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Socioeconomic Status and the Development of Executive Function: Behavioral and Neuroscience Approaches
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Introduction
Socioeconomic status (SES) exerts a powerful effect on cognitive development, as measured by intelligence and academic achievement. Executive function (EF) is one important facet of cognitive ability that appears to play a role in many real-world domains of success and well-being including general intellectual ability (e.g., Brydges, et al., 2012) and academics (e.g., Bull, Espy & Wiebe, 2008). For this reason, the relation between SES and EF has recently become a topic of intense research interest.

Here we review the relationship of childhood socioeconomic status (SES) to behavioral and neural measures of EF, with particular focus on the preschool years. We also examine evidence for EF’s role as a mediator between SES and differences in academic achievement by children of lower and higher SES. EF is a particularly promising candidate mediator of SES-achievement differences because it is associated with both socioeconomic status and academic achievement.

Neuroanatomically, EF is reliant on the prefrontal cortex, which is highly plastic and undergoes a long period of post-natal development (e.g. Casey, Giedd, & Thomas, 2000). Given the importance of prefrontal cortex to EF, this suggests that EF may be particularly susceptible to influences of childhood experience in general, and disparities between lower and higher SES environments in particular. Indeed, a growing body of behavioral and neural evidence, to be reviewed shortly, suggests that executive function varies along socioeconomic gradients, showing stronger associations with SES than do many other neurocognitive systems (Hackman & Farah, 2009). Executive function in early childhood is highly predictive of later academic achievement (Blair & Diamond, 2008; Buckner, Mezzacappa, Enrico, & Beardslee, 2009), suggesting that differences in executive function in preschool and beyond may powerfully affect the life trajectories of children growing up in poverty.

Using the methods of cognitive neuroscience to investigate the relationships among environmental factors, developing executive function, and disparities in academic achievement has the potential to address basic scientific questions about how the environment influences the development of executive function. This work also has important societal applications. Identifying specific factors that mediate the relationship between SES and executive function may help provide specific targets for interventions, potentially reducing the achievement gap that plays a critical role in reinforcing the intergenerational cycle of poverty. Here we review what is known about socioeconomic influences on executive function development in the preschool and school years.

Socioeconomic status and executive function: Definitional challenges
What is SES? As the term itself implies, SES combines both economic factors such as a person’s income and material wealth, along with noneconomic characteristics such as social prestige and education (Adler & Rehkopf, 2008; Bradley & Corwyn, 2002). These
factors correlate with a wide range of neighborhood and family characteristics, such as frequency of stressful life events, exposure to toxins and violence, school quality, and parental care (Bradley & Corwyn, 2002; Evans, 2004). Given the intercorrelated nature of these different factors, most researchers either combine income, education and occupational status into a composite index of SES, or measure income or educational attainment alone with the assumption that any one will provide a serviceable estimate of the more complete set. This is the case for most of the studies reviewed here. However, it is likely that different aspects of SES may play different roles in producing the life outcomes discussed here, suggesting that, in the future, different economic and social factors should be examined separately (Braveman et al., 2005; Duncan & Magnuson, 2012).

Executive function is also a multifaceted construct, which is also conceptualized and operationalized differently by different researchers. Its components have been subdivided into working memory, set shifting and inhibition (Miyake et al., 2000), planning, working memory, response control and attentional shifting (Robbins, 1996), and response initiation, task set and self-monitoring (Stuss & Alexander, 2007). Furthermore, there is reason to believe that the componential structure of executive function may change over development (Isquith, Gioia, & Espy, 2004; Senn, Espy, & Kauffmann, 2004; Wiebe, Espy, & Charak, 2008). Although these issues add to the challenge of interpreting research results, they do not represent an insurmountable obstacle. As with the different approaches to assessing SES, which generally converge in finding SES differences in EF, different approaches to EF assessment generally converge in demonstrating SES differences.

