Socioeconomic Status and Neurocognitive Development: Executive Function

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Introduction

It has been well established that socioeconomic status (SES) during childhood is highly predictive of a wide array of outcomes, including physical and mental health, cognitive ability, and academic achievement (Adler & Rehkopf, 2008;Gottfried, Gottfried, Bathurst, Guerin & Parramore, 2003; Merikangas et al., 2010; Shanahan, Copeland, Costello & Angold, 2008 Sirin, 2005). SES must exert its effects on academic performance, mental health and cognitive performance, at least in part, through an effect on the neurocognitive systems underlying these behavioral outcomes. One of the most likely candidates for a mediating neurocognitive system is the prefrontal cortex system of executive function.

Executive function (EF) provides a particularly promising area for study because it is associated with both socioeconomic status and academic achievement. Because the prefrontal cortex is highly plastic and undergoes a long period of post-natal development (e.g. Casey, Giedd & Thomas, 2000), it may be particularly susceptible to influences of childhood experience. Indeed, a growing body of behavioral and neural imaging evidence, to be reviewed shortly, suggests that executive function varies along socioeconomic gradients, showing stronger associations with SES than many other neurocognitive systems. Importantly, 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 also help provide specific targets for interventions, potentially reducing the achievement gap that plays a critical role 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.

Measuring socioeconomic status

What is SES? As the term itself implies, it 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. Other researchers, impressed by the lack of perfect correlation among the different factors, as well as the possibility that different aspects of SES may play different roles in producing the life outcomes discussed here, argue for the need to examine different economic and social factors separately (Braveman et al., 2005). However, measures of family income, parental education, and composite SES, as well as measures of neighborhood SES, have all been found to predict individual differences in

academic achievement (Sirin, 2005) suggesting that SES relates to developmental outcomes regardless of how it is operationalized.

Behavioral studies of SES and executive function

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). Lipina et al. (2005) compared performance on this task in six- 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 made more errors than more socioeconomically advantaged infants.

Several studies using diverse tasks and populations have found similar SES effects during the preschool years. In a study of two-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, which included 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 and Colombo, 2004) and in measures of alerting and executive attention in 4-7 year olds (Mezzacappa, 2004). Additionally, studies investigating the latent structure of executive function in preschoolers have found support for SES disparities in the latent factor identified for executive function. In a study that followed children between the ages of 4 and 6, Hughes et al.

(2011) 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, Rhoades, Greenberg, Lanza & Blair, 2011). While Wiebe et al. (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 high sociodemographic risk, as compared to their low-risk peers (Wiebe et al., 2011). Notably, SES differences are found 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, with studies showing SES disparities in fluency in children age 5-14 (Ardila, Rosselli, Matute & Guajardo, 2005), and in working memory, inhibitory control and cognitive flexibility in a sample of 8-12 year old children (Sarsour, Sheridan, Jutte, Nuru-Jeter, Hinshaw & Boyce, 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? Does SES affect all neurocognitive systems equally, or is executive function uniquely affected? 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 separate studies, kindergarteners, first-graders, and middle schoolers of varying socioeconomic status were assessed on batteries of tasks assessing the prefrontal/executive, left perisylvian/language, medial temporal/memory, parietal/spatial cognition, and occipotemporal/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 such factors.

Neural processing studies of SES and prefrontal cortical function

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 and colleagues (1997; 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 age of 3 and 8 years, Stevens and colleagues (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.

D'Anguilli and colleagues (2008) have 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 recent 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. Together, these ERP 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.

Functional magnetic resonance imaging (fMRI) offers much better spatial resolution than EEG or ERPs, and fMRI studies have revealed socioeconomic differences in neural recruitment on language processing tasks (Noble et al., 2006; Raizada, Richards, Meltzoff & Kuhl, 2008). However, we know of no published studies that have used fMRI to study the relationship between socioeconomic status and executive function, and this remains an important goal for future research.

Candidate Mechanisms

While executive function has been found to be a highly heritable trait (Friedman, Miyake, Young, DeFries, Corley & Hewitt, 2008), a growing body of evidence suggests that environmental factors also influence developing executive function. For example, both the experience of schooling (Burrage et al, 2008) and participation in training programs (Jaeggi, Buschkuel, Jonides & Shah, 2011; Klingberg, 2010) have been shown to improve executive function performance. Behavioral genetics studies using broader measures of cognitive development (e.g. 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). Specific environmental influences on executive function are thus an important topic for investigation.

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). Consistent with this model, Evans and Shamberg (2009) 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 nurturance 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 infancy is associated with greater cortisol reactivity in infancy (indicating more developed HPA regulation) and lower basal cortisol in childhood (Blair et al., 2008). 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 perinatal programming of the stress response may also occur in humans, potentially influencing cognitive development throughout the lifespan.

