Research in Health Science
ISSN 2470-6205 (Print) ISSN 2470-6213 (Online)
Vol. 6, No. 4, 2021
www.scholink.org/ojs/index.php/rhs

Review Paper

Racism-Related Diminished Returns of Socioeconomic Status on Adolescent Brain and Cognitive Development

Shanika Boyce[1], Mona Darvishi[2], Roghayeh Marandi[2], Roxana Rahmanian[2], Sumreen Akhtar[3], Jasmine Patterson[3] & Shervin Assari[2,4,5]

[1] Department of Pediatrics, Charles Drew University, Los Angeles, CA 90059, USA

[2] Marginalization-related Diminished Returns (MDRs) Research Center, Los Angeles, CA 90059, USA

[3] Department of Family Medicine, Charles Drew University, Los Angeles, CA 90059, USA

[4] Undergraduate Research Opportunity Program (UROP), University of Michigan, Ann Arbor, MI 48109, USA

[5] Department of Urban Public Health, Charles Drew University, Los Angeles, CA 90059, USA

Abstract

Socioeconomic status (SES) influences health, behaviors, and well-being. Emerging information suggests that SES effects on health may be in part be due to SES effects on brain development. We have conducted a mini review of U.S.-based studies examining SES effects on brain development to synthesize the existing knowledge on what brain structures and functions show large and consistent SES influences. We have reviewed SES effects on performance in various cognitive functions such as learning, memory, and language. Additionally, we have reviewed the emerging literature from the Adolescent Brain Cognitive Development (ABCD) study on the effects of social marginalization in reducing the effects of SES on children and youth brain development. These diminished returns of SES in minoritized youth are not due to genetics; rather, we argue that they stem from systemic and structural racism, social stratification, and marginalization that generate inequalities across the SES spectrum. As a result of these diminished returns, inequalities expand from low-SES to mid- and high SES sections of US society.

Keywords

brain health, cognitive impairment, dementia, ethnicity, health disparities, race, socioeconomic status

Introduction

Farah (Farah, 2017), Noble (Noble & Giebler, 2020), and others (Natalie H Brito & Kimberly G Noble, 2014; Johnson, Riis, & Noble, 2016) have conducted reviews on socioeconomic status (SES) influences on brain development and health. The mini review we have conducted further summarizes research on the mechanisms of SES on brain development and cognitive function, including language development. The main contribution of this review is to go beyond overall effects of SES and show how SES effects differ across various social groups who live in different context.

Brain health has been repeatedly linked to environmental factors (Holt & Mikati, 2011). Early life determinants can predict the risk of neurodegenerative diseases (Staff, Murray, Deary, & Whalley, 2004). Recent advances in neuroimaging technologies have enhanced our ability to conduct precise brain structure measurements, showing differences in the effects of early life experiences on brain development (Staff et al., 2012). Moreover, adverse childhood experiences are related to abnormalities in brain structure and function in adulthood (Bremner, 2003; van Harmelen et al., 2010). Extensive research has shown that childhood socioeconomic status has long-lasting influences on functional and structural brain development (Tomalski & Johnson, 2010). Some researchers define SES as the combination of non-economic features, such as education and the prestige of social standing, as well as material possessions (Hackman & Farah, 2009). While SES is a concept with high predictability and stability, other environmental factors such as stress and neighborhood quality have more transient effects on one's cognitive, mental, and physical health development (Adler & Rehkopf, 2008; Rand D Conger & M Brent Donnellan, 2007; Duncan & Magnuson, 2003; Sirin, 2005).

The influence of childhood SES on brain development is, in part, mediated by more proximal factors such as exposure to environmental toxins, diet, stress, cognitive stimulation, and various aspects of parenting such as parental engagement (Tomalski & Johnson, 2010). It is unclear to what degree the adult environment contributes to adult brain structure and associated brain function or cognitive decline (Hedges et al., 2008). A large number of cognitive systems including but not limited to memory, language and executive function are influenced by SES (Hackman & Farah, 2009; Raizada & Kishiyama, 2010).

Despite these findings, the literature connecting SES and the brain is also characterized by a number of significant limitations. One is a lack of sample diversity, which means that few studies have tested whether associations between SES and brain outcomes are moderated by contextual or demographic factors (Staff et al., 2012). A second limitation is the cross-sectional design of most previous studies, which limits causal inference. Cross-sectional studies in adulthood also have the challenge of distinguishing between the effects of early life and later life exposures, such as childhood and adulthood SES. In addition, the extent to which early SES effects on brain development can be "rescued" by conditions in later life is currently unknown.

Farah (Farah, 2017), Noble (Noble & Giebler, 2020), and others (Natalie H Brito & Kimberly G Noble, 2014; Johnson et al., 2016) have conducted reviews on socioeconomic status (SES) influences on brain development and health. The mini review we have conducted builds on this foundation in two ways: First, we summarize new research on the mechanisms connecting brain development and cognitive function, focusing on the domains of memory, language development, and executive functioning. Second, we also go beyond the marginal effects of SES to review emerging research testing whether SES effects differ across various social groups who live in different contexts.

Memory

Several studies have reported an SES gradient in performance on memory tests. Lipina et al. showed that infants from low SES families' were less likely to possess the working memory and inhibitory control abilities required to pass the 'A not B' test, an early measure of executive function (Diamond, 1990; Lipina, Martelli, Vuelta, & Colombo, 2005). Studies have also reported associations between SES and the structure and function of brain regions responsible for memory. For example, Jednoróg et al. found positive correlations between SES and gray matter volumes in the right inferior occipito-temporal gyri, left fusiform gyri, bilateral hippocampi, and middle temporal gyri. These are brain regions related to cognitive abilities known to be influenced by SES (Jednoróg et al., 2012). Consistent relationships between SES the bilateral hippocampi and parahippocampal gyri, regions associated with memory performance and prenatal and early stress, were also found (Jednoróg et al., 2012). Similarly, in a study of 317 children, ages 4-18 years old, Hanson et al. found that that children in low-income families had less gray matter in the bilateral hippocampi compared to children in high-income families (Hanson, Chandra, Wolfe, & Pollak, 2011).

Language Development

SES is strongly associated with language skills, such as literacy, vocabulary, syntax, and phonological awareness (Farah et al., 2006; Fluss et al., 2009; Noble & McCandliss, 2005; Noble, McCandliss, & Farah, 2007). For example, one study found that three-year-old children from high SES families have an average vocabulary size that is twice as large as children who participate in welfare programs (Hart & Risley, 1995). Since language abilities have been shown to be one of the cognitive systems highly affected by SES, there may be some SES effects on structural characters of the hippocampus, prefrontal cortex and medial temporal lobes (Hackman & Farah, 2009; Jednoróg et al., 2012). In fact, high SES is associated with higher language competence. Hart and Risely found that three year old children from high SES families have an average vocabulary size that is twice as large as children who participate in welfare programs (Hart & Risley, 1995). Moreover, SES gradients were observed for vocabulary, phonological awareness, and syntactic development at different developmental stages, presenting explicit evidence for SES effects on the left perisylvian cortex (responsible for language processing), which could explain language disparities (Whitehurst, 1997).

Additionally, Hackman & Farah found that children ages 6 to 9 with below average reading ability show different associations between SES activation in the left fusiform gyrus (plays important role in visual word recognition), and phonological awareness (Hackman & Farah, 2009). In lower SES levels, a strong positive relationship between left fusiform activity and phonological awareness was observed, while there was no correlation between the two in higher SES children (Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006). Likewise, in a functional Magnetic Resonance Imaging (fMRI) study where 5-year-old children judged whether words and non-words rhyme, researchers found that the amount of hemispheric specialization in the left inferior frontal gyrus was positively associated with SES (Raizada, Richards, Meltzoff, & Kuhl, 2008). One study that investigated asymmetries in parietal and temporal lobes in children failed to find SES disparities (Eckert, Lombardino, & Leonard, 2001). However, another specifically studying the left inferior frontal gyrus found a higher probability to see a marginal tendency towards smaller volumes in lower SES children (Raizada et al., 2008). Furthermore, a strong association was found between SES and Broca's area (motor speech area) located within the left inferior frontal gyrus (Raizada et al., 2008).

