

## PAPER

# Neurocognitive correlates of socioeconomic status in kindergarten children

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### Abstract

*Socioeconomic status (SES) is strongly associated with cognitive ability and achievement during childhood and beyond. Little is known about the developmental relationships between SES and specific brain systems or their associated cognitive functions. In this study we assessed neurocognitive functioning of kindergarteners from different socioeconomic backgrounds, using tasks drawn from the cognitive neuroscience literature in order to determine how childhood SES predicts the normal variance in performance across different neurocognitive systems. Five neurocognitive systems were examined: the occipitotemporal/visual cognition system, the parietal/spatial cognition system, the medial temporal/memory system, the left perisylvian/language system, and the prefrontal/executive system. SES was disproportionately associated with the last two, with low SES children performing worse than middle SES children on most measures of these systems. Relations among language, executive function, SES and specific aspects of early childhood experience were explored, revealing intercorrelations and a seemingly predominant role of individual differences in language ability involved in SES associations with executive function.*

Socioeconomic status (SES) is strongly associated with cognitive ability and achievement during childhood and beyond. SES predicts many outcome measures, including IQ (Liaw & Brooks-Gunn, 1994; Smith, Brooks-Gunn & Klebanov, 1997), achievement test scores (Brooks-Gunn, Guo & Furstenberg, 1993), grade retentions and functional literacy (Baydar, Brooks-Gunn & Furstenberg, 1993). Indeed, SES has stronger associations with cognitive performance than with other seemingly more concrete outcomes, such as health and behavior (Duncan, Yeung, Brooks-Gunn & Smith, 1998). Furthermore, these statistical effects are quite large. In one study, for example, SES accounted for approximately 20% of the variance in childhood IQ (Gottfried, Bathurst, Guerin & Parramore, 2003). Although SES is most commonly measured using education, occupation and income (Ensminger & Fothergill, 2003), in reality many other factors, including physical health, home environment, early education and neighborhood characteristics, vary systematically with SES and are likely to play a role in creating the SES gap in cognitive performance and

achievement (Bornstein & Bradley, 2003). This gap is likely to contribute to the persistence of poverty across generations, and affects the life chances of some 12 million US children and 2.5 million UK children living below the absolute poverty line (US Census Bureau, 2000; Schifferes, 2002). Extensive research on the SES gap in cognitive performance has been carried out, aimed at characterizing the gap in terms of standardized psychological testing, school achievement and sociological variables. In contrast, there has been little study of the brain functions that mediate between childhood experience and cognitive performance. Although broad measures such as IQ and school achievement certainly indicate that SES is associated with cognition, they were not designed to describe which underlying components of the child's mind are involved. How does the naturally occurring variation in childhood environment captured by SES relate to brain development? The present study is a preliminary attempt to address this question, with the ultimate goal of guiding interventional efforts.

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Three general classes of findings provide the scientific background to this study. First, although not all the factors that mediate the relationship between SES and cognitive performance are necessarily experiential in nature, evidence from a variety of sources indicates that at least part of the SES gap in cognitive performance is attributable to childhood environment. These include adoption studies (e.g. Capron & Duyme, 1990) and comparisons of early versus later childhood transitory poverty (Duncan, Brooks-Gunn & Klebanov, 1994). Additional evidence that childhood experience *per se* plays a role in SES disparities in cognitive performance comes from studies relating specific aspects of children's experience to cognitive performance, either through intervention (e.g. Ramey & Ramey, 1998) or through statistical regression of specific environmental factors, such as home literacy environment or disciplinary style, on cognitive outcome measures (e.g. Jackson, Brooks-Gunn, Huang & Glassman, 2000).

Second, beginning with the work of Greenough and colleagues, it has been demonstrated that experience affects brain development at many levels of organization, from molecules to systems (Greenough, Black & Wallace, 1987; Lupien, King, Meaney & McEwen, 2000; McEwen, 2001; Rosenweig & Bennett, 1996). Variation in both cognitive stimulation and in early life stress lead to measurable functional and anatomical differences throughout the brain.

Third, whereas standardized tests and school achievement generally measure the combined functioning of multiple neurocognitive systems, including memory, language, executive functions and certain high-level perceptual functions and spatial ability, recent work in cognitive neuroscience has allowed these specific neurocognitive systems to be assessed more selectively.

In the present study we assess five domains of neurocognitive functioning of kindergarteners from different socioeconomic backgrounds, using tasks drawn from the cognitive neuroscience literature in order to determine how childhood SES helps to predict the normal variance in performance across different neurocognitive systems. Five neurocognitive systems were examined: the left perisylvian/language system, the prefrontal/executive system, the parietal/spatial cognition system, the medial temporal/memory system, and the occipitotemporal/visual cognition system. These systems were selected for being relatively independent of one another, with correspondingly distinct anatomical loci, and for playing substantial roles in cognition and school performance.

It is possible that SES-related factors impact cognitive functioning across the board, and that SES will account for similar portions of the variance in performance across all neurocognitive systems. An alternative hypo-

thesis is that SES will disproportionately or exclusively account for the variance in cognitive functioning subserved by particular brain systems. It stands to reason that neurocognitive systems with prolonged periods of postnatal development may exhibit a greater susceptibility to environmental factors that (detrimentally or positively) affect outcome. On the basis of prolonged postnatal development, we hypothesize that the language and executive function systems will show the greatest performance gaps across SES, whereas the variance in performance in other neurocognitive systems will be less accounted for by socioeconomic factors.