**Behavioral studies of SES and executive function in children**

SES differences in executive function can be observed as early as infancy. Performance on the A-not-B task is often considered one of the first measures of emerging executive function and is believed to reflect frontal lobe maturation (Diamond, 2001). This task requires infants to search for a toy that they have watched the experimenter hide. After several trials in which the toy is hidden in one location, A, and the infant successfully retrieves it, the infant then watches the experimenter hide the toy in a new location, B. Retrieving the toy this time requires both working memory (to retain the location of the toy) and inhibitory control (to avoid habitually reaching for the old location). Lipina, Martelli, Vuelta & Colombo (2005) compared performance on this task in 6- to 14-month-old Argentinian infants from homes with “satisfied” and “unsatisfied” basic needs (based on a composite score of parental education, occupation, dwelling, and overcrowding conditions). Results showed that infants from poor homes performed fewer consecutive correct responses and reached erroneously to location A more frequently than those from more socioeconomically advantaged homes.

Several studies have found SES effects during the preschool years. In a study of 2-year olds, Hughes & Ensor (2005) found that social disadvantage (as indicated by markers such as “family living in publicly funded housing” and “head of household unemployed”) predicted poorer performance on a battery of executive function tasks, including developmentally-appropriate versions of working memory, set-shifting, and inhibition tasks. SES disparities have also been found in tasks of goal-setting, cognitive flexibility, and working memory in 3-5 year-olds (Lipina, Martelli, Vuelta, Injoque-Ricle, & Colombo, 2004) and in measures of alerting and executive attention in 4-7 year olds (Mezzacappa, 2004).
Studies of young children using latent EF factors derived from a number of EF tasks rather than the individual tasks themselves have also documented SES disparities. In a study that followed children between the ages of 4 and 6, Hughes et al. (2010) found that family income predicted mean levels of a single latent executive function construct that supported performance on planning, inhibitory control, and working memory tasks. Similarly, demographic factors, including income-to-needs ratio and maternal education, have been found to predict performance on latent executive function in a sample of 3-year-olds from predominantly low-income non-urban families (Blair et al., 2011; Rheades, Greenberg, Lanza, & Blair, 2011). While Wiebe, Espy, and Charak (2008) did not find an SES difference in mean levels of a latent executive function construct in one sample of 2-6 year-olds, a second sample showed lower mean latent executive function in children of lower SES as compared to their higher SES peers (Wiebe et al., 2011). In sum, SES differences can be found in very young children whether executive function is operationalized as a single, latent factor or as individual tasks or domains.

Evidence suggests that early SES-related differences in executive function persist throughout childhood. To highlight a few examples, there are SES disparities in fluency in children 5-14 years of age (Ardila, Rosselli, Matute, & Guajardo, 2005), in a latent measure of working memory in children 10-18 years of age (Hackman et al., 2014), and in working memory, inhibitory control and cognitive flexibility in a sample of 8-12 year old children (Sarsour et al. 2011). Although not all studies find SES differences in all tasks of executive function (e.g., Engel, Santos, & Gathercole, 2008; Waber et al., 2007), in some cases this may be due to rigorous exclusion criteria that result in samples with particularly healthy and able low-SES children.

How do the SES disparities in executive function compare with SES disparities in other neurocognitive systems? We have addressed the neurocognitive profile of SES disparities in a series of studies, which indicate that executive function is disproportionately, but not uniquely, affected by SES. In three studies of kindergarteners, first-graders, and middle schoolers, batteries of tasks were administered assessing the prefrontal/executive, left perisylvian/language, medial temporal/memory, parietal/spatial cognition, and occipitotemporal/visual cognition systems. The most robust differences between lower- and middle-income children were in language abilities and executive function, particularly in the domains of working memory and cognitive control (Farah et al., 2006; Noble, Norman, & Farah, 2005; Noble, McCandliss, & Farah, 2007). This profile of differences suggests it is implausible that SES differences in executive function arise due to differences in general factors such as motivation, comfort in the research environment, or task understanding, as it is unlikely that only certain neuropsychological domains would be influenced by such factors. Further support for this interpretation comes from more direct studies of the brain, particularly studies of brain structure.