In line with several studies (Fluss et al., 2009; Noble & McCandliss, 2005; Noble et al., 2007), Jednoróg et al. found positive relationships between SES and reading and verbal abilities, elucidating that language is one of the domains of cognition that is most influenced by SES (Jednoróg et al., 2012). While most studies have shown phonological awareness and SES to be correlated (Dickinson & Snow, 1987; Noble & McCandliss, 2005; Wallach, Wallach, Dozier, & Kaplan, 1977), a relationship between SES and phonological awareness was not found in Jednoróg et al. study, likely because children with reading disabilities were excluded, causing the range of phonological awareness to be too narrow to show a significant effect (Jednoróg et al., 2012). There are other studies not showing a correlation between phonological awareness and SES (Dodd, Holm, Hua, & Crosbie, 2003; Fluss et al., 2009). Consistent correlation between SES and the left temporal-occipital areas (fusiform and middle temporal gyrus) has been reported that is particularly related with written language (Dehaene et al., 2010). Given the strong influence of SES on reading proficiency, this is a highly plausible finding (Fluss et al., 2009; Molfese, Modglin, & Molfese, 2003). In addition, a positive correlation has been observed between SES and gyrification in the left medial prefrontal cortex which is implicated in language (Jednoróg et al., 2012).

Moreover, Hackman and Farah used the Neuropsychological Assessment Battery to assess five cognitive domains (attention, language, memory, spatial, and executive functions) across three different age samples. Hackman and Farah found that middle-SES kindergarteners perform better, especially on the left perisylvian/language system and Prefrontal/ Executive system tests compared to their low-SES counterparts (Hackman & Farah, 2009), even though the results from the other neurocognitive assessments did not remarkably differ between low and middle SES children (Noble, Norman, & Farah, 2005). Additionally, Hackman and Farah presented substantial evidence that showed a strong association between the left perisylvian/language system and SES (Hackman & Farah, 2009), similarly the Medial temporal/Memory system, parietal/spatial cognition system (Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005), and the executive functions of Lateral prefrontal/Working memory and Anterior cingulate/Cognitive control (Noble et al., 2007) showed an SES gradient. A similar pattern was seen in low and middle SES children as there were SES disparities in working memory, language, spatial cognition, and cognitive control (Farah et al., 2006). In fact, the impact of poverty is disproportionate to some neurocognitive systems, such as language and executive function (Hackman & Farah, 2009). Some areas of the brain that remain to be confirmed and interpreted include the right middle temporal gyrus and the right inferior occipito-temporal region (Jednoróg et al., 2012). The latter might be correlated with literacy, as some studies have indicated its functional participation in the acquisition of reading skills (Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003).

Executive Function

Multiple studies have documented SES influences on executive function and selective attention. For example, Mezzacappa reported SES variations in tests of ‘executive attention’ in 6-year-old children using Posner’s Attention Network Task (Mezzacappa, 2004; Rueda et al., 2004). This finding is also substantiated by neuropsychological test studies on adults (Singh-Manoux, Richards, & Marmot, 2005; Turrell et al., 2002).

Several studies have used electrophysiological measures to investigate SES influenced disparities in resting state brain functions. For example, Otero et al. found a maturational lag in the prefrontal cortex in Mexican and low SES preschool children (Otero, 1997). Tomarken et al. found left-frontal hypoactivity in low SES children (Tomarken, Dichter, Garber, & Simien, 2004). Using event-related potentials, poverty is shown to decline executive function development and selective attention (Czernochowski, Fabiani, & Friedman, 2008; D’Angiulli, Weinberg, Grunau, Hertzman, & Grebenkov, 2008; Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009; Stevens, Lauinger, & Neville, 2009). Moreover, a study investigating the impacts of the level of a mother’s education on a selective auditory attention task in 3- to 8-year-old children, found differing patterns of neural responses which correlated to SES, thus showing that SES is a broad, positive indicator of attention span (Stevens et al., 2009). Children from low-SES families showed a higher breadth of responses to the probes in the unattended channel, indicating difficulty in stopping distracting stimuli from disrupting the processing stream (Stevens et al., 2009). Another study found lower selective attention was electro-physiologically observed in low-SES children (Hackman & Farah, 2009). Moreover, using event-related potentials, D’Anguilli et al. found that children from low-SES families show reduced selective attention, although reaction time and accuracy were equal regardless of SES (D'Angiulli, Herdman, Stapells, & Hertzman, 2008; D’Angiulli et al., 2008). Another study using event-related potentials displayed that the recruitment of prefrontal attentional control mechanisms in children with higher SES tend to be greater than control mechanisms in children with low SES (Kishiyama et al., 2009). Such subtle SES differences in attention may explain the effects of SES on language development, which requires selective attention to verbal stimuli (Stevens et al., 2009). These processes may be disrupted in low-SES conditions with high-frequency noises and distracting stimuli (Evans, 2004).

Brain Structure

Associations between SES and morphometric measures such as brain size are commonly reported. Jednoróg et al. found positive associations between gray matter dimensions and SES, suggesting that conducive environments are generally correlated with larger amounts of grey matter (Jednoróg et al., 2012). In contrast, Staff et al., did not find a relationship between childhood SES and entire brain volume (Staff et al., 2012). Interestingly, a higher rate of brain atrophy in individuals with high socioeconomic status has been reported (Fotenos, Mintun, Snyder, Morris, & Buckner, 2008). So, the findings are mixed, and more research is needed on this topic.

Affective Processes

SES influences on affective neuronal process have been frequently reported. For example, a study that found a relationship between low SES and increased amygdala activation in response to negative and threatening faces (Gianaros et al., 2008). Furthermore, a fMRI study that examined neural responses to unstable and stable hierarchies established in the context of an economically interactive game, found extensive influences in brain regions involved in affective and cognitive processes (Zink et al., 2008).

Functional Connectivity

An Adolescent Brain Cognitive Development (ABCD) study by Rakesh et al. on 7618 children aged 9-10 years old revealed that social disadvantage such as higher crime rates, pollution, and lower quality health care and schooling, was associated with widespread alterations in resting state functional connectivity (rsFC) in both the default mode network and sensorimotor functional systems (Rakesh, Seguin, Zalesky, Cropley, & Whittle, 2021). Sex, positive parenting, and schooling, however, were found to moderate some of the effects of neighborhood disadvantage on rsFC (Rakesh, Seguin, et al., 2021). In particular, females showed a stronger negative association between the area deprivation index (ADI) and rsFC than males (Rakesh, Seguin, et al., 2021).

Likewise, another study by Rakesh et al. of 9475 children aged 9-10, found three SES factors, neighborhood disadvantage, parental education attainment, and income-to needs ratio were associated with the connectivity of similar networks (Rakesh, Zalesky, & Whittle, 2021). Higher neighborhood advantage, higher household income-to-needs ratio, and higher educational attainment were all associated with reduced connectivity within and between sensorimotor networks and increased sensorimotor connections to frontal functional networks (Rakesh, Zalesky, et al., 2021).