In fact, language development, including complexity of speech, receptive and expressive vocabularies, and phonological awareness, has long been known to differ across SES (see Whitehurst, 1997, for a review). Whereas far less research has been conducted characterizing how SES differences relate to differences in executive function skills, postmortem (Huttenlocher, 1997), structural (Giedd *et al.*, 1999), and functional (Casey, Giedd & Thomas, 2000) neuroimaging all indicate that the prefrontal cortex has a prolonged period of postnatal development in humans, including protracted synaptogenesis (Huttenlocher, 1997), pruning (Giedd *et al.*, 1999), and myelination (Klingberg, Vaidya, Gabrieli, Moseley & Hedehus, 1999). In addition, an abundance of evidence suggests that many of the major cognitive achievements of infancy and childhood appear to depend on the development of the prefrontal cortex (Diamond, 1990; Diamond, Prevor, Callender & Druin, 1997; Johnson, 1997; Posner & Rothbart, 1998). We therefore expect that differences in SES will predict differences in performance involving the prefrontal/executive system and the perisylvian/language system. Of course, duration of development *per se* is not the only factor determining susceptibility to environmental influences. All brain systems are to some degree modifiable by experience, and the specific environmental factors associated with SES may impact cognitive functions that rely on certain brain systems for reasons other than the systems' developmental timetable.

The first goal of this research is to characterize the neurocognitive correlates of SES in terms of specific systems. This is a prerequisite for the design of more targeted programs of intervention and prevention. A second goal of the present study is to test hypotheses concerning the causal factors involved in the neurocognitive outcomes under study here. Physical health factors (Hawley & Disney, 1992; Klein, Hack & Breslau, 1989; McCormick, 1989; Needleman, Schell, Bellinger, Leviton & Allred, 1990), characteristics of the home environment (Brooks-Gunn, Klebanov & Duncan, 1996; Jackson *et al.*, 2000; Korenman, Miller & Sjaastad, 1995), and early

**Table 1** *Demographics of low and middle SES samples*

	Low SES	Middle SES
Mean age	5 years, 10 months	5 years, 10 months
Gender	17 male, 13 female	13 male, 17 female
Mean birthweight	111 oz.; 3 known NICU stays	111 oz.; 2 known NICU stays
Race	African-American	African-American
Mean income-to-needs ratio	0.77	3.57
Mean parental education	11.4 years	14.8 years
Mean Hollingshead occupation score	6.2	3.1

childhood education (Barnett, 1998; Ramey & Ramey, 1998) are all correlated with both SES and cognitive achievement. Although the number of candidate factors is enormous and their possible interactions even more numerous, we sought to constrain the field of candidate mechanisms by correlating outcomes with a small number of simple, parent-reported aspects of children's experience.

## Methods

### *Subjects*

Thirty middle SES and 30 low SES children were recruited from Philadelphia public school kindergarten classes. Exclusionary criteria included very low birthweight (<1500 grams), maternal alcohol or drug use reported during pregnancy, history of head injury, ADHD, learning disability, developmental delay, or other neurological or psychiatric problems. Twenty-six low SES and 24 middle SES parents provided consent to contact their pediatrician's office; of pediatricians who were contacted, we received responses from 90% of the consenting middle SES sample and 49% of the consenting low SES sample, which in every case confirmed the information provided by parents (birth weights inaccurate by no more than 17 oz and no exclusionary criteria violated). Children whose parents did not provide consent to contact pediatricians were not excluded from the study; however, key predictions were also tested with the data from the subset of children with pediatrician-verified medical histories, as reported below.

A stable measure of socioeconomic status accounts for parental education and occupational status, as well as family income (McCloyd, 1998). To qualify as 'low SES', a child was required to come from a family in which the highest level of education of an adult in the home did not exceed high school, and the occupation for all adults in the household rated from 4 to 7 on the 7-point Hollingshead Occupational Status Scale (Hollingshead, 1975), corresponding to occupations that ranged from 'technical or clerical occupations' to 'unskilled'. In addition,

we calculated the income-to-needs ratio for each child, defined as the total family income divided by the official poverty threshold for a family of that size (McCloyd, 1998). To qualify as low SES, the income-to-needs ratio of the family could be no greater than 1.2, or just above the poverty line.

The middle SES group was limited to children whose families had income-to-needs ratios that were greater than 1.5, with no upper limit imposed. In addition, at least one adult in the household was required to have at least two years of college education, and the occupation of at least one adult was required to fall into Hollingshead categories 1–4, ranging from 'higher executives' to 'technical or clerical occupations'. All participating children in both groups were African-American native English speakers. Table 1 shows the demographics of the two samples.

### *Procedures*

We developed a battery of tasks designed to parse cognition into five broad neurocognitive systems: visual cognition, visuospatial processing, memory, language and executive function. The five systems assessed cover a range of cognitive abilities, grouped into broad categories whose validity is supported both by anatomical and information-processing considerations, as discussed below. When forced to choose, we felt it more imperative to use tasks that had a clear neural basis, based on lesion and neuroimaging data, rather than using only tasks which had previously been tested in kindergarten-aged children. However, we conducted pilot studies to ensure that kindergarteners would be able to perform all tasks.

Each neurocognitive system was assessed using two or more tasks that were superficially different, but that predominantly taxed that system. Although a child's entire brain is working while performing a given task, the tasks were relatively selective measures of particular neurocognitive systems in that they taxed one system and placed relatively light demands on the others. The level of functioning of each of the five neurocognitive systems was measured by a composite score derived from that system's tasks.