Substantial evidence also suggests that early cognitive stimulation may affect later neurocognitive outcomes, including executive function. 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, with the quality of the home environment—including cognitive stimulation and parental nurturance—frequently implicated as an important mediator. Work investigating the factors that mediate the relationship between income and broad measures of intellectual development, such as achievement tests, has found cognitive stimulation in the home to be an important mediator (Guo & Mullan-Harris, 2000; Linver, Brooks-Gunn & Kohen, 2002). Recent studies using more specific measures of executive function have found generally consistent results. The quality of parent-child interactions, particularly during infancy, has been found to mediate SES effects on executive function at 36 months of age (Rhoades, Greenberg, Lanza & Blair, 2011; Blair 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.

Analysis using NIHCD Study of Early Child Care

Despite the gathering evidence documenting SES effects on executive function, it remains unclear if these effects emerge early and persist or if SES affects the rate of developmental change in EF as well. In addition, a significant challenge with using mediation analyses in the study of socioeconomic status and child development is the fact that potential mediators, such as stress, parenting, and the home environment, tend to be highly correlated with one another (Adler et al., 1994; Bradley & Corwyn, 2002; Evans, 2004). This makes it difficult

to identify specific mediating pathways, especially when all candidate pathways are not measured and included in the model, as is often the case (MacKinnon, 2008). The mediation analyses regarding SES effects on executive function described above did not simultaneously include measures of parenting, stress, and the home environment, or other correlated candidate mediators, to determine if such pathways are truly specific.

Recent work (Hackman et al., unpublished) utilized data from the NICHD Study of Early Child Care to address two primary aims. First, Hackman and colleagues examined the relationship between childhood SES and executive function performance, investigating both initial level of performance level and trajectories of executive function development. Second, they conducted multilevel mediation analyses (Krull & MacKinnon, 2001) with multiple candidate mediators to identify specific mechanisms underlying the effect of SES on each component of executive function development. Controlling for the effect of correlated candidate mediators allows stronger claims to be made about dissociable effects of mediating pathways.

The National Institute of Child Health and Development Study of Early Child Care (NICHD SECCYD) provides a promising longitudinal dataset for investigating these questions. This multi-site, prospective study originally enrolled 1,364 children and families and measured working memory, sustained attention, impulsivity, and planning at different points during children's early development. Children were enrolled from a wide range of socioeconomic backgrounds, and many detailed environmental measures were included in the study, making this an appropriate source of data for investigations of possible mediating pathways between childhood socioeconomic status and executive function development. Prior analyses of this dataset found that early childhood home environment during the preschool years, primarily

between 36 and 54 months, is a stronger predictor of executive function in first grade than child care or school classroom quality (NICHD Early Child Care Research Network, 2005).

This study used two measures within the NICHD Study of Early Child Care to assess family socioeconomic status: income-to-needs and maternal education. Income-to-needs was measured as the ratio of total family income to the poverty threshold, accounting for the total size of the household, and was assessed at 1, 6, 15, 24, and 36 months. Maternal education was measured in years when children were 1 month old. Four aspects of executive function were measured during early childhood: working memory, attention, impulsivity, and planning. Growth curve analyses revealed that lower family income-to-needs ratio significantly predicted worse executive function performance, an effect that emerged by 54 months for working memory, attention, and impulsivity, and by first grade for planning. Lower maternal education independently predicted worse performance that emerged by 54 months for attention and impulsivity, by first grade for planning, and by third grade for working memory. Neither measure of socioeconomic status significantly predicted different developmental trajectories of executive function development. Consequently, there were independent effects of both income-to-needs and maternal education that emerged early in childhood and persisted without change.

To identify specific, dissociable environmental factors that mediate the relationship between childhood socioeconomic status and executive function, Hackman et al. examined nine separate candidate mediating pathways: birth weight, gestational age, postpartum depression, parent stress in infancy, negative life events, the overall quality of the home environment in infancy/toddlerhood and early childhood, and maternal sensitivity in infancy/toddlerhood and early childhood. Since all nine mediators were highly correlated, adjusted mediators were

calculated as the unique variance in each mediator that was not shared with other potential mediators.

These analyses revealed strikingly consistent results across the four domains of executive function studied, with early childhood home environment and maternal sensitivity emerging most frequently as significant mediators when raw, unadjusted mediators were tested individually or in combination with other candidate mediators. When mediators were adjusted to control for their correlation with one another, only the childhood home environment emerged as a significant mediator for executive function performance. Because the correlation between mediators was controlled for, this provides strong evidence that the quality of the childhood home environment is a specific, dissociable pathway through which SES influences the development of executive function.