Subjective SES

Subjective SES refers to comparative social standing relative to others and differs from objective measures such as education and income (Natalie H. Brito & Kimberly G. Noble, 2014; Mudd, van Lenthe, Verra, Bal, & Kamphuis, 2021). Gianaros et al. found subjective social status was associated with reduced gray matter volume in the anterior cingulate cortex, a region involved in the regulation of behavioral and physiologic reactions to stress, and not correlated with hippocampal or amygdala volumes (Natalie H. Brito & Kimberly G. Noble, 2014). Another study assessing stable (social ranking fixed) and unstable (social ranking changes based on performance) status hierarchies revealed that when a picture of a person of higher social status is presented, an evident pattern of neural activity in the ventral striatum and the dorsolateral prefrontal cortex is elicited. Conversely, in unstable hierarchies, activity patterns were observed in the amygdala, posterior cingulate, medial prefrontal cortex, and thalamus, regions of the brain involved in social cognition and emotional processing (Zink et al., 2008).

Stress Tolerance

Economically disadvantaged children exposed to economic, social, physiological, and perinatal disadvantages and stressors show lower levels of well-being and cognitive function (Duncan & Brooks-Gunn, 2000; Hussey, Chang, & Kotch, 2006; K. M. Kim et al., 2018). Chronic exposure to stressors may contribute to a dysregulated stress response, therefore leading to altered activation of the hypothalamic-pituitary-adrenal axis (HPA) (Vliegenthart et al., 2016). In turn, chronically high levels of cortisol appear to lead to physiological dysfunction, poor cognitive development, and increased risk of physical illness (P. Kim, Evans, Chen, Miller, & Seeman, 2018; McLoyd, 1998). A study carried out by Staff et al. suggests a link between lower childhood SES and increased cortisol release. Moreover, high cortisol levels and long-lasting socioeconomic difficulties has also been linked to circadian rhythm disruptions.

Tomalski et al. demonstrated that early years' experiences may result in different functional and structural brain development (Tomalski & Johnson, 2010). Another study conducted by Knickmeyer et al. showed a growth pattern in the hippocampus and caudate that differs with other regions of the brain in the first 2 years of life, suggesting that differential structural brain development exists (Knickmeyer et al., 2008). It is argued that early stress leads to reduced development of the hippocampus. McEwen proposed that repeated exposure to stressors may reduce both neuronal numbers and dendritic branching stemming from the dendrite gyrus (McEwen, 2003). In fact, with decreasing dendritic trees and neuronal numbers, the hippocampus increasingly reacts to chronic stress[81]. Based on the association between the hippocampus and parts of the prefrontal cortex, with the stress response system in humans (Evans & Schamberg, 2009; Frodl, Reinhold, Koutsouleris, Reiser, & Meisenzahl, 2010) and animals (Cerqueira, Mailliet, Almeida, Jay, & Sousa, 2007; Hawley & Leasure, 2012; J. J. Kim & Diamond, 2002), ROI-based studies (Hanson et al., 2011) have documented SES effects on the hippocampus and prefrontal cortex (Jednoróg et al., 2012).

Marginalization-related Diminished returns (MDRs)

The effects of SES indicators on health and well-being vary across racial groups (Assari, 2018a). Our empirically supported Marginalization-related Diminished Returns, also known as Minorities' Diminished Returns (MDRs) framework, suggests that social stratification may weaken the economic and health returns of SES, such as health and well-being, for Blacks and Latinos compared to US-born non-Latino Whites (Assari, 2018d). At a cognitive level, there are weaker SES effects for emotion regulation, inhibitory control, reward processing, and executive function for Blacks compared to Whites (Assari, 2020c, 2020h, 2020i, 2020l; Assari & Boyce, 2021; Assari, Boyce, Akhlaghipour, Bazargan, & Caldwell, 2020; Assari, Boyce, & Bazargan, 2020a, 2020b). Cross-sectional analyses of the ABCD study data shows weaker effects of SES on the function/size of the thalamus (Assari & Curry, 2021), hippocampus (Assari, 2020b), amygdala (Assari, Boyce, et al., 2020b), and cerebral cortex (Assari, 2020g; Assari, Boyce, Bazargan, et al., 2021; Assari, Boyce, Saqib, Bazargan, & Caldwell, 2021) for Black children compared to White children.

In addition, there are weaker SES effects for Blacks and Latinos compared to Whites for a wide range of emotional, behavioral, and health outcomes (Assari, 2019, 2020a; Assari, Boyce, Bazargan, Caldwell, & Mincy, 2020). MDR framework acknowledges that high SES Black and high SES White families highly differ in their exposure to risky environment, protective social and physical environment, economic opportunities, and health-promoting resources. These variations reflect structural and societal inequities in social status, family wealth, social capital, and neighborhood quality between daily experiences of high SES White and Black individuals (Assari, 2018d). These systemic structural disadvantages lead to the diminished returns of SES resources for racial and ethnic minority groups particularly Black and Latino families (Assari, 2018a). As a result of these MDRs, while non-Latino White youth display low risk, their high SES Black and Latino counterparts display higher-than-expected risk across domains (Assari, 2020b, 2020f; Assari, Boyce, Caldwell, & Bazargan, 2020).

Neighborhood conditions such as residential segregation also contribute to MDRs, although this research has primarily been conducted in Black communities rather than other ethnic groups (Assari, 2016, 2020d; Assari, Boyce, Mistry, et al., 2021; Assari & Caldwell, 2017; Assari, Caldwell, & Zimmerman, 2015). High SES Black adolescents and adults report higher exposure and vulnerability to discrimination than their low-SES counterparts. Although living in a predominantly White neighborhood comes with a wide range of advantages and benefits such as better schools and an increased availability of health-promoting goods, proximity to Whites also comes at a psychological cost to many middle-class Black families. An increased level of discrimination thus increases the risk of mental health problems for high SES Black people in predominantly White neighborhoods (Assari, 2018b; Assari & Moghani Lankarani, 2018). Discrimination is a risk factor for a multitude of undesirable health outcomes, such as substance use. Youth and adults may turn to use substance to cope with neighborhood, family, and discrimination stress (Assari, Mistry, Lee, Caldwell, & Zimmerman, 2019).

In the ABCD data, we have found weaker SES effects on the function and size of the thalamus (Assari & Curry, 2021), hippocampus (Assari, 2020b), amygdala (Assari, Boyce, et al., 2020b), and cortical surface (Assari, 2020g; Assari, Boyce, Bazargan, et al., 2021; Assari, Boyce, Saqib, et al., 2021) for Black children compared to their White counterparts. Studies have also suggested that exposure to stress caused by a variety of causes such as life events (Assari, 2020a), financial instability (Assari, 2020k), and race/ethnicity (Assari, 2018b)explain the observed MDRs for Black adolescents.

Regardless of social mobility, stressful life events remain common for Black families (Assari, 2018c). In the ABCD data, high SES Black children report high amounts of stressful life events, whereas high

SES White children report low stressful life events (Assari, 2018b, 2020e). According to the Fragile Families and Child Well-being Study (FFCWS), spanking of children remains high in high SES Black families, whereas high SES White families report the lowest level of spanking (Assari, 2020e). Equally, high SES Black families report higher financial insecurity (Assari, 2020k) and stress (Assari & Bazargan, 2019), in part because highly educated Black families live in poorer neighborhoods and work in worse jobs (Assari, 2018a). Due to high levels of discrimination, Black families struggle to be recognized for their SES (educational achievements/income) rather than their skin color, and therefore face challenges trying to translate their educational achievements into better opportunities (Assari, 2020k).

SES Influences on Brain Development

A wide range of SES factors measured at individual, family, and neighborhood levels are shown to affect brain development. Liu et al. found that amygdala reactivity to positive/negative stimuli was a differential sensitivity indicator that moderates the effects of family environment on youth's prosocial behaviors. A greater amygdala response during emotional processing was linked to increased sensitivity to positive and/or negative environments, while lesser amygdala response was linked to a reduced responsivity to environmental and familial influences (Liu, Oshri, Kogan, Wickrama, & Sweet, 2021). In addition, Assari found that Black youth who live in poorer neighborhoods are at a higher risk for poor emotion regulation (Assari, 2020d). Lower SES indicators have been found to partially explain smaller amygdala sizes of Black and Latino children compared to White children (Assari, 2020j).