The battery consisted of paper-and-pencil and computerized tasks, each lasting approximately 5–10 minutes, with the complete battery requiring three 30-minute sessions. Children were tested individually in a quiet location at their school. Each session included tasks from multiple systems and the order of sessions was randomized between subjects.

Data collection also included a questionnaire for parents documenting the number of hours per week a child had spent in preschool and/or daycare prior to kindergarten, the frequency with which they currently engage in pro-academic activities (reading at home, talking about what was learned in school that day, talking about numbers in everyday activities, and practicing writing letters or words), the frequency with which they themselves read books or the newspaper, and the frequency of physical punishment. Parents of all 60 participants completed this questionnaire.

#### *Occipitotemporal/visual cognition system*

Pattern perception and visualization from memory are functions of occipitotemporal visual association cortex, which are likely to play a role in range of non-verbal cognitive abilities (Farah, 1994).

#### Shape detection task

This is a subtest of the visual object and space perception battery (VOSP) (Warrington & James, 1991) that taxes the perception of global pattern structure. Twenty black and white images of visual noise are presented, half with no coherent pattern and half with a weakly coherent X, and subjects must detect the X. Agnosic patients with damage to visual association cortices in the occipital and inferior temporal regions have difficulty with this task (Milner & Goodale, 1995).

#### Color imagery task

This visualization task tests the ability to retrieve knowledge of the color of objects such as a tomato or a frog. For each item, children were shown a black and white drawing and were asked which of three crayons could be used to color the picture as realistically as possible. Color imagery may be impaired after bilateral or left hemisphere occipitotemporal damage (De Vreese, 1991) and is associated with occipitotemporal cortex in functional neuroimaging studies (Howard *et al.*, 1998).

#### *Parietal/spatial cognition system*

Spatial cognition is a multifaceted aspect of intelligence, involving the perception and mental manipulation of

spatial relations (Macaluso & Driver, 2003; Vecera & Rizzo, 2003), and plays a role in mathematics and technical subjects (Zago & Tzourio-Mazoyer, 2002) as well as artistic endeavors (Kirk & Kertesz, 1989).

#### Line orientation task

This test is a modified version of the classic clinical neuropsychology test (Benton, Varney & Hamsher, 1978) in which a subject judges the orientation of pairs of line segments at the top of the page, selecting the corresponding orientations from a response display of 11 numerically labeled, radially arranged lines at the bottom of the page. Since knowledge of the written numerals used to label the lines in the original version could potentially confound any group differences, we modified the task slightly. In our version, all but two of the radially arranged lines at the bottom of the page have been erased, and no numerical labels are used. The subject must decide if the lines at the top of the page are the same as or different from the lines at the bottom of the page. The task consists of five practice items with feedback, and 30 test items without feedback. Line orientation judgment is most impaired by lesions to the parietal cortex in humans (Walsh, 1987).

#### Mental rotation task

In this task, the experimenter used laminated pictures of candy canes to demonstrate how, when the hooks of two candy canes point the same way, they can be superimposed, but when they point different ways, they cannot be superimposed no matter how they are rotated. The child was then told to decide, without touching them, whether the candy canes 'could be placed perfectly on top of each other'. Three practice trials with feedback ensued, followed by 30 test trials without feedback. The candy cane on the right was always rotated zero, 45 or 90 degrees clockwise from the reference candy cane on the left. Candy canes had the same handedness in half the trials. Both patient data (Ratcliff, 1979) and pediatric fMRI (Booth *et al.*, 1999) have linked mental rotation to the parietal lobes.

#### *Medial temporal/memory system*

The ability to form new memories is essential to success in school and most other aspects of life. The memory tasks used here assess incidental memory, that is, memory formed without the benefit of strategic effort to learn. It affords a relatively pure measure of medial temporal memory processing, independent of prefrontally mediated strategy (Rugg, Fletcher, Frith, Frackowiak &

Dolan, 1997). The critical feature of incidental learning paradigms is that the subject does not know that memory will be tested during presentation of the to-be-remembered stimuli.

#### Incidental picture learning task

In this task, the child is shown 20 pairs of line drawings from the Snodgrass and Vanderwart (1980) corpus (e.g. a book and a clock), and is asked to point to one picture of each pair (e.g. the clock). The test phase follows immediately. During the test phase, the child is shown 40 pictures, half of which comprise the first set of named pictures, and the other half novel pictures; the child is asked which pictures were seen before. Patients with medial temporal damage are impaired at recognizing stimuli from a series viewed just minutes before, and their impairment is evident in incidental learning tasks (Mayes, Meudell & Neary, 1978). Functional neuroimaging studies support this localization (Squire *et al.*, 1992).

#### Incidental face learning task

This task is analogous to the preceding one, except that the stimuli are 25 faces, presented individually, which the child must classify as a boy or girl. During the test phase the child is presented with 50 faces, half of which were seen previously, and is asked to classify each face as being from the earlier set or new. Medial temporal damage impairs incidental learning of faces (Mayes, Meudell & Neary, 1980), and face learning is known to activate medial temporal regions of normal humans (Haxby, Hoffman & Gobbini, 2002).

#### *Left perisylvian/language system*

Language acquisition is crucial for many aspects of cognition as well as communication. SES associations have been found in all domains of linguistic competence, but especially in lexical-semantic knowledge and phonological awareness (Whitehurst, 1997). Three standardized tests offering relatively pure measures of vocabulary, phonological awareness and syntax were administered.