Findings from this study add to the growing body of evidence suggesting that executive function varies along socioeconomic lines, with income-to-needs ratio and maternal education independently predicting differences in performance on four measures of executive function that are apparent in preschool and persist through middle childhood. These results also emphasize the importance of controlling for the correlation between potential mediating pathways and implicate the quality of the childhood home environment as a specific, dissociable mediator between socioeconomic status and executive function.

Issues going forward

Research on socioeconomic status and executive function is still in its earliest stages. Although SES disparities in executive function are apparent as early as the preschool years by many measures, there is much we do not yet know about executive function at this age, its

relation to SES and its relation to later real-world outcomes. With respect to basic research on the development of executive function, a better understanding of how to conceptualize executive function in preschoolers and children will strengthen research on socioeconomic disparities. The nature and organization of executive function in adults in still unclear, with different theories featuring different basic component processes, such as 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). The possibility that the componential structure of executive function may change over development (Senn, Espy, Kauffmann, 2004; Isquith, Gioia & Espy, 2004; Wiebe, Espy, Charak, 2008) introduces another layer of complexity to the task of understanding the influence of SES on the development of executive function. However, as noted, SES differences in executive function have been reported with multiple approaches to measurement.

Future research on the relationship between executive function and socioeconomic status will benefit from adopting a longitudinal approach. While cross-sectional studies have demonstrated socioeconomic disparities in executive function in preschool and beyond, the trajectory of these disparities is largely unknown. The analysis described above suggests that SES differences emerge by preschool and persist, with no differences in the rate of development over time, through middle childhood. Longitudinal studies that measure executive function in younger children and extend through adolescence and adulthood are needed to shed additional light on when socioeconomic disparities emerge and how long they persist, allowing researchers to determine whether SES differences in executive function represent a developmental delay or enduring life-long deficits. It will also be possible to determine identify possible whether sensitive periods, in which environmental factors exert greater influence, exist in the

development of executive function. The identification of possible sensitive periods has 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.

Another issue that should be addressed in future research is the link between early-childhood executive function and life-long outcomes. Emerging evidence suggests that early executive function is a robust predictor of later academic achievement (Blair & Diamond, 2008; Buckner, Mezzacappa, Enrico & Beardslee, 2009). Thus, it is plausible that SES-related disparities in early executive function are an important mediator between socioeconomic status and achievement outcomes. Investigating the life-long implications of SES-related cognitive disparities will contribute to our understanding of the relationship between early executive function and developmental outcomes. These questions also have critical implications for the design of well-targeted interventions to reduce SES disparities.

While evidence suggests that both genetic and environmental factors play a role in cognitive development and influence executive functions in particular (e.g., Friedman, Miyake, Young, DeFries, Corley & Hewitt, 2008; Rueda, Rothbart, McCandliss, Saccomanno & Posner, 2005), we have much to learn about causality in the relationship between SES and executive function. A number of approaches may be useful in addressing this question. For example, 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 in their middle-class sample, and noted that a wider range of SES would enable them to address questions about the causes of SES disparities in executive function. Additionally, new analytic methods such as time-series analysis and

causal structural equation modeling have been useful in promoting causal inference in the study of socioeconomic disparities in health (Adler & Rehkopf, 2008) and may also be applied in studies of executive function.

A final area of research with both scientific and practical importance is the study of interventions designed to improve executive function in preschoolers and children. While social policies designed to reduce SES disparities have traditionally targeted either socioeconomic status itself or achievement outcomes broadly, the study of socioeconomic influences on brain development has revealed additional targets: factors that mediate the relationship between SES and neurocognitive development (e.g. the home environment), and executive function itself (Hackman, Farah & Meaney, 2010). Implementing interventions at both of these levels and studying them using the tools of cognitive neuroscience will allow causal inference, advancing the scientific understanding of the malleability of executive function and the environmental factors that influence its development. Intervention studies also have social and practical significance, as they may lead to the design of more effective policies to reduce socioeconomic disparities in cognition, academic achievement, and mental health.

Conclusion

Research described throughout this chapter has provided consistent evidence that socioeconomic status is systematically related to executive function, with low-SES children showing worse performance across many tasks, ages, and methodological approaches. Evidence from a wide range of methodologies suggests that environmental factors related to SES account for at least part of this disparity, and recent mediation analyses suggest that the home environment may be a particularly important factor mediating the relationship between

socioeconomic status and executive function. This field of research is well suited to inform and refine societal policies and programs designed to address the urgent challenges faced by low-income families and children. It is our hope that the study of socioeconomic status and executive function will contribute to our basic understanding of cognitive development across a range of environmental experiences. We also hope that this research will ultimately be applied to improve the life chances and social mobility of children growing up in poverty.

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