**Neuroscience studies of SES and prefrontal cortical function in children**

To investigate SES disparities in brain development more directly, several research groups have used electrophysiological measures, which may reveal differences in cognitive processing even when no differences in behavioral measures are apparent (see Hackman & Farah, 2009). Baseline electroencephalographic (EEG) activity has been used to assess overall differences in resting brain function and can be used as a measure of brain maturation, particularly in regions subserving executive function. In a longitudinal study of
Mexican preschool children, Otero (1997) and Otero, Pliego-Rivero, Fernández and Ricardo (2003) found differences in resting EEG patterns as a function of socioeconomic status. The observed differences were consistent with a maturational lag in frontal areas among low-SES children.

Several recent studies have used event-related potential (ERP) measures of selective attention to examine SES differences in neural processing. These studies have shown SES differences in patterns of neural processing even when task performance does not differ between SES groups. In a study of children between the ages of 3 and 8 years, Stevens, Lauinger and Neville (2009) examined the effects of maternal education level (a proxy for SES) on ERP measures of a selective auditory attention task. Children were presented two narrative stories simultaneously, one in each ear, and were cued to attend to one of the stories while ERPs to probe stimuli were recorded. There were no SES differences in ERP responses to probes in the attended channel, but low-SES children exhibited a higher amplitude response to the probes in the unattended channel, indicative of difficulty suppressing distracting stimuli. These reduced effects of selective attention were observed electrophysiologically despite similar behavioral performance between the low and middle SES children, and provide direct evidence for socioeconomic differences in early stages of executive function processing.

An analysis of brain structure using the NIH MRI Study of Normal Brain Development’s sample of 5 month – 4-year-old children found that early brain growth in frontal gray matter was more rapid among the higher SES children scanned (Hanson et al., 2013). In a study focused on functional brain asymmetries for language in 5-year-olds, Raizada et al. (2008) reported a borderline significant effect of SES on grey matter volume in the left IFG, with higher SES associated with greater volume.

Additional neuroscience evidence concerning frontal lobe development and EF is available from older school-age children. D’Anguilli, Herdman, Stapells and Hertzman (2008) found similar SES differences in selective attention using a task of nonspatial auditory selective attention. In this task, lower- and higher-SES preadolescent children were instructed to attend to two types of tones but ignore two other types. The two SES groups showed equivalent accuracy and reaction time, but different patterns of ERP waveform activity. Specifically, high-SES children showed significantly different ERP waveforms between attended (relevant) and unattended (irrelevant) stimuli, while low-SES children showed equivalent ERP responses to both types of stimuli. The authors interpreted these results as evidence that low-SES children made less use of selective attention, allocating greater attentional resources to the irrelevant stimuli than did their high-SES counterparts. Additionally, a study of 7-12 year-old children used a simple target detection task, on which behavioral performance between SES groups did not differ, to measure the ERP response to task-relevant and task-irrelevant stimuli (Kishiyama, Boyce, Jimenez, Perry, & Knight, 2008). Low-SES children showed reduced extrastriate (P1 and N1) and novelty (N2) ERP responses relative to high-SES children, consistent with reduced recruitment of prefrontal attentional mechanisms among low-SES children. In a study combining ERP and spectral analysis of EEG, D’Anguilli, Weinberg, Oberlander, Grunau Hertzman and Maggi (2014) replicated earlier findings of larger ERP attentional effects in higher SES children as well as EEG indications of greater left frontal activity. Together, these electrophysiological studies extend the behavioral research summarized in the previous section by demonstrating that there may be SES-related differences in the degree
to which specific neural systems are recruited during attentional processing even when there are no task performance differences.