#### Peabody picture vocabulary test (PPVT)

This is a standardized test of lexical-semantic knowledge. On each trial the child hears a word and must select the corresponding picture from among four choices. Certain forms of aphasia (Goodglass & Kaplan, 1982) and semantic memory impairments (McCarthy &

Warrington, 1990), both of which involve damage to left perisylvian cortex, produce impairments in this task. Similar word-picture matching tasks used in functional neuroimaging studies also implicate left perisylvian cortex (Thompson-Schill, D'Esposito, Aguirre & Farah, 1998).

#### Test of phonological awareness (TOPA) – kindergarten, subtests 1 and 2

This is a standardized test that assesses phonological awareness, a crucial predictor of reading ability. Subtests 1 and 2 consist of ten trials each, and test the recognition of phonological similarity and difference, respectively. Phonological processing is often compromised after perisylvian damage (Blumstein, 1994) and has been linked to a left perisylvian network in neuroimaging studies in children (Shaywitz *et al.*, 2002; Temple *et al.*, 2001).

#### Test of reception of grammar (TROG)

This is a test of syntactic knowledge designed by Bishop (1983) for children between 4 and 12 years of age. On each of 80 trials, the child hears a sentence and must choose the picture, from a set of four, which depicts the sentence. The syntactic abilities tested here engage perisylvian frontal and temporal cortex on the basis of patient studies (Rothi, McFarling & Heilman, 1982) and fMRI (Just, Carpenter, Keller, Eddy & Thulborn, 1996).

#### *Prefrontal/executive function system*

Prefrontal function has been characterized in many interrelated ways, which, for simplicity's sake, will together be termed 'executive function'. Evidence from animal models (Bourgeois, Goldman-Rakic & Rakic, 1994; Diamond, 1990), structural imaging (Giedd *et al.*, 1999; Klingberg *et al.*, 1999), functional imaging (Casey, Giedd & Thomas, 2000; Chugani, Phelps & Maziotta, 1987) and human autopsy (Huttenlocher, 1997) suggests that prefrontal cortex continues to undergo extensive development, including synaptogenesis (Huttenlocher, 1997), pruning (Giedd *et al.*, 1999) and myelination (Klingberg *et al.*, 1999) well into childhood. Consistent with this, psychological research demonstrates substantial development of executive systems past the age of the kindergarteners studied here (Casey, Tottenham & Fossella, 2000; Diamond & Taylor, 1996; Gerstadt, Hong & Diamond, 1994). The prefrontal/executive composite was based on performance in two tasks from the cognitive neuroscience literature and a measure of false

alarm rate across three previously described tasks. Supplementary evidence on prefrontal/executive function was obtained in two other tasks that yield non-continuous measures not suitable for incorporating into a continuous composite measure.

#### Go/no-go task

In this task, the child is told that he will see pictures of different animals on the computer screen, and that he should press the space bar every time he sees an animal, but never when he sees the cat. Trials consist of a 500 ms fixation cross, followed by presentation of the stimulus for up to 1000 ms, followed by a 500 ms inter-trial interval. Stimulus presentation is terminated upon the child's pressing the space bar. Items are pseudorandomized, and the cat appears on 10 out of 60 trials. This task assesses the child's ability to inhibit a prepotent response, an ability that has been linked to PFC in both lesion studies (Drewe, 1975) and pediatric and adult fMRI (Casey *et al.*, 1997). Note that although both hit rate and rate of correct no-go trials are reported below, only the correct no-go trials were entered into the executive composite, as this is the score that is indicative of inhibitory control.

#### Spatial working memory task

This task, adapted from Hughes (1998) involves eight identical opaque bottles, each with a ball placed inside. The bottles are placed in a rectangular container with one compartment for each bottle, arranged in two rows of four. The child is instructed to point to any bottle; when the child points to a bottle, the ball is removed. The entire container (containing all eight bottles) is then covered with a cloth, spun and returned to its original position relative to the child. The child is then instructed to pick a new bottle that she has not already looked in. The game is repeated until all eight balls are found, or until 15 trials are conducted, whichever comes first. Performance is measured by an average of the z-score for the total number of trials, and the negative z-score of the number of correct trials until the first error. Spatial working memory has been linked to prefrontal cortex function, particularly dorsolateral PFC, in both lesion studies (Shimamura, 1994) and functional neuroimaging studies, including fMRI of pediatric populations (Thomas *et al.*, 1999).

#### False alarms

Finally, we included in the executive composite an average of the total number of false alarms observed in the

incidental face memory, incidental picture memory and shape detection tasks, combined. Although overall error rate in these tasks is not a measure of executive function, the pattern of false alarm errors at any given level of performance is indicative of prefrontal executive function. Multiple studies have demonstrated that patients with frontal lesions exhibit increased false alarms across tasks that use a variety of verbal and non-verbal stimuli, including objects and faces (Swick & Knight, 1999; Parkin, Bindschaedler, Harsent & Metzler, 1996; Schacter, Curran, Galluccio, Milberg & Bates, 1996; Delbecq-Derousne, Beauvois & Shallice, 1990). Differences in prefrontal cortex activity have also been associated with increased false alarms in neuroimaging studies (Goldmann *et al.*, 2003; Schacter, Buckner, Koutstaal, Dale & Rosen, 1997).

#### *Additional measures of prefrontal/executive function*

Three additional tasks assessing prefrontal/executive function were administered. They were not included in the composite because of the non-continuous nature of their dependent measures.