Furthermore, a study by Cho et al. using fractional anisotropy (FA) from Diffusion Tensor Images from the ABCD data found that there was a significant difference in brain structure in 11 ROIs in Low vs. Middle income groups but did not identify any ROIs of significant difference in Middle vs. High income groups (Cho, Park, Isaiah, & Kim, 2021). In a study of 4,650 children aged 9-10, Paul et al. found that SES and genetic factors measured by polygenic score cognition score composites, were independently associated with cognitive performance indicators such as executive function, memory, general ability, with no evidence that SES moderates the influence of polygenic score cognition score composites (Paul et al., 2021). In a cross-sectional study examining 11,875 children aged 9 to 10 years old, Taylor et al. found that neighborhood poverty was linked to differences in the volume of prefrontal and hippocampal areas, and also affected performance on cognitive tests (R. L. Taylor, Cooper, Jackson, & Barch, 2020) (Amso, 2020). Tomasi and Volkow found cognitive family SES and health behavior variables significantly correlates with family income, cortical volume, and cortical thickness, suggesting that the lack of emotional and educational support/education children from low-income families might experience may result in reduced cortical volume and cortical thickness (Tomasi & Volkow, 2021). Interestingly, Krogsrud et al. found that the relationship between working memory and cortex thickness was not mediated by genetics nor socioeconomic status (Krogsrud et al., 2021).

In a recent analysis of the ABCD data, stigma related to gender, race, and ethnicity was associated with smaller hippocampus size. The results showed specificity of the effects. The magnitude of the effects of stigma was equivalent to the predicted impact of a $20,000 difference in annual family income in the same sample. Interestingly, perceived discrimination was not related to hippocampal volume in stigmatized groups (Mark et al.).

Theories of SES effects on children

Conger and Donnellan theorize that there are three possible explanations for the association between SES and the brain development of children: the social selection perspective, social causation perspective, and interactionist perspective (R. D. Conger & M. B. Donnellan, 2007).

The social causation view suggests that SES affects families and the development of children through family stress and investment processes. The family stress processes of economic hardship theorizes that low income is associated with low development in children due to economic stressors experienced by parental figures. These stressors leave low-income families at an increased risk for emotional and/or behavioral problems, which then lead to marital problems. Parents occupied by their own worries are less likely to pay attention to children and are more likely to be short and irritable towards their children, thus diminishing nurturing and involved parenting (R. D. Conger & M. B. Donnellan, 2007). A study by Conger et al. involving 422 two parent African American families, found significant support for the family stress processes. Economic pressure was related to distress in parents, causing problems in the parent-child relationship, resulting in higher levels of depression and anxiety in children (Conger et al., 2002). Similarly, a study by Emmen et al. found that the relationship between SES and positive parenting was partially mediated by both maternal psychological and maternal acculturation stress (Emmen et al., 2013). Masarik and Conger also found empirical support for the family stress processes (Masarik & Conger, 2017).

The family investment model hypothesizes that families with higher economic status and income can make significant investments towards their children’s development, such as tutoring and additional learning materials. More disadvantaged families, however, must instead invest in their more immediate needs, such as bills and food (R. D. Conger & M. B. Donnellan, 2007). This inequality leads to gaps in educational achievement, as family income during childhood is positively related to academic, financial, and occupational success (R. D. Conger & M. B. Donnellan, 2007). A study by Preston et al. evaluated the effects of SES on parental investment of children and child development through the family investment model lens. This study found a positive association between parents’ SES and interpersonal investments in their children (Sohr-Preston et al., 2013). Simons et al found that the effect of economic stressors on parental investment in youth was mediated by neighborhood disadvantage. Interestingly, when comparing family investment model and family stress model in families simultaneously, the family stress model was found to best explain behavioral problems in young children (Simons et al., 2016). These findings have been replicated in a previous study by Yeung et al. (Yeung, Linver, &

Brooks-Gunn, 2002).

The social selection perspective argues that individual differences in traits and personality are what most influence one's accumulation of social advantages. These advantages are then transferred from parent to child (R. D. Conger & M. B. Donnellan, 2007). For example, during adolescence, individuals make decisions about their educational attainment, and by extension their social status, therefore "selecting" themselves into higher or lower social strata (Miech, Caspi, Moffitt, Wright, & Silva, 1999). However, if the social selection perspective is found to be true, social causation view must be incorrect, since theoretically, the effects of economic hardship and neighborhood disadvantage would be greatly reduced or eliminated after positive parental traits are included in the data (R. D. Conger & M. B. Donnellan, 2007). Some research offers support for the social selection perspective. Donellan et al. proposed that personal characteristics are important factors when considering the link between economic conditions and individual development/family processes. Furthermore, personal characteristics play an important role in resilience to economic hardship (Donnellan, Conger, McAdams, & Neppl, 2009). McLeod and Kaiser found that externalizing disorders were significantly associated with high school diploma attainment and college enrollment, thus demonstrating that social selection processes contribute to economic disparities. Miech et al. (McLeod & Kaiser, 2004) found no evidence of social selection effects among youth with anxiety and depressive disorders, however, strong evidence of selection effects were found in youth with attention deficit disorder and conduct disorder (Miech et al., 1999). Wadsword et al. reported similar results (Wadsworth & Achenbach, 2005).

The social causation view could be criticized , because it minimizes the power of individual decision. Conversely, it could be argued that the social selection perspective places too little importance on the effects of SES. Emerging research is consistent with the interactionist perspective, a view that incorporates both social causation and social selection models (Z. E. Taylor & Conger, 2014). The interactionist perspective argues that a dynamic relationship between individual traits and SES affect child development, rather than one or the other (R. D. Conger & M. B. Donnellan, 2007). A study by Martin et al. concluded that neither the social causation nor the social selection perspective was satisfactory on its own, arguing instead that the interactionist perspective more accurately depicts the relationship between SES and problem behaviors over time (Martin et al., 2010). In addition, a study by Wright et al. found evidence for the coexistence of both social selection and social causation in explaining high risk behaviors (R. D. Conger & M. B. Donnellan, 2007). The new and evolving research supporting the interactionist perspective indicates that the interactionist perspective could guide future research regarding the interactions between SES and the development of children (R. D. Conger & M. B. Donnellan, 2007).

Intervention Programs

Most of the existing evidence on SES influences on brain development are originated from observational studies. There are very few intervention research on the effects of SES on brain development. Exceptions are the Perry Preschool Program and the Abecedarian Program (Anderson, 2008; Schweinhart, 2003). The Perry Preschool Program was a 2-year experimental intervention for disadvantaged children ages 3-4 (Anderson, 2008; Schweinhart, 2003). It consisted of daily morning teaching sessions for 2.5 hours that engaged children in activities that build their decision-making and problem-solving skills and weekly 1.5 hours home visits by teachers to build parental involvement in the educational process (Anderson, 2008; Schweinhart, 2003). Program outcomes showed that despite no improvement in cognitive function for the treatment group over the control group by age 10, there was long-term improvement in non-cognitive skills, including motivation and perseverance (Anderson, 2008; Schweinhart, 2003). Follow-ups at age 40 showed that the treatment group had higher rates of high school graduation, higher salaries, higher home ownership percentage rates, fewer out of wedlock births, lower rates of receipt of welfare benefits as adults, and fewer arrests than controls (Anderson, 2008; Schweinhart, 2003). The Abecedarian program was a larger and more intensive program for disadvantaged children (Anderson, 2008; Schweinhart, 2003). Children started the program at age 4.4 months and remained in the program until age 8 receiving full day care for 6-8 hours, 5 days per week with free transportation included (Anderson, 2008; Schweinhart, 2003). Nutritional services, social work services and medical care were provided to the control group families (Anderson, 2008; Schweinhart, 2003). Outcomes of this program showed a permanent increase in cognitive and non-cognitive skillset of the treatment group (Anderson, 2008; Schweinhart, 2003).. Overall, the success of both programs indicated that early interventions targeting youth from low SES backgrounds might have higher returns than later interventions (Anderson, 2008; Schweinhart, 2003). It must be acknowledged that early interventions are most effective if they are followed by high quality learning experiences (Anderson, 2008; Schweinhart, 2003).

