found during language and reading tasks, including phonemic discrimination and phonological processing (Farah, 2017). Regions that have been implicated include the left perisylvian cortical regions underlying language production and comprehension,

and temporal-occipital regions underlying reading skills (Conant, Liebenthal, Desai, & Binder, 2017; Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006). For example, one fMRI study of 5-year-olds examined associations between socioeconomic background and neural activation during a phonological awareness (rhyming) task. Higher SES was associated with greater left lateralization of inferior frontal activation during rhyming (Raizada, Richards, Meltzoff, & Kuhl, 2008). Although another study did not find socioeconomic differences in brain activation during language perception (Monzalvo, Fluss, Billard, Dehaene, & Dehaene-Lambertz, 2012), this could be a result of the procedures used (measuring brain function during passive perception of speech or printed words; Farah, 2017).

Researchers have also reported socioeconomic differences in brain function during EF tasks. In some studies, socioeconomic disadvantage has been linked with increased brain activation in prefrontal regions in the context of similar task performance. For example, youth from disadvantaged families performed less successfully on EF tasks but showed greater recruitment of PFC regions than youth from more advantaged families (Sheridan, Peverill, Finn, & McLaughlin, 2017; Sheridan, Sarsour, Jutte, D'Esposito, & Boyce, 2012; Spielberg et al., 2015). In another study, lower family income tended to be associated with reduced PFC activation as a function of higher working memory load, as well as with reduced accuracy (though lower family income was associated with greater PFC activation at lower working memory loads; Finn et al., 2017). These differences in brain function explained differences in mathematics achievement (Finn et al., 2017). Taken together, this work could suggest that children from higher and lower SES backgrounds rely on different patterns of neural activation to perform EF tasks (Luna, Padmanabhan, & O'Hearn, 2010).

Several studies have demonstrated socioeconomic differences in event-related potential (ERP) activity during selective attention tasks involving EF (D'Angiulli, Herdman, Stapells, & Hertzman, 2008). Children from disadvantaged families have demonstrated decreased neural activity during processing of relevant information or decreased neural suppression of irrelevant information in regions of the scalp consistent with PFC locations. In some cases, this occurred even in the absence of socioeconomic differences in task accuracy. For example, in a study of 7- to 12-year-olds in which children from different socioeconomic backgrounds performed equivalently on a target detection task, ERPs nonetheless revealed that children from lower income families showed an attenuated response to target stimuli (Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009). Another study investigated socioeconomic disparities in neural indices of auditory selective attention in 3- to 8-year-olds; although behavioral performance was identical among children from different socioeconomic backgrounds, children from more advantaged backgrounds showed evidence of neural suppression of unattended auditory stimuli compared with children from more disadvantaged backgrounds (Stevens, Lauinger, & Neville, 2009).

Considering the functional neuroimaging and electrophysiological results together, circumstances surrounding socioeconomic disadvantage may favor the development of less efficient EF, requiring greater recruitment of PFC regions to complete tasks involving these skills. One explanation is that it may be adaptive to maintain higher vigilance (and thus less selective attention and less efficient EF) when threat is more likely (Ellis, Bianchi, Griskevicius, & Frankenhuis, 2017). Such an interpretation suggests that socioeconomic disparities in neural function are not more or less optimal, but that neural function may be optimized for the situation at hand.

MEDIATORS LINKING SOCIOECONOMIC BACKGROUND WITH LANGUAGE AND EF DEVELOPMENT

Socioeconomic factors are theorized to be distal factors that exert their effects on brain development through more proximal factors or mediating mechanisms (Bronfenbrenner & Morris, 1998). Linguistic input in the home environment and family stress may be important mediators of the effects of socioeconomic disadvantage on the brain regions responsible for language and EF, respectively (Noble, Houston, Kan, & Sowell, 2012).

Language

Striking socioeconomic disparities can be identified in the quantity and quality of linguistic input that children receive (Pace et al., 2017). For example, in a seminal study, Hart and Risley (1995) observed large disparities in the number of words children heard from their parents—more than three times as many in higher income families as in lower income families. In follow-up work, 3-year-olds from lower income families had less than half the vocabulary of their counterparts from higher income families. With these findings replicated in numerous studies, converging evidence indicates that SES-based variability in linguistic stimulation in the home (especially the quality of language input) accounts partially for socioeconomic differences in children's language development (Pace et al., 2017). Echoing these behavioral findings, in a recent study using fMRI, less advantaged parents had fewer conversational exchanges with their 4- to 6-year-olds than more advantaged parents. In turn, children who experienced fewer conversational exchanges had reduced activation in left inferior frontal regions during language processing (Romeo et al., 2018).