Sheridan and colleagues (2012) conducted the first fMRI study of SES and EF in 8-12 year old children. Low and high SES subjects performed a stimulus classification task using either a familiar, practiced classification rule or a novel rule. The latter requires resisting use of the more habitual rule and therefore places heavier demands on EF. Brain activation associated with the novel-familiar contrast was localized to several prefrontal regions and SES differences in activation were observed, most clearly in the right superior frontal gyri. A number of recent studies have measured structural differences in prefrontal areas among school-age children. Given the lengthy and nonlinear patterns of structural brain development observed across childhood and adolescence (Gogtay et al., 2004), as well as the complexity of structure-function relations in cognitive development (Crone & Ridderinkhof, 2011), these findings provide context concerning SES differences in EF development, but they cannot be applied directly to understanding EF during the preschool years. In contrast to the findings already cited from Hanson and colleague's (2013) analysis of growth trajectories in frontal volume over the preschool years, no SES difference has been observed in frontal lobe volume among the 4-18 year old children from the NIH MRI Study of Normal Brain Development (Brain Development Cooperative Group, 2012; Lange, Fromowitz, Bigler, Lainhart, & Brain Development Cooperative Group, 2010). However, when the same data set was used to examine cortical thickness in subregions of prefrontal cortex and the anterior cingulate gyrus, lower SES children were found to have thinner cortex in some regions (Lawson et al., 2013). A small sample of 10 year old children of diverse SES revealed volumetric differences in certain regions of PFC, with lower SES associated with smaller volumes, and differences in PFC gyrification were also found as a function of SES (Jednoróg et al., 2012).

**Candidate mechanisms for the development of SES disparities in EF**

While executive function has been found to be a highly heritable trait (Friedman et al., 2008), a growing body of evidence suggests that environmental factors also influence developing executive function (e.g., Hammond et al., 2012; see also Deater-Deckard, 2014). Burrage et al. (2008) used the natural experiment of a school cut-off design, which compared cognitive abilities in children of approximately the same age with or without a year of schooling, to show that school promoted executive function. Participation in training programs has also been shown to improve executive function performance (Diamond et al., 2007; Jaeggi, Buschkuel, Jonides, & Shah, 2011; Klingberg, 2010; but see Shipstead, Hicks & Engle, 2012). The behavioral genetics evidence regarding a broader measure of cognitive development, IQ, suggest that, while cognitive ability is highly heritable within a middle- or high-SES population, the environment accounts for the majority of IQ variance in impoverished families (Turkheimer, Haley, Waldron, D’Onofrio, & Gottesman, 2003; Harden, Turkheimer, & Loehlin, 2007).

What aspects of the environment might be responsible for SES disparities in EF? As observed earlier, socioeconomic status is not a unitary construct, but consists of multiple economic and social factors. Children growing up in poverty are more likely to be exposed to inadequate nutrition, violence, and toxins in their environment, and are less likely to be spoken to in complex sentences, to be read to at home, or to be provided a challenging curriculum in school (Bradley & Corwyn, 2002; Evans, 2004). Each of these factors has the
potential to explain socioeconomic differences in the development of executive function, making it challenging to determine the pathway through which poverty exerts its effects. Several proposed mediating pathways have received support from developmental psychology studies as well as from experiments with animal models (for a review, see Hackman, Farah, & Meaney, 2010).

One candidate mediating pathway through which socioeconomic status may influence the development of executive function is through the direct effect of stress on the developing brain. It has been well established that children of lower socioeconomic status experience greater levels of environmental and psychosocial stressors (Bradley & Corwyn, 2002; Evans, 2004; Goodman, McEwen, Dolan, Shafer-Kalkohoff, & Adler, 2005), and show increased levels of the stress hormone cortisol (Evans, 2003; Lupien, King, Meaney, & McEwen, 2001). Chronically elevated levels of stress hormones may exert damaging effects on neural and other body systems (McEwen & Gianaros, 2011). Brain areas that are involved in the stress response, such as the prefrontal cortex, may be particularly vulnerable to heightened levels of cortisol, implicating executive function as a neurocognitive system that is particularly likely to be affected by chronic stress (Blair, 2010; Liston, McEwen, & Casey, 2009; Lupien, Maheu, Tu, Fiocco, & Schramek, 2007; McEwen & Gianaros, 2010). Sheridan and colleagues (2012) measured the rise of the stress hormone cortisol as a result of fMRI participation in their 8-12 year old subjects and found that stress reactivity was related to both SES and prefrontal activation. More directly consistent with the stress account of the SES-EF relation are the findings of Evans and Shamberg (2009), who found that elevated allostatic load in childhood mediated the effect of chronic, rural poverty on working memory in adolescence.