Summary

Although there have been multiple review studies on SES effects on brain development (Natalie H Brito & Kimberly G Noble, 2014; Johnson et al., 2016; Noble & Giebler, 2020) (Letourneau, Duffett-Leger, Levac, Watson, & Young-Morris, 2013) all previous reviews have focused on overall SES influences on brain development. This mini review adds to current knowledge by showing that social marginalization, stratification, and systemic racism weaken the well-described SES influences on brain development of racial and ethnic minority populations.

Funding and Acknowledgement. Assari is supported by the following National Institutes of Health awards: 5S21MD000103 and U54MD007598. Boyce is supported by the following National Institutes of Health (NIH) awards:

G008070, U 54MD007598 and 5S21MD000103. We are grateful to Dr. Jonathan Schaefer for his generous comments on this paper. This study is also a review of multiple papers using the ABCD data. The ABCD Study is supported by the National Institutes of Health and additional federal partners under award numbers U01DA041022, U01DA041028, U01DA041048, U01DA041089, U01DA041106, U01DA041117, U01DA041120, U01DA041134, U01DA041148, U01DA041156, U01DA041174, U24DA041123, U24DA041147, U01DA041093, and U01DA041025. A full list of supporters is available at https://abcdstudy.org/federal-partners.html (accessed on 5 May 2021). A listing of participating sites and a complete listing of the study investigators can be found at https://abcdstudy.org/Consortium_Members.pdf (accessed on 5 May 2021). ABCD consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in the analysis or writing of this report. This manuscript reflects the views of the authors and may not reflect the opinions or views of the NIH or ABCD consortium investigators. The ABCD data repository grows and changes over time. The current paper used the Curated Annual Release 2.0, also defined in NDA Study 634 (doi:10.15154/1503209).

References

Adler, N., & Rehkopf, D. (2008). Disparities in Health, Descriptions, Causes, and Mechanisms. Annu Rev Public Health.

Amso, D. (2020). Neighborhood Poverty and Brain Development: Adaptation or Maturation, Fixed or Reversible? *JAMA Netw Open, 3*(11), e2024139. doi:10.1001/jamanetworkopen.2020.24139

Anderson, M. L. (2008). Multiple inference and gender differences in the effects of early intervention: A reevaluation of the Abecedarian, Perry Preschool, and Early Training Projects. *Journal of the American statistical Association, 103*(484), 1481-1495.

Assari, S. (2016). Perceived Neighborhood Safety Better Predicts Risk of Mortality for Whites than Blacks. *J Racial Ethn Health Disparities*. doi:10.1007/s40615-016-0297-x

Assari, S. (2018a). Blacks' Diminished Return of Education Attainment on Subjective Health; Mediating Effect of Income. *Brain Sci, 8*(9). doi:10.3390/brainsci8090176

Assari, S. (2018b). Does School Racial Composition Explain Why High Income Black Youth Perceive More Discrimination? A Gender Analysis. *Brain Sci, 8*(8). doi:10.3390/brainsci8080140

Assari, S. (2018a). Health disparities due to diminished return among black Americans: Public policy solutions.

Assari, S. (2018b). Parental Education Better Helps White than Black Families Escape Poverty: National Survey of Children's Health. *Economies, 6*(2), 30. Retrieved from http://www.mdpi.com/2227-7099/6/2/30

Assari, S. (2018c). Race, Intergenerational Social Mobility and Stressful Life Events. *Behav Sci (Basel), 8*(10). doi:10.3390/bs8100086

Assari, S. (2018d). Unequal Gain of Equal Resources across Racial Groups. *Int J Health Policy Manag, 7*(1), 1-9. doi:10.15171/ijhpm.2017.90

Assari, S. (2019). Educational Attainment and Exercise Frequency in American Women; Blacks' Diminished Returns. *Womens Health Bull, 6*(3). doi:10.5812/whb.87413

Assari, S. (2020a). American Children's Screen Time: Diminished Returns of Household Income in Black Families. *Information (Basel), 11*(11). doi:10.3390/info11110538

Assari, S. (2020b). Association of Educational Attainment and Race/Ethnicity With Exposure to Tobacco Advertisement Among US Young Adults. *JAMA Netw Open, 3*(1), e1919393. doi:10.1001/jamanetworkopen.2019.19393

Assari, S. (2020a). Family Socioeconomic Status and Exposure to Childhood Trauma: Racial Differences. *Children, 7*(6), 57. Retrieved from https://www.mdpi.com/2227-9067/7/6/57

Assari, S. (2020c). Mental Rotation in American Children: Diminished Returns of Parental Education in Black Families. *Pediatr Rep, 12*(3), 130-141. doi:10.3390/pediatric12030028

Assari, S. (2020d). Neighborhood Poverty and Amygdala Response to Negative Face. *J Econ Public Financ, 6*(4), 67-85. doi:10.22158/jepf.v6n4p67

Assari, S. (2020e). Parental Education and Spanking of American Children: Blacks' Diminished Returns. *World J Educ Res, 7*(3), 19-44. doi:10.22158/wjer.v7n3p19

Assari, S. (2020f). Parental Education on Youth Inhibitory Control in the Adolescent Brain Cognitive Development (ABCD) Study: Blacks' Diminished Returns. *Brain Sci, 10*(5). doi:10.3390/brainsci10050312

Assari, S. (2020g). Parental Education, Household Income, and Cortical Surface Area among 9-10 Years Old Children: Minorities' Diminished Returns. *Brain Sci, 10*(12). doi:10.3390/brainsci10120956

Assari, S. (2020b). Race, Ethnicity, Family Socioeconomic Status, and Children’s Hippocampus Volume. *Research in health science, 5*(4), 25.

Assari, S. (2020h). Racial Variation in the Association between Suicidal History and Positive and Negative Urgency among American Children. *J Educ Cult Stud, 4*(4), 39-53. doi:10.22158/jecs.v4n4p39

Assari, S. (2020i). Social Determinants of Delayed Gratification among American Children. *Casp J Neurol Sci, 6*(3), 181-189. doi:10.32598/cjns.6.22.2

Assari, S. (2020j). Socioeconomic Status Inequalities Partially Mediate Racial and Ethnic Differences in Children's Amygdala Volume. *Stud Soc Sci Res, 1*(2), 62-79. doi:10.22158/sssr.v1n2p62

Assari, S. (2020k). Understanding America: Unequal Economic Returns of Years of Schooling in Whites and Blacks. *World J Educ Res, 7*(2), 78-92. doi:10.22158/wjer.v7n2p78

Assari, S. (2020l). Youth Social, Emotional, and Behavioral Problems in the ABCD Study: Minorities' Diminished Returns of Family Income. *J Econ Public Financ, 6*(4), 1-19. doi:10.22158/jepf.v6n4p1

Assari, S., & Bazargan, M. (2019). Unequal Associations between Educational Attainment and Occupational Stress across Racial and Ethnic Groups. *Int J Environ Res Public Health, 16*(19). doi:10.3390/ijerph16193539