Executive Function

Chronic stress is thought to be a key factor through which socioeconomic background influences the development of EF. Disadvantaged families tend to have many stressors in their lives (e.g., financial strain, neighborhood violence, crowding and noise, and household chaos and unpredictability; Evans & Kim, 2013). At the level of stress physiology, children from disadvantaged families exhibit dysregulation of the hypothalamic-pituitary-adrenal

axis, as indicated by higher or lower levels of cortisol (Ursache, Merz, Melvin, Meyer, & Noble, 2017). Chronic stress exerts powerful effects in areas of the brain with high concentrations of glucocorticoid receptors, such as the PFC (McEwen & Morrison, 2013). Empirical work suggests that chronic stress may mediate the effects of socioeconomic disadvantage on the developing PFC (Farah, 2017). For example, in a study using fMRI, chronic exposure to stressors in childhood significantly mediated the association between family income in childhood and PFC activity in young adulthood (Kim et al., 2013).

Thus, linguistic input in the home and chronic stress may be important mechanisms underlying socioeconomic disparities in language and EF, respectively, and more work is needed to examine the role of these mediators with regard to the underlying neural circuitry. These mediators are not thought to be mutually exclusive. Indeed, it is likely that to an extent, language input also influences the development of EF and chronic stress also affects language development. In particular, in addition to language outcomes, evidence suggests that children's language experiences influence their development of EF (Carlson, Zelazo, & Faja, 2013).

DEVELOPMENTAL TIMING OF SOCIOECONOMIC DISADVANTAGE

Exposure to socioeconomic disadvantage early in life may have marked and enduring effects on brain development. Early childhood is a sensitive period when the brain may be particularly malleable to environmental effects as a result of its rapid development (Sheridan & McLaughlin, 2016). Empirical evidence supports the notion that exposure to poverty during early childhood may be especially detrimental to children's brain development. Socioeconomic differences in brain structure and function have been observed from the first year of life (Betancourt et al., 2016; Hanson et al., 2013; Tomalski et al., 2013) through adolescence, paralleling differences in cognitive performance that persist or widen over time. Moreover, in research with adults, SES in childhood was associated with brain structure and function even after accounting for SES in adulthood (Farah, 2017; Staff et al., 2012). Nonetheless, although neural plasticity may be diminished, it is not absent later in childhood or adolescence. In particular, the PFC develops in a protracted manner through adolescence, suggesting a longer window of plasticity for EF. Thus, evidence points to early childhood as a prime time for interventions to reduce socioeconomic differences in language and EF, but suggests that interventions at older ages may also be effective.

PROGRAMS AND POLICIES TO REDUCE SOCIOECONOMIC DIFFERENCES IN BRAIN DEVELOPMENT

Several interventions and policies have improved language and EF in children from disadvantaged families. Interventions have

taken various approaches, such as targeting the putative mediators of SES effects (e.g., linguistic stimulation in the home), providing enhanced curricula and early educational programs, or changing SES directly by increasing family income. Early home visiting programs, such as the Nurse–Family Partnership, have yielded positive long-term outcomes for disadvantaged families (Donelan-McCall, 2017). These programs aim to improve family functioning or the home environment, with some interventions narrower in scope and developmental mechanisms than others. Pertinent to this article, some programs have enhanced the quantity and quality of parents’ speech to children, which in turn facilitated language development in children from disadvantaged families. For example, mothers who participated in the Play and Learning Strategies intervention demonstrated greater sensitivity and contingent responsiveness during interactions with their infants than mothers who did not receive the intervention; these increases in the quality of mother–child interactions were linked with improved language skills in the children (Landry, Smith, & Swank, 2006).