#### Dimensional change card sort task

In this task, developed by Zelazo, Frye and Rapus (1996), children are shown a set of cards with pictures of a yellow car, a yellow flower, a blue car and a blue flower. They are then asked to sort the cards by color or by shape (the 'color game' and the 'shape game', the order of which is randomly assigned). After the first sorting, which is easily accomplished, they must then sort on the other dimension, and the number of cards sorted perseveratively on the first dimension is recorded. If the child has continued to sort by the first dimension, the task is administered again, with verbal prompts for each card reminding the child of which 'game' they are playing. This task is based on the Wisconsin card sort test (WCST), a clinical test sensitive to prefrontal damage (Drewe, 1974), which also activates the prefrontal cortex of normal subjects in fMRI (Konishi *et al.*, 1999).

#### Theory of mind

This is a cluster of abilities related to the understanding of mental states, including the ability to view the world from a different individual's point of view. All of our tasks were adapted from Frye, Zelazo and Tibor (1995). The understanding of appearance as opposed to reality (Flavell, Green & Flavell, 1986) was tested using the following task: a band-aid box containing crayons is shown

**Table 2** Raw scores, *D*-values, *t*-values and *p*-values for tasks and composite measures

Task	Raw score (SD) – low SES	Raw score (SD) – middle SES	<i>D</i> -value (Effect size)	<i>t</i>	<i>p</i>
<b>Language composite</b>	<b>N/A</b>	<b>N/A</b>	<b>1.10</b>	<b>-4.3</b>	<b>&lt; 0.0001</b>
PPVT (percentile)	28.2 (22.1)	52.7 (22.0)	1.11	-4.3	< 0.0001
TROG (percentile)	30.3 (24.2)	41.1 (23.9)	0.45	-1.7	0.09
TOPA (percentile)	34.2 (24.8)	61.5 (24.8)	1.10	-4.3	< 0.0001
<b>Executive composite</b>	<b>N/A</b>	<b>N/A</b>	<b>0.68</b>	<b>-2.8</b>	<b>0.007</b>
Go/no-go correct no-gos (10)	7.4 (1.8)	8.2 (1.2)	0.56	-2.2	0.03
hits (50); see caption	45.6 (3.7)	45.7 (4.9)	0.03	-0.13	0.90
Spatial working memory	# correct trials/15: 11.1 (2.5)	# correct trials/15: 11.1 (2.8)	0.31	-1.2	0.23
	# trials till 1st error: 4.9 (1.5)	# trials till 1st error: 6.3 (1.6)			
False alarms	Shape detection: 0.3 (0.6)	Shape detection: 0.2 (0.4)	0.58	-3.0	0.004
	Picture memory: 1.7 (2.1)	Picture memory: 0.9 (0.9)			
	Face memory: 2.9 (4.5)	Face memory: 1.2 (2.1)			
<b>Visual composite</b>	<b>N/A</b>	<b>N/A</b>	<b>0.48</b>	<b>-1.8</b>	<b>0.08</b>
Color imagery (17)	13.8 (2)	14.9 (1)	0.70	-2.7	0.01
Shape detection (20)	18.5 (1.5)	18.6 (1.5)	0.09	-0.33	0.74
<b>Spatial composite</b>	<b>N/A</b>	<b>N/A</b>	<b>0.48</b>	<b>-1.9</b>	<b>0.07</b>
Line orientation (30)	21.2 (2.3)	21.9 (2.9)	0.27	-1.04	0.30
Mental rotation (30)	26.0 (4)	27.8 (3)	0.48	-1.8	0.07
<b>Memory composite</b>	<b>N/A</b>	<b>N/A</b>	<b>0.04</b>	<b>-0.16</b>	<b>0.87</b>
Picture memory (40)	36.6 (2.8)	36.9 (2.0)	-0.06	-0.53	0.60
Face memory (50)	41.5 (6.1)	41.1 (5.3)	0.14	0.25	0.81

*Note:* When appropriate, maximum score is listed in parentheses next to task name. *D*-values represent effect sizes, or standard deviations of difference between groups. Significant differences were observed on language and executive composites, but not visual, visuospatial or memory composites. Individual tasks that exhibited significant differences include the PPVT, TOPA, go/no-go, false alarms and color imagery. Although both hit rate and rate of correct no-go trials are presented for the go/no-go task, only the correct no-go trials are indicative of inhibitory control and are entered into the executive composite. *D*-, *t*- and *p*-values for the spatial working memory task and the false alarms measure were calculated from composite scores of the raw scores presented.

and the child is asked what is inside. After eliciting the answer 'band-aids', the child is shown the contents of the box, and is asked what he originally thought was in the box, and what it looks like is in the box. Understanding of false belief was then tested within this task by then producing a toy horse and asking the child what the horse thinks is in the box. A second false belief task (Wimmer & Perner, 1983) involved an unexpected transfer of a toy from one box to another; the child was asked to report which box the toy horse, who had not 'seen' the transfer, thought contained the toy. Theory of mind has been associated with medial PFC in lesion studies (Stone, Baron-Cohen & Knight, 1998) and using fMRI (Gallagher *et al.*, 2000).

#### Delay of gratification

In each of the three testing sessions, the child is shown a variety of stickers after the first task. The child is given the choice of having either one sticker immediately or of having more stickers later, specifically two, three or four stickers at the end of the first, second and third session, respectively. The ability to delay gratification has been decreased in rats with lesions to the orbital PFC (Newman, Gorenstein & Kelsey, 1983), and is noted clinically in patients with damage to this brain area (Stuss & Benson, 1984).