Assari, S., & Boyce, S. (2021). Family's Subjective Economic Status and Children's Matrix Reasoning: Blacks' Diminished Returns. *Res Health Sci, 6*(1), 1-23. doi:10.22158/rhs.v6n1p1

Assari, S., Boyce, S., Akhlaghipour, G., Bazargan, M., & Caldwell, C. H. (2020). Reward Responsiveness in the Adolescent Brain Cognitive Development (ABCD) Study: African Americans' Diminished Returns of Parental Education. *Brain Sci, 10*(6). doi:10.3390/brainsci10060391

Assari, S., Boyce, S., & Bazargan, M. (2020a). Subjective Family Socioeconomic Status and Adolescents' Attention: Blacks' Diminished Returns. *Children (Basel), 7*(8). doi:10.3390/children7080080

Assari, S., Boyce, S., & Bazargan, M. (2020b). Subjective Socioeconomic Status and Children's Amygdala Volume: Minorities' Diminish Returns. *NeuroSci, 1*(2), 59-74. doi:10.3390/neurosci1020006

Assari, S., Boyce, S., Bazargan, M., Caldwell, C. H., & Mincy, R. (2020). Maternal Education at Birth and Youth Breakfast Consumption at Age 15: Blacks' Diminished Returns. *J (Basel), 3*(3), 313-323. doi:10.3390/j3030024

Assari, S., Boyce, S., Bazargan, M., Thomas, A., Cobb, R. J., Hudson, D., . . . Zimmerman, M. A. (2021). Parental Educational Attainment, the Superior Temporal Cortical Surface Area, and Reading Ability among American Children: A Test of Marginalization-Related Diminished Returns. *Children (Basel), 8*(5). doi:10.3390/children8050412

Assari, S., Boyce, S., Caldwell, C. H., & Bazargan, M. (2020). Parent Education and Future Transition to Cigarette Smoking: Latinos' Diminished Returns. *Front Pediatr, 8*, 457. doi:10.3389/fped.2020.00457

Assari, S., Boyce, S., Mistry, R., Thomas, A., Nicholson, H. L., Jr., Cobb, R. J., . . . Zimmerman, M. A. (2021). Parents' Perceived Neighborhood Safety and Children's Cognitive Performance: Complexities by Race, Ethnicity, and Cognitive Domain. *Urban Sci, 5*(2). doi:10.3390/urbansci5020046

Assari, S., Boyce, S., Saqib, M., Bazargan, M., & Caldwell, C. H. (2021). Parental Education and Left Lateral Orbitofrontal Cortical Activity during N-Back Task: An fMRI Study of American Adolescents. *Brain Sci, 11*(3). doi:10.3390/brainsci11030401

Assari, S., & Caldwell, C. H. (2017). Neighborhood Safety and Major Depressive Disorder in a National Sample of Black Youth; Gender by Ethnic Differences. *Children (Basel), 4*(2). doi:10.3390/children4020014

Assari, S., Caldwell, C. H., & Zimmerman, M. A. (2015). Perceived Neighborhood Safety During Adolescence Predicts Subsequent Deterioration of Subjective Health Two Decades Later; Gender

Differences in a Racially-Diverse Sample. *Int J Prev Med, 6*, 117. doi:10.4103/2008-7802.170431

Assari, S., & Curry, T. J. (2021). Parental Education Ain't Enough: A Study of Race (Racism), Parental Education, and Children's Thalamus Volume. *J Educ Cult Stud, 5*(1), 1-21. doi:10.22158/jecs.v5n1p1

Assari, S., Mistry, R., Lee, D. B., Caldwell, C. H., & Zimmerman, M. A. (2019). Perceived Racial Discrimination and Marijuana Use a Decade Later; Gender Differences Among Black Youth. *Front Pediatr, 7*, 78. doi:10.3389/fped.2019.00078

Assari, S., & Moghani Lankarani, M. (2018). Workplace Racial Composition Explains High Perceived Discrimination of High Socioeconomic Status African American Men. *Brain Sci, 8*(8). doi:10.3390/brainsci8080139

Bremner, J. D. (2003). Long-term effects of childhood abuse on brain and neurobiology. *Child and Adolescent Psychiatric Clinics, 12*(2), 271-292.

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

Brito, N. H., & Noble, K. G. (2014). Socioeconomic status and structural brain development. *Frontiers in neuroscience, 8*(276). doi:10.3389/fnins.2014.00276

Cerqueira, J. J., Mailliet, F., Almeida, O. F., Jay, T. M., & Sousa, N. (2007). The prefrontal cortex as a key target of the maladaptive response to stress. *Journal of neuroscience, 27*(11), 2781-2787.

Cho, H., Park, G., Isaiah, A., & Kim, W. H. (2021). *Covariate Correcting Networks for Identifying Associations Between Socioeconomic Factors and Brain Outcomes in Children*, Cham.

Conger, R. D., & Donnellan, M. B. (2007). An interactionist perspective on the socioeconomic context of human development. *Annu Rev Psychol, 58*, 175-199. doi:10.1146/annurev.psych.58.110405.085551

Conger, R. D., & Donnellan, M. B. (2007). An interactionist perspective on the socioeconomic context of human development. *Annu. Rev. Psychol., 58*, 175-199.

Conger, R. D., Wallace, L. E., Sun, Y., Simons, R. L., McLoyd, V. C., & Brody, G. H. (2002). Economic pressure in African American families: a replication and extension of the family stress model. *Dev Psychol, 38*(2), 179-193. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/11881755

Czernochowski, D., Fabiani, M., & Friedman, D. (2008). Use it or lose it? SES mitigates age-related decline in a recency/recognition task. *Neurobiology of aging, 29*(6), 945-958.

D'Angiulli, A., Herdman, A., Stapells, D., & Hertzman, C. (2008). Children's event-related potentials of auditory selective attention vary with their socioeconomic status. *Neuropsychology, 22*(3), 293.

D’Angiulli, A., Weinberg, J., Grunau, R., Hertzman, C., & Grebenkov, P. (2008). *Towards a cognitive science of social inequality: children’s attention-related ERPs and salivary cortisol vary with their socioeconomic status.* Paper presented at the Proceedings of the 30th Cognitive Science Society Annual Meeting.

Dehaene, S., Pegado, F., Braga, L. W., Ventura, P., Nunes Filho, G., Jobert, A., . . . Cohen, L. (2010). How learning to read changes the cortical networks for vision and language. *science, 330*(6009), 1359-1364.

Diamond, A. (1990). The Development and Neural Bases of Memory Functions as Indexed by the AB and Delayed Response Tasks in Human Infants and Infant Monkeys a. *Annals of the New York Academy of Sciences, 608*(1), 267-317.

Dickinson, D. K., & Snow, C. E. (1987). Interrelationships among prereading and oral language skills in kindergartners from two social classes. *Early Childhood Research Quarterly, 2*(1), 1-25.

Dodd, B., Holm, A., Hua, Z., & Crosbie, S. (2003). Phonological development: a normative study of British English-speaking children. *Clinical Linguistics & Phonetics, 17*(8), 617-643.

Donnellan, M. B., Conger, K. J., McAdams, K. K., & Neppl, T. K. (2009). Personal characteristics and resilience to economic hardship and its consequences: conceptual issues and empirical illustrations. *J Pers, 77*(6), 1645-1676. doi:10.1111/j.1467-6494.2009.00596.x

Duncan, G. J., & Brooks-Gunn, J. (2000). Family poverty, welfare reform, and child development. *Child development, 71*(1), 188-196.

Duncan, G. J., & Magnuson, K. A. (2003). Off with Hollingshead: Socioeconomic resources, parenting, and child development. *Socioeconomic status, parenting, and child development*, 83-106.