High-quality early care and education programs also support language and EF development in children from disadvantaged families. Intensive preschool interventions (e.g., the Perry Preschool and Abecedarian projects) have had positive effects into adulthood (Ramey & Ramey, 2004), and in evaluations of publicly funded prekindergarten programs, children had more optimal language, literacy, and math outcomes (Weiland & Yoshikawa, 2013). Although most of the research has focused on early academic outcomes, especially language and literacy, some studies have also demonstrated effects on EF (Weiland & Yoshikawa, 2013). In addition, targeted preschool curricula (e.g., classroom activities, approaches to teacher training) have improved EF in preschoolers (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Raver et al., 2011).

Programs and policies that provide income support to disadvantaged families have also improved children’s cognitive development or academic outcomes, although they have not measured language and EF specifically (Duncan et al., 2017). For example, in the late 1960s and 1970s, policymakers considered a negative income tax that would provide a guaranteed minimum income to families with children. In studies of this approach, elementary school children’s attendance and achievement rose (Duncan et al., 2017).

Few intervention studies focused on socioeconomic disadvantage have included measures of brain structure or function. These interventions have sought to improve the environments of children from disadvantaged families to address some of the proximal causes of socioeconomic disparities in cognitive development. For example, in one study, sessions to improve children’s attention coupled with sessions to teach parents strategies to support children’s attention and reduce family stress led to enhanced brain function (e.g., ERP correlates of selective attention) in disadvantaged preschoolers (Neville et al., 2013). In another study, families

were randomly assigned to a multisession intervention focused on parenting skills or a control group that received information on children’s development, stress management, and exercise (Brody et al., 2017). A longer duration of childhood poverty was associated with smaller hippocampal and amygdala volume in children in the control group when they were young adults. For children whose parents participated in the intervention, the duration of childhood poverty was not linked to brain structure in these regions, suggesting that the intervention mitigated the negative effects of childhood poverty on these brain structures (Brody et al., 2017). Taken together, these findings suggest that prevention and intervention programs may ameliorate the negative impact of socioeconomic disadvantage on language and EF skills at the neural level.

CONCLUSIONS AND RECOMMENDATIONS

Recent research has yielded evidence of associations between family SES and children’s brain structure and function. Although these differences tend to be in widespread areas across the brain, some of the largest and most consistent associations are in regions underlying language and EF. Socioeconomic disadvantage has been linked with reduced gray matter and integrity of white matter tracts in language and EF regions. Functionally, socioeconomic disadvantage has been associated with differences in the recruitment of the left perisylvian cortex during language tasks, and in the recruitment of the PFC during EF tasks. These brain differences partially account for the associations between socioeconomic disadvantage and cognitive and academic outcomes.

Most studies on this topic have been cross-sectional. Research is needed that leverages prospective longitudinal designs to elucidate how family SES influences developmental trajectories of brain structure or function. In addition, longitudinal designs can test the effects of the timing and duration of socioeconomic disadvantage on brain development. Research is also needed on the mediators of SES effects on language and EF brain regions (Noble et al., 2012). Because it is likely that many co-occurring mediators link SES with these brain outcomes, it is important to measure and analyze many mediators simultaneously to uncover their relative contributions.

Although experimental and quasi-experimental research (e.g., natural experiments) has supported causal effects of family SES on children’s cognitive and academic outcomes (Duncan et al., 2017), few studies using these designs have included measures of the brain. Thus, researchers should use these designs to make inferences about the causal role of socioeconomic background in children’s brain development. Additionally, such studies make it possible to identify the neural mechanisms underlying the effects of an intervention on children’s language and EF skills. Pinpointing how an intervention works at the neural level helps us understand what is needed to produce gains in children’s language and EF.

The families and children who participate in the interventions we have described share the experience of socioeconomic disadvantage but are otherwise a heterogeneous group, varying in ways that could relate to whether and how much they benefit from certain interventions. Researchers should explore neurobiological factors as moderators of response to interventions in this group. Studies that couple experimental designs with measurement of potential biomarkers would provide information on the mechanisms underlying the effects of socioeconomic disadvantage. Ultimately, this research could be used to more precisely match children and families with effective interventions.

Although socioeconomic disparities in children's academic outcomes represent a challenging public health problem, recent research linking SES and children's brain structure and function has opened new avenues for addressing the problem. With this work as a critical foundation, the field is now positioned to understand in a more nuanced way how these brain differences lead to differences in achievement and how proximal processes contribute to these outcomes. Applying these findings to practice and policy will help close the SES-achievement gap, and will improve the educational outcomes and life chances of children from disadvantaged families.

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