## Results

For the 12 continuous measures, a total of five individual scores fell more than three standard deviations on either side of the mean of other children in the same SES group and were eliminated from the data set (three outliers from the low and two from the middle SES groups). Means and standard deviations of the remaining scores for each task and each SES group are shown in Table 2, demonstrating the absence of ceiling or floor effects in that all means were at least one standard deviation from the maximum possible score and from chance. Scores were converted to z-scores relative to the entire distribution of 60 children, thus putting all task performances on a common scale, and a composite score for each neurocognitive system was then constructed by averaging the relevant z-scores. In overview, subsequent analyses included (1) group comparisons across SES of differences on neurocognitive system composites, (2) group comparisons across SES of differences on individual task performance, (3) multiple regression analyses of the interrelations of SES and neurocognitive systems, and (4) further multiple regressions including these measures and parent-reported measures of early childhood experience.

The composite scores from the five neurocognitive systems were submitted to repeated measures MANOVA

with factors SES and gender. This showed a main effect for SES,  $F(1, 57) = 13.6$ ,  $p < .0005$ , replicating the well documented SES gap in global measures of cognitive performance. There was no main effect of gender,  $F(1, 57) = 1.7$ ,  $p = .19$ ). The question of whether SES equally predicts the variance in performance of all neurocognitive systems or else disproportionately accounts for the variance in certain systems was answered by testing the SES by neurocognitive system interaction. This interaction was significant,  $F(4, 54) = 2.77$ ,  $p < .036$ . There was no significant gender by neurocognitive system interaction,  $F(4, 54) = 1.12$ ,  $p = .35$ .

Five independent  $t$ -tests were then carried out on the composite scores for each system, comparing the performance of low and middle SES children. To correct for the effect of multiple tests on the likelihood of a type I error, a significance cut-off of  $p < .01$  was adopted, representing a Bonferroni correction for five tests ( $0.05/5 = 0.01$ ). The two neurocognitive systems for which differences were predicted showed highly significant effects of SES. For the left perisylvian/language system,  $t(58) = -4.3$ ,  $p < .0001$ . For the prefrontal/executive system,  $t(58) = -2.8$ ,  $p < .007$ . In contrast, there were non-significant trends in the occipitotemporal/visual cognition system and the parietal/spatial system composites,  $t(58) = -1.8$ ,  $p < .08$  and  $t(58) = -1.9$ ,  $p < .07$ , respectively, and no difference in the medial temporal/memory composite,  $t(58) = -0.16$ ,  $p < .87$ . Of course, it should be noted that had the sample size been larger, both the visual and visuospatial composites might well have reached significance also. The present data should not be interpreted as evidence for SES associations with language and executive function exclusively, but rather as evidence for a disproportionate association with these two systems as demonstrated by the SES  $\times$  system interaction reported above.

The same pattern held among the subset of children for whom a pediatrician verified the parent-reported medical history: large differences were observed across SES in performance of tasks comprising the language ( $t(28) = -3.4$ ;  $p < .002$ ) and executive ( $t(28) = -3.2$ ;  $p < .003$ ) composites, whereas no differences were seen in the visual ( $t(28) = -1.7$ ;  $p < .11$ ), visuospatial ( $t(28) = -1.1$ ;  $p < .32$ ) or memory ( $t(28) = -1.6$ ;  $p < .13$ ) composites.

The size, as well as the significance level, of SES associations with the different neurocognitive system composites was also consistent with our expectations: as shown in Table 2, the effect size for the left perisylvian/language system was 1.1 standard deviations between the means of the groups; for the prefrontal/executive system it was 0.68 standard deviations. Both are considered large by conventional effect size criteria, whereas the size of the (non-significant) associations of SES with

the remaining system composites varied from .04 to .48 standard deviations.

With so many tasks, and with unequal numbers of tasks being used to assess different neurocognitive systems, it is important to verify that the disproportionate differences in the language and executive systems observed across SES are manifest at the individual task level, rather than emerging artifactually from a more thorough sampling of those systems. Table 2 summarizes the inferential statistics on SES differences for the 13 individual tasks with continuous measures. Of the posterior brain systems, one of the occipitotemporal/visual cognition tasks showed a significant SES effect, and one of the parietal/spatial tasks showed a trend, whereas the other tasks used to test those systems, and the two medial temporal/memory tasks, showed no differences. In contrast, within the left perisylvian/language system, two tasks showed highly significant differences and one showed a trend. Norms for the PPVT show that the SES effect can be interpreted as depressed performance for the low SES children rather than enhanced performance for the middle SES children, in that the mean percentiles of the two groups were 28th and 53rd, respectively.

Among the three continuous measures of prefrontal/executive function, two showed significant differences: go/no-go and the false alarm index. The task that did not show a difference – spatial working memory – was similar to a task found to be insensitive to prefrontal dopamine dysfunction in children with early-treated phenylketonuria (Diamond *et al.*, 1997).

Turning next to the non-continuous measures of prefrontal/executive function, we find mixed results. In the dimensional change card sort task, the vast majority of children scored either five or zero correct on each trial (i.e. either all correct or all incorrect). Results were therefore analyzed with ordinal regression analysis. In the first rule change block there was a non-significant trend for better performance by the middle SES children (22 out of 30 versus 15 out of 30 children with errorless blocks, for middle and low SES, respectively; pseudo R-squared = .051;  $p < .075$ ). In the second rule change block, performed only by children who made errors in the first, three out of eight middle SES children and four out of 15 low SES children had error-free blocks. Combining both blocks, with the assumption that perfect performance on the first would have been followed by perfect performance on the second (required because such children were not given the second block), the difference between groups was again borderline significant (pseudo R-squared = .06;  $p < .054$ ).