A related candidate mediating pathway focuses on the potential role of parental behavior in influencing developing executive function. Lower household income tends to be associated with lower maternal responsivity, an effect that may be mediated by increased maternal stress among low-SES populations (Evans, Boxhill, & Pinkava, 2008). Research using animal models suggests that parental nurturance in infancy is critical in programming stress responsivity throughout the lifespan (Champagne & Curley, 2009; Meaney, Szyf, & Seckl, 2007). In humans, maternal engagement in early childhood is associated with greater cortisol reactivity (indicating more developed HPA regulation), an effect that carries over until at least adolescence (Hackman et al., 2013). Parental care also influences basal cortisol in childhood (Blair et al., 2008; Gunnar & Quevedo, 2007). Similarly, salivary cortisol levels have been found to partially mediate the association between positive parenting measured at 7, 15 and 24 months and executive function at 3 years (Blair et al., 2011). These findings suggest that early programming of the stress response may also occur in humans, potentially influencing cognitive development throughout the lifespan.

In addition to stress and parenting, cognitive stimulation also affects later EF. It has been well established that access to cognitively enriching materials varies with socioeconomic status: children below the poverty line have less access to reading materials and enriching learning activities (e.g., trips to a museum; Bradley, Corwyn, McAdoo, & Coll, 2001) and hear fewer words of speech (Hart & Risley, 1992). Animal models of early experience have demonstrated that environmental complexity alters a wide range of neural outcomes, such as dendritic branching, gliogenesis and synaptic density (van Praag, Kempermann, & Gage, 2000; Sale, Beradi & Maffei, 2009), suggesting that cognitive
stimulation may be one pathway through which socioeconomic status affects the developing brain.

Several studies have investigated the role of these and other candidate mediating pathways in creating SES disparities in preschool EF. The quality of parent-child interactions, particularly during infancy, has been found to mediate SES effects on executive function at 36 months of age (Blair et al., 2011; Rhoades et al., 2011). Other studies have found support for parental support of child autonomy (Bernier, Carlson, & Whipple, 2010), as well as parent scaffolding and family chaos (Bibok, Carpendale, & Muller, 2009; Hughes & Ensor, 2009) as important predictors of early childhood executive function. The quality of home environment—including cognitive stimulation and parental nurturance—partially accounts for these disparities throughout childhood according to an analysis of data from the National Institute of Child Health and Human Development (NICHD) Study of Early Childcare (Hackman, Evans & Farah, in press). This study used the longitudinal measures of EF, SES and multiple potential mediators for the SES-EF relation, to identify mediators of SES disparities in early childhood EF. This rich data set also made it possible to examine prospective mediators in relation to one another, reducing the problem of omitted variable bias that complicates the interpretation of many studies in this area. Specifically, when potential mediators are correlated with one another, and not all of them are measured, the finding that one factor statistically mediates the SES-cognition relation does not rule out the possibility that unmeasured correlated factors are the true causal mediators. In the NICHD Study of Early Childcare, although early childhood home environment and maternal sensitivity both emerged as significant mediators when raw, unadjusted mediators were tested individually or in combination with other candidate mediators, Hackman et al. (in press) found that only childhood home environment was a significant mediator after controlling for the correlation between maternal sensitivity and home environment. This provides strong evidence that the quality of the childhood home environment is a specific, dissociable pathway through which SES influences the development of early childhood executive function.

**SES, EF and academic achievement**

One reason EF is an important topic within developmental psychology in general, and studies of SES and development in particular, is that it plays a role in school achievement. Current research is addressing the role of EF in SES disparities in school readiness and academic performance. These disparities are evident at the earliest experiences of children in school or preschool and persist throughout the course of schooling (e.g., Bradley & Corwyn, 2002; Reardon, 2011).