Eckert, M. A., Lombardino, L. J., & Leonard, C. M. (2001). Planar asymmetry tips the phonological playground and environment raises the bar. *Child development, 72*(4), 988-1002.

Emmen, R. A., Malda, M., Mesman, J., van Ijzendoorn, M. H., Prevoo, M. J., & Yeniad, N. (2013). Socioeconomic status and parenting in ethnic minority families: testing a minority family stress model. *J Fam Psychol, 27*(6), 896-904. doi:10.1037/a0034693

Evans, G. W. (2004). The environment of childhood poverty. *American psychologist, 59*(2), 77.

Evans, G. W., & Schamberg, M. A. (2009). Childhood poverty, chronic stress, and adult working memory. *Proceedings of the National Academy of Sciences, 106*(16), 6545-6549.

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.

Fluss, J., Ziegler, J. C., Warszawski, J., Ducot, B., Richard, G., & Billard, C. (2009). Poor reading in French elementary school: the interplay of cognitive, behavioral, and socioeconomic factors. *Journal of Developmental & Behavioral Pediatrics, 30*(3), 206-216.

Fotenos, A. F., Mintun, M. A., Snyder, A. Z., Morris, J. C., & Buckner, R. L. (2008). Brain volume decline in aging: evidence for a relation between socioeconomic status, preclinical Alzheimer disease, and reserve. *Archives of neurology, 65*(1), 113-120.

Frodl, T., Reinhold, E., Koutsouleris, N., Reiser, M., & Meisenzahl, E. M. (2010). Interaction of childhood stress with hippocampus and prefrontal cortex volume reduction in major depression. *Journal of psychiatric research, 44*(13), 799-807.

Gianaros, P. J., Horenstein, J. A., Hariri, A. R., Sheu, L. K., Manuck, S. B., Matthews, K. A., & Cohen, S. (2008). Potential neural embedding of parental social standing. *Social cognitive and affective neuroscience, 3*(2), 91-96.

Hackman, D. A., & Farah, M. J. (2009). Socioeconomic status and the developing brain. *Trends in cognitive sciences*, *13*(2), 65-73.

Hanson, J. L., Chandra, A., Wolfe, B. L., & Pollak, S. D. (2011). Association between income and the hippocampus. *PloS one, 6*(5), e18712.

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*: Paul H Brookes Publishing.

Hawley, D. F., & Leasure, J. L. (2012). Region-specific response of the hippocampus to chronic unpredictable stress. *Hippocampus, 22*(6), 1338-1349.

Hedges, D. W., Thatcher, G. W., Bennett, P. J., Sood, S., Paulson, D., Creem-Regehr, S., . . . Froelich, B. (2008). Brain integrity and cerebral atrophy in Vietnam combat veterans with and without posttraumatic stress disorder. *Neurocase, 13*(5-6), 402-410.

Holt, R. L., & Mikati, M. A. (2011). Care for child development: basic science rationale and effects of interventions. *Pediatric neurology, 44*(4), 239-253.

Hussey, J. M., Chang, J. J., & Kotch, J. B. (2006). Child maltreatment in the United States: Prevalence, risk factors, and adolescent health consequences. *Pediatrics, 118*(3), 933-942.

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.

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

Kim, J. J., & Diamond, D. M. (2002). The stressed hippocampus, synaptic plasticity and lost memories. *Nature reviews neuroscience, 3*(6), 453-462.

Kim, K. M., Lim, M. H., Kwon, H.-J., Yoo, S.-J., Kim, E.-j., Kim, J. W., . . . Paik, K. C. (2018). Associations between urinary cotinine and symptoms of attention deficit/hyperactivity disorder and autism spectrum disorder. *Environmental research, 166*, 481-486.

Kim, P., Evans, G. W., Chen, E., Miller, G., & Seeman, T. (2018). How socioeconomic disadvantages get under the skin and into the brain to influence health development across the lifespan. *Handbook of life course health development*, 463-497.

Kishiyama, M. M., Boyce, W. T., Jimenez, A. M., Perry, L. M., & Knight, R. T. (2009). Socioeconomic disparities affect prefrontal function in children. *Journal of cognitive neuroscience, 21*(6), 1106-1115.

Knickmeyer, R. C., Gouttard, S., Kang, C., Evans, D., Wilber, K., Smith, J. K., . . . Gilmore, J. H. (2008). A structural MRI study of human brain development from birth to 2 years. *Journal of neuroscience, 28*(47), 12176-12182.

Krogsrud, S. K., Mowinckel, A. M., Sederevicius, D., Vidal-Pineiro, D., Amlien, I. K., Wang, Y., . . . Fjell, A. M. (2021). Relationships between apparent cortical thickness and working memory across the lifespan - Effects of genetics and socioeconomic status. *Dev Cogn Neurosci*, *51*, 100997. doi:10.1016/j.dcn.2021.100997

Letourneau, N. L., Duffett-Leger, L., Levac, L., Watson, B., & Young-Morris, C. (2013). Socioeconomic status and child development: A meta-analysis. *Journal of Emotional and Behavioral Disorders, 21*(3), 211-224.

Levine, S. C., Vasilyeva, M., Lourenco, S. F., Newcombe, N. S., & Huttenlocher, J. (2005). Socioeconomic status modifies the sex difference in spatial skill. *Psychological Science*, *16*(11), 841-845.

Lipina, S. J., Martelli, M. I., Vuelta, B., & Colombo, J. A. (2005). Performance on the A-not-B task of Argentinean infants from unsatisfied and satisfied basic needs homes. *Revista Interamericana de Psicolog ía/Interamerican Journal of Psychology, 39*(1), 49-60.

Liu, S., Oshri, A., Kogan, S. M., Wickrama, K. A. S., & Sweet, L. (2021). Amygdalar Activation as a Neurobiological Marker of Differential Sensitivity in the Effects of Family Rearing Experiences on Socioemotional Adjustment in Youths. *Biol Psychiatry Cogn Neurosci Neuroimaging*. doi:10.1016/j.bpsc.2021.04.017

Mark, L. H., Weissman, D. G., McKetta, S., Micah, R. L., Ford, J. V., Barch, D. M., & McLaughlin, K. A. Smaller Hippocampal Volume Among Black and Latinx Youth Living in High-Stigma Contexts.

Martin, M. J., Conger, R. D., Schofield, T. J., Dogan, S. J., Widaman, K. F., Donnellan, M. B., & Neppl, T. K. (2010). Evaluation of the interactionist model of socioeconomic status and problem behavior: a developmental cascade across generations. *Dev Psychopathol*, *22*(3), 695-713. doi:10.1017/S0954579410000374

Masarik, A. S., & Conger, R. D. (2017). Stress and child development: a review of the Family Stress Model. *Curr Opin Psychol*, *13*, 85-90. doi:10.1016/j.copsyc.2016.05.008

McEwen, B. S. (2003). Mood disorders and allostatic load. *Biological psychiatry, 54*(3), 200-207.

McLeod, J. D., & Kaiser, K. (2004). Childhood Emotional and Behavioral Problems and Educational Attainment. *American Sociological Review, 69*(5), 636-658. doi:10.1177/000312240406900502

McLoyd, V. C. (1998). Socioeconomic disadvantage and child development. *American psychologist, 53*(2), 185.

Mezzacappa, E. (2004). Alerting, orienting, and executive attention: Developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child development, 75*(5), 1373-1386.

Miech, R. A., Caspi, A., Moffitt, T. E., Wright, B. R. E., & Silva, P. A. (1999). Low Socioeconomic Status and Mental Disorders: A Longitudinal Study of Selection and Causation during Young Adulthood. *American journal of sociology, 104*(4), 1096-1131. doi:10.1086/210137

Molfese, V. J., Modglin, A., & Molfese, D. L. (2003). The role of environment in the development of reading skills: A longitudinal study of preschool and school-age measures. *Journal of learning disabilities, 36*(1), 59-67.