Performance on the combined set of theory of mind problems, which included appearance – reality and false belief tasks, did not show a significant difference across

**Table 3** Regressions demonstrating variance in language and executive function composites accounted for by individual subcomponents of SES (parental education, parental occupation and family income-to-needs ratio)

Step		R-square	Significance of R-square change	Beta	T	Significance
<b>Language</b>						
1	Parental education	0.267	0.0001	0.517	4.558	0.0001
2	Parental education	0.311	0.065	0.226	1.190	0.239
	Parental occupation			-0.358	-1.882	0.065
3	Parental education	0.314	0.618	0.201	1.017	0.313
	Parental occupation			-0.313	-1.485	0.143
	Income-to-needs			0.087	0.502	0.618
<b>Executive</b>						
1	Parental education	0.119	0.008	0.345	2.771	0.008
2	Parental education	0.142	0.222	0.132	0.621	0.537
	Parental occupation			-0.262	-1.236	0.222
3	Parental education	0.153	0.401	0.085	0.386	0.701
	Parental occupation			-0.179	-0.763	0.449
	Income-to-needs			0.163	0.846	0.401

Note: parental occupation and income-to-needs do not account for unique variance after controlling for parental education.

SES. However, an ordinal regression analysis did show a borderline difference on performance of the two false belief tasks (defined as zero, one or two correct), such that middle SES children were more likely to perform more accurately (pseudo R-squared = .059;  $p < .056$ ).

Finally, the two groups of children were equally inclined to delay their sticker reward in order to get more stickers (mean delay choices 22.6 for both low and middle SES children), and this was true even for the most tempting delay problem, of one sticker now or just two later (18 versus 20 children choosing to delay gratification for low and middle SES, respectively, chi-square (1) = .287,  $p < .59$ ).

Taken together, the results from the individual measures generally affirm the conclusions drawn from the composite measures, namely that SES differences may be apparent in multiple systems, but that SES differences are most pronounced in the functioning of the left perisylvian/language and prefrontal/executive systems, although trend-level effects suggest the need for future research with larger sample sizes. Given the involvement of the language and executive systems in virtually any task, behavioral data is unlikely to discriminate between weaker effects of SES on visual and spatial task performance via language and executive function.

Turning next to the regression analyses, we examined to what extent the variance in performance within each neurocognitive system could be statistically accounted for by SES. We first entered the three subcomponents of SES (average parental education, highest occupation as measured by the Hollingshead occupational status index, and income-to-needs ratio) into a single step, because SES as a construct is considered more stable than the individual components (McCloyd, 1990). Analyses showed

that SES accounted for 31.4% of the variance in the language composite ( $F(3, 55) = 8.39$ ;  $p < .0001$ ) and 15.3% of the variance in the executive function composite ( $F(3, 55) = 3.32$ ;  $p < .02$ ). SES did not significantly account for any portion of the variance in the visual, visuospatial, or memory composites.

Because our means of subject selection used the SES component variables of education, occupation and income-to-needs as inclusion criteria for the two groups, they are not independent in our sample. Therefore, we do not have the same power to conduct hierarchical regressions separating the effects of the individual SES components that we would in a sample in which all three measures were allowed to vary continuously. Nonetheless, because it is sometimes argued that the constituents of SES may have separate effects on outcomes (Bornstein, Hahn, Suwalsky & Haynes, 2003; Duncan & Magnuson, 2003), we conducted such hierarchical regressions in a preliminary attempt to disentangle the role of each component in the association between SES and the language and executive systems (see Table 3).

In agreement with others who contend that parental education is the single most predictive constituent of SES for developmental outcomes (Bornstein, Hahn, Suwalsky & Haynes, 2003), we found that parental education most strongly accounted for variance in these two neurocognitive systems. In particular, parental education alone accounted for 26.7% of the variance in performance in the language system ( $F(1, 57) = 20.1$ ;  $p < .0001$ ). Neither the addition of parental occupation nor the addition of the family's income-to-needs ratio significantly increased the predicted variance. In the executive function composite, parental education accounted for 11.9%

of the variance ( $F(1, 57) = 7.7; p < .008$ ). Again, neither parental occupation nor income-to-needs significantly increased the predicted variance. However, Table 3 shows that, at the final step of both regressions, the models were significant, whereas the individual regressors were not, implying that the subcomponents exhibit shared variance, and perhaps that SES as a construct is more reliable than its constituent components (McCloyd, 1998).

In order to examine the relationships between SES, language and executive function performance, we conducted multiple regression analyses of the effects of each factor on the others. Regression analysis demonstrated that executive function statistically accounts for 9.4% of the variance in the language composite ( $F(1, 57) = 5.9; p < .018$ ). When SES is then added to the model as a predictor of language, 32.4% of the variance in the language composite is accounted for ( $F(4, 54) = 6.46; p < .0001$  for the whole model.) The 23% increase in variance is significant ( $p < .001$ ). A similar regression was conducted on predictors of executive function. As above, language predicts 9.4% of the variance in the executive function composite. However, when SES is added as a predictor of executive function, only 7.1% of additional variance is accounted for, and this increase is non-significant ( $p < .22$ ).

Multiple regression analysis was also used to examine potential mediating factors underlying SES associations with language and executive function. As reported above, SES and executive function together account for over 30% of the variance in language performance for the whole group. Because we did not have *a priori* hypotheses as to the order of importance, we next added birthweight, time in preschool/daycare, pro-academic activities in the home (averaged across reading to the child, practising writing, talking to the child about school and talking about numbers), adult literacy activity (averaged across reading books and newspapers), and frequency of physical punishment in the next step of the model. Although predicted variance in language performance increased by 12.5%, this increase was not significant ( $p < .13$ ).