EF would be expected to support school achievement for several reasons. It can enable students to focus on learning in the classroom, ignoring distractions from without (e.g., other students talking) or within (e.g., daydreaming or worrying). In addition, some academic subjects, particularly math, require information to be held in working memory and manipulated. Indeed, evidence is accumulating that EF does indeed support school achievement, from studies of early childhood school readiness (e.g., Alloway et al., 2005; Blair & Razza, 2007) to school performance throughout childhood and adolescence (Best, Miller & Naglieri, 2011; St Clair-Thompson & Gathercole, 2006). Measures of executive function performance during childhood and adolescence correlate strongly with concurrent measures of reading and math performance, as measured on standardized
achievement tests (Best, Miller & Naglieri, 2011; St Clair-Thompson & Gatherole, 2006). Furthermore, longitudinal studies have found that executive function prospectively predicts academic achievement (e.g., Bull, Espy & Weibe, 2008; Mazzocco & Kover, 2007; Passolunghi, Vercelloni, & Schadee, 2007), even after controlling for prior measures of academic achievement (Welsh et al., 2010).

Evidence for a causal relation between EF and academic achievement comes from intervention programs. Direct training of EF may boost academic achievement, although the literature is mixed (Titz & Karbach, 2014). More broadly-based intervention programs for preschoolers produce gains in academic readiness partly through their impact on EF (Bierman et al., 2008; Raver et al., 2011).

Several studies have directly tested the hypothesis that executive function mediates SES disparities academic achievement in the earliest years of schooling. In the NICHD Study of Early Childcare, children’s sustained attention and impulsivity were found to partially mediate the relationship between home environment quality and achievement at 54 months (NICHD Early Child Care Research Network, 2003). Another study using a sample of preschool children enrolled in either needs-based or private preschools found that EF partially mediated the relationship between SES group and achievement (Fitzpatrick, McKinnon, Blair, & Willoughby, 2014). Other studies using early childhood samples find that EF partially mediates the relationship between SES and math skill (Dilworth-Bart, 2012) and between SES and math and literacy achievement (Nesbitt, Baker-Ward, & Willoughby, 2013). Two more recent studies with older children indicate that EF continues to mediate at least certain aspects of academic achievement throughout the school years (Crook & Evans, 2014; Lawson & Farah, 2014).

Conclusions

What can we conclude about SES and EF in preschoolers, and what remains to be understood? It is clear that EF in the preschool years differs across levels of SES. As early as infancy, children’s behavior indicates that higher SES is associated with more mature EF. Neuroscience research shows corresponding differences in the neural substrates of EF. The causes of these physical and psychological differences are not well understood, but certain factors seem likely to play a role. As noted earlier, life stress and parenting behavior are known to differ by SES. So do many aspects of the environment that provide or restrict opportunities to explore and learn.

Future research will have the opportunity to extend our understanding of SES-EF relations in several ways. A better understanding of mediational processes, that is, the mechanisms by which childhood SES and EF are related, is needed to help prevent and redress the cognitive disadvantages of low SES children. In particular, a more detailed understanding of how and when mediators influence EF development would provide a valuable theoretical basis for the design of prevention and intervention programs. A number of approaches may be useful in addressing the question of causality. Natural experiments on EF development, such as the school cut-off design of Burrage et al. (2008), could incorporate measures of SES, and natural experiments on SES and child development , such as Costello et al. (2003) could assess EF. In addition, intervention research represents an important opportunity to advance our scientific understanding of the causal relations linking SES and EF, as well as a means to eventually improve the life chances of low SES children.
We note that most research to date has involved samples of young children studied cross-sectionally. Longitudinal studies, measuring executive function early and extending through adolescence and adulthood, would illuminate the ultimate scope and impact of the effects of preschool EF disparities. A longitudinal approach would also help identify sensitive periods, in which environmental factors associated with SES exert greater influence on EF. This would have important implications for the timing of interventions designed to improve executive function among at-risk children. To date, the evidence suggests that infancy through preschool may be such an important developmental epoch. With continued research an understanding of the role of SES in EF development, and EF’s contributions to myriad life outcomes, can be harnessed to improve the life chances and social mobility of children growing up in poverty.
References


Brain Development Cooperative Group. (2012). Total and regional brain volumes in a population-based normative sample from 4 to 18 years: the NIH MRI study of normal brain development. Cerebral Cortex, 22(1), 1-12.


a population based sample of healthy children aged 6 to 18 years on a 

cognitive skills and gains in academic school readiness for children from low-

understand executive control in preschool children: I. Latent structure. 
*Developmental Psychology, 44*, 575-587.