Mudd, A. L., van Lenthe, F. J., Verra, S. E., Bal, M., & Kamphuis, C. B. M. (2021). Socioeconomic inequalities in health behaviors: exploring mediation pathways through material conditions and time orientation. *Int J Equity Health, 20*(1), 184. doi:10.1186/s12939-021-01522-2

Noble, K. G., & Giebler, M. A. (2020). The neuroscience of socioeconomic inequality. *Current Opinion in Behavioral Sciences, 36*, 23-28.

Noble, K. G., & McCandliss, B. D. (2005). Reading development and impairment: behavioral, social, and neurobiological factors. *Journal of Developmental & Behavioral Pediatrics, 26*(5), 370-378.

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. (1997). Poverty, cultural disadvantage and brain development: a study of pre-school children in Mexico. *Electroencephalography and clinical neurophysiology, 102*(6), 512-516.

Paul, S. E., Elsayed, N. M., Bogdan, R., Colbert, S. M. C., Hatoum, A. S., & Barch, D. M. (2021). Childhood Socioeconomic Status and Polygenic Scores for Cognition Have Independent Associations with Cognitive Performance During Middle Childhood. *medRxiv*, 2021.2008.2026.21262684. doi:10.1101/2021.08.26.21262684

Raizada, R. D., & Kishiyama, M. M. (2010). Effects of socioeconomic status on brain development, and how cognitive neuroscience may contribute to leveling the playing field. *Frontiers in human neuroscience, 4*, 3.

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.

Rakesh, D., Seguin, C., Zalesky, A., Cropley, V., & Whittle, S. (2021). Associations Between Neighborhood Disadvantage, Resting-State Functional Connectivity, and Behavior in the Adolescent Brain Cognitive Development Study: The Moderating Role of Positive Family and School Environments. *Biol Psychiatry Cogn Neurosci Neuroimaging*, *6*(9), 877-886. doi:10.1016/j.bpsc.2021.03.008

Rakesh, D., Zalesky, A., & Whittle, S. (2021). Similar but distinct - Effects of different socioeconomic indicators on resting state functional connectivity: Findings from the Adolescent Brain Cognitive Development (ABCD) Study®. *Dev Cogn Neurosci, 51*, 101005. doi:10.1016/j.dcn.2021.101005

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia, 42*(8), 1029-1040.

Schweinhart, L. J. (2003). Benefits, Costs, and Explanation of the High/Scope Perry Preschool Program.

Simons, L. G., Wickrama, K. A. S., Lee, T. K., Landers-Potts, M., Cutrona, C., & Conger, R. D. (2016). Testing Family Stress and Family Investment Explanations for Conduct Problems Among African American Adolescents. *Journal of Marriage and Family*, *78*(2), 498-515. https://doi.org/10.1111/jomf.12278

Singh-Manoux, A., Richards, M., & Marmot, M. (2005). Socioeconomic position across the lifecourse: how does it relate to cognitive function in mid-life? *Annals of epidemiology, 15*(8), 572-578.

Sirin, S. R. (2005). Socioeconomic status and academic achievement: A meta-analytic review of research. *Review of Educational Research, 75*(3), 417-453.

Sohr-Preston, S. L., Scaramella, L. V., Martin, M. J., Neppl, T. K., Ontai, L., & Conger, R. (2013). Parental socioeconomic status, communication, and children's vocabulary development: a third-generation test of the family investment model. *Child Dev*, *84*(3), 1046-1062. doi:10.1111/cdev.12023

Staff, R. T., Murray, A. D., Ahearn, T. S., Mustafa, N., Fox, H. C., & Whalley, L. J. (2012). Childhood socioeconomic status and adult brain size: childhood socioeconomic status influences adult hippocampal size. *Annals of neurology, 71*(5), 653-660.

Staff, R. T., Murray, A. D., Deary, I. J., & Whalley, L. J. (2004). What provides cerebral reserve? *Brain, 127*(5), 1191-1199.

Stevens, C., Lauinger, B., & Neville, H. (2009). Differences in the neural mechanisms of selective attention in children from different socioeconomic backgrounds: an event-related brain potential study. *Developmental science, 12*(4), 634-646.

Taylor, R. L., Cooper, S. R., Jackson, J. J., & Barch, D. M. (2020). Assessment of neighborhood poverty, cognitive function, and prefrontal and hippocampal volumes in children. *JAMA Network Open, 3*(11), e2023774-e2023774.

Taylor, Z. E., & Conger, R. D. (2014). Risk and Resilience Processes in Single-Mother Families: An Interactionist Perspective. In Z. Sloboda & H. Petras (Eds.), *Defining Prevention Science* (pp. 195-217). Boston, MA: Springer US.

Tomalski, P., & Johnson, M. H. (2010). The effects of early adversity on the adult and developing brain. *Current opinion in psychiatry, 23*(3), 233-238.

Tomarken, A. J., Dichter, G. S., Garber, J., & Simien, C. (2004). Resting frontal brain activity: linkages to maternal depression and socio-economic status among adolescents. *Biological psychology,* *67*(1-2), 77-102.

Tomasi, D., & Volkow, N. D. (2021). Associations of family income with cognition and brain structure in USA children: prevention implications. *Mol Psychiatry*. doi:10.1038/s41380-021-01130-0

Turkeltaub, P. E., Gareau, L., Flowers, D. L., Zeffiro, T. A., & Eden, G. F. (2003). Development of neural mechanisms for reading. *Nature neuroscience, 6*(7), 767-773.

Turrell, G., Lynch, J. W., Kaplan, G. A., Everson, S. A., Helkala, E.-L., Kauhanen, J., & Salonen, J. T. (2002). Socioeconomic position across the lifecourse and cognitive function in late middle age. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 57*(1), S43-S51.

van Harmelen, A.-L., van Tol, M.-J., van der Wee, N. J., Veltman, D. J., Aleman, A., Spinhoven, P., . . . Elzinga, B. M. (2010). Reduced medial prefrontal cortex volume in adults reporting childhood emotional maltreatment. *Biological psychiatry, 68*(9), 832-838.

Vliegenthart, J., Noppe, G., Van Rossum, E., Koper, J., Raat, H., & Van den Akker, E. (2016). Socioeconomic status in children is associated with hair cortisol levels as a biological measure of chronic stress. *Psychoneuroendocrinology, 65*, 9-14.

Wadsworth, M. E., & Achenbach, T. M. (2005). Explaining the link between low socioeconomic status and psychopathology: testing two mechanisms of the social causation hypothesis. *J Consult Clin Psychol*, *73*(6), 1146-1153. doi:10.1037/0022-006X.73.6.1146

Wallach, L., Wallach, M. A., Dozier, M. G., & Kaplan, N. E. (1977). Poor children learning to read do not have trouble with auditory discrimination but do have trouble with phoneme recognition. *Journal of Educational Psychology, 69*(1), 36.

Whitehurst, G. (1997). Language processes in context: Language learning in children reared in poverty (pp. 233-266). *Research on communication and language disorders: Contribution to theories of language development. Baltimore: Paul H. Brookes*.

Yeung, W. J., Linver, M. R., & Brooks-Gunn, J. (2002). How money matters for young children's development: parental investment and family processes. *Child Dev, 73*(6), 1861-1879. doi:10.1111/1467-8624.t01-1-00511

Zink, C. F., Tong, Y., Chen, Q., Bassett, D. S., Stein, J. L., & Meyer-Lindenberg, A. (2008). Know your place: neural processing of social hierarchy in humans. *Neuron*, *58*(2), 273-283.