A similar hierarchical regression analysis investigated factors that may predict executive function performance, above and beyond the variance that SES and language together account for. In this case, the above factors accounted for an additional 17.5% of the variance ( $p < .39$ ). Birthweight ( $p < .006$ ) and frequency of physical punishment ( $p < .013$ ) were the only additional significant regressors.

Interpretation of these results must take into account the self-report nature of all of the early childhood experience measures. This is particularly relevant in light of our failure to find the expected SES differences in frequency with which parents report preschool experience

and engaging in pro-academic activities. When corrected for multiple comparisons, contingency analysis failed to demonstrate a significant difference across SES in the amount of time spent in preschool or daycare before entering kindergarten. Similarly, there were no differences in the frequency with which parents report engaging in the behaviors listed earlier, including pro-academic activities, adult linguistic activities, or physical punishment practices.

## Discussion

Socioeconomic background has traditionally been associated with large outcome differences across a variety of broad-band measures of cognitive performance. This study was designed to better elucidate the specific neurocognitive systems in which performance was associated with SES differences, so that we may more precisely target interventional efforts. To this end, we parsed cognition into five broad neurocognitive systems. It was found that SES differences were associated with disparities in performance in both the language and executive function systems, and with lesser disparities in visual cognition, visuospatial skills and memory. Furthermore, in addition to their statistical significance, the reported differences might be described as having a high degree of *social* significance in the sense that the effects were sizable, with a large effect size for the language system and a moderately large effect size for the executive system.

The relations among SES, language and executive function in our sample hint at a possible causal pathway. Both SES and executive function ability independently predict language ability, but SES does not statistically account for any variance in executive function ability over and above that predicted by language performance. Perhaps, then, SES has an effect on language, which then independently drives executive function performance. Of course, an alternate explanation is that some other variable that is correlated with SES could drive both language and executive function, but that this other variable is more strongly associated with language abilities than with executive function abilities. Given the relatively small size and bimodal distribution of SES in our sample, further research is necessary. One way to address the question of causal mechanism directly would be through intervention programs targeting language and executive function. Such a prospective study in which two groups are randomly assigned to different interventions could potentially elucidate the causal factors in cognitive outcome differences.

Intervention is more than just an experimental design capable of testing hypotheses about SES and neurocog-

nitive development, however. The design of more targeted and efficient intervention methods is the ultimate goal of our research program. A number of randomized controlled trials have shown that educational intervention has the potential to narrow the performance gap across SES. For instance, the IQ of low SES children who have participated in intensive early education is between one-half and one full standard deviation higher than low SES control groups (Ramey & Ramey, 1998). Frequently, it has been concluded that the benefits of early education wane shortly after termination of the intervention program (e.g. Haskins, 1989). However, the positive effects of intervention on verbal ability and reasoning skills were sustained for two years following the end of one randomized control trial (Brooks-Gunn *et al.*, 1994). A meta-analysis of the long-term effects of early childhood programs demonstrated that early childhood education produces persistent, cost-effective effects on academic achievement (Barnett, 1998).

However, to maximize the potential for narrowing the gap in cognitive achievement across SES, we must increase the precision with which we intervene. A promising approach is to focus on the development of the neurocognitive systems that have been shown here to reflect the greatest gulf across SES, namely, language and executive function. In fact, it has been reported that the training of executive control tasks in children with weak performance on these tasks actually leads to generalized improvement in inhibitory control, even on non-trained tasks (Dowsett & Livesey, 2000; Kerns, Eso & Thomson, 1999).

These results also have practical implications for research. Investigators must take SES differences into account when designing studies investigating the basic development of language and executive function. It is a variable that has clear power to impact results, and if not controlled for, may confound data.

The data presented here generally support our hypothesis that SES differences are associated with differences within the normal range of performance across a number of cognitive abilities, and have disproportionate associations with children's language and executive control abilities. A great deal of research is needed to further characterize these relationships, however, and many questions remain to be investigated.

For example, what are the specific etiological factors associated with the variance in each system's performance? To what extent are they environmental as opposed to genetic, and if environmental, to what extent are somatic factors (such as nutrition, lead exposure and prenatal care) and experiential factors (including home and school cognitive stimulation and emotional stress levels) responsible? Prospective studies that systematic-

ally investigate the relationships between these types of factors and the function of specific neurocognitive systems – through the use of both cognitive tasks and neuroimaging techniques – would begin to shed light on these issues.

Why are the associations between SES and cognitive performance disproportionate for language and executive function? The prolonged maturation of these systems could lead to increased susceptibility to environmental differences that may mediate outcome. Alternatively, different systems may be differentially reliant on the types of enculturation processes that vary across SES. For instance, SES differences are associated with robust differences in the home literacy environment, and these differences have been shown to be directly related to language skill development (e.g. Whitehurst, 1997).

Other questions remain to be addressed as well. Within the language and executive function systems, are certain sub-systems (e.g. phonological awareness or cognitive conflict monitoring) differentially impacted? Do the present conclusions, drawn from a study of urban African-American kindergarteners, apply to other demographic groups and ages? And perhaps most importantly, what neurocognitively targeted interventional efforts are most effective? By more precisely understanding the association between SES and cognitive achievement, we hope to ultimately develop and test more finely tuned intervention strategies.

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Received: 14 October 2003

Accepted: 7 April 2004