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PAPER

Socioeconomic gradients predict individual differences in neurocognitive abilities

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Abstract

Socioeconomic status (SES) is associated with childhood cognitive achievement. In previous research we found that this association shows neural specificity; specifically we found that groups of low and middle SES children differed disproportionately in perisylvian/language and prefrontal/executive abilities relative to other neurocognitive abilities. Here we address several new questions: To what extent does this disparity between groups reflect a gradient of SES-related individual differences in neurocognitive development, as opposed to a more categorical difference? What other neurocognitive systems differ across individuals as a function of SES? Does linguistic ability mediate SES differences in other systems? And how do specific prefrontal/executive subsystems vary with SES? One hundred and fifty healthy, socioeconomically diverse first-graders were administered tasks tapping language, visuospatial skills, memory, working memory, cognitive control, and reward processing. SES explained over 30% of the variance in language, and a smaller but highly significant portion of the variance in most other systems. Statistically mediating factors and possible interventional approaches are discussed.

Introduction

SES is strongly associated with a number of indices of children's cognitive ability and achievement, including IQ, achievement tests, grade retentions and literacy (Baydar, Brooks-Gunn & Furstenberg, 1993; Brooks-Gunn, Guo & Furstenberg, 1993; Liaw & Brooks-Gunn, 1994; Smith, Brooks-Gunn & Klebanov, 1997). These associations are typically quite large (Gottfried, Gottfried, Bathurst, Guerin & Parramore, 2003), and are observed throughout development, from infancy through adolescence and into adulthood (Bradley & Corwyn, 2002). Many decades of research have sought to characterize the mediators and moderators of socioeconomic effects on cognitive ability (Bradley & Corwyn, 2002; McLoyd, 1998).

The traditional measures of cognitive performance used in this research have been broad-based, lacking specificity regarding the underlying cognitive abilities involved. Standardized tests and school achievement generally measure the combined functioning of multiple neurocognitive systems. With the advent of cognitive neuroscience, it has become possible to assess specific neurocognitive systems more selectively.

Recently, we applied this approach in two preliminary investigations of the developmental relationships between SES and certain cognitive functions associated with specific brain systems (Noble, Norman & Farah, 2005; Farah, Shera, Savage, Betancourt, Gianetta, Brodsky, Malmud & Hurt, 2006). Hypothesizing that brain systems with protracted postnatal development would have greater susceptibility to environmental influences, we proposed that perisylvian regions underlying language processing (Giedd, Blumenthal, Jeffries, Castellanos, Liu, Zijdenbos, Paus, Evans & Rapoport, 1999; Paus, Zijdenbos, Worsley, Collins, Blumenthal, Giedd, Rapoport & Evans, 1999; Sowell, Peterson, Thompson, Welcome, Henkenius & Toga, 2003; Sowell, Thompson, Rex, Kornsand, Tessner, Jernigan & Toga, 2002) and prefrontal regions underlying executive functioning (Casey, Giedd & Thomas, 2000; Giedd *et al.*, 1999; Huttenlocher, 1997) would show the strongest associations with SES. Supporting this, we found that children from low SES backgrounds tended to perform below their middle SES peers on most measures of the language and executive systems. The effect sizes were striking: group means were on the order of a standard deviation apart on composites of

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language skills, and on the order of half a standard deviation apart on executive function tasks. The studies produced differing results on the relation of SES to medial temporal memory function. In the first study, of kindergarten-aged children, no SES difference was found in memory ability, whereas in the second study, of middle school-aged children, a substantial difference, on the order of two-thirds of a standard deviation, was observed. In the present study, the relationship between SES and neurocognitive outcome is further explored, addressing three new issues.

First, our previous research concerned groups of low SES and middle SES children. In contrast, here we study SES as a continuous variable across the broad range represented in our sample, increasing both our statistical power and ecological validity. Second, the previous studies left several open questions about SES disparities in neurocognitive systems other than language and executive function. Although no SES differences were observed in kindergarteners' performance on memory tasks, this may have been due to the extremely brief retention interval used in that study. In addition, non-significant trends were observed for SES differences in visual and spatial cognition in both of the earlier studies. An additional goal of the present study is to provide more powerful tests of these observed but unreliable differences using a larger sample and a new set of tasks. Finally, only the middle school study assessed individual subsystems of executive ability, and found some, but not all, correlating with SES. Both 'working memory' and 'cognitive control' (associated with lateral prefrontal and anterior cingulate cortex, respectively) were found to vary with SES, whereas 'reward processing' (associated with ventromedial prefrontal cortex) was not. A final goal of the present study is to assess the subsystems of prefrontal/executive function in a larger group of children with new tasks.

In the present study, New York City first-graders from a wide range of socioeconomic backgrounds were administered a set of tasks drawn from the cognitive neuroscience literature, to assess relatively specific neurocognitive systems: the left perisylvian/language system, the parietal/spatial cognition system, the medial temporal/memory system, the lateral prefrontal/working memory system, the anterior cingulate/cognitive control system, and the ventromedial/reward processing system. SES was estimated by parental education, occupation, and income, the three most frequently used indices of SES (Ensminger & Fothergill, 2003). These can be considered proxies for the many other factors that vary systematically with SES and are likely to influence child development, including physical health, home environment, early education, and neighborhood characteristics (Bornstein & Bradley, 2003). In addition, parents responded to a questionnaire concerning the children's home environment and parenting practices.

The hypotheses to be tested include the degree to which SES accounts for individual differences in the neurocognitive systems listed, including a finer-grained analysis of prefrontal/executive function than was previously carried out, and more powerful assessments of visual/spatial and memory functions. In addition, we constrain possible causal hypotheses concerning the association of SES and neurocognitive development, by examining the relations among the systems in mediating the observed effects of SES, and the relations among parent-reported aspects of the children's home lives and neurocognitive development.

Method

Subjects

One hundred and sixty-eight first-graders were recruited from nine New York City public schools that serve families from a wide range of socioeconomic backgrounds. Parents of participants signed IRB-approved permission slips for their children to engage in a short in-school battery of cognitive tests for a research study, for which their children would receive a free book. The parents of 150 of these children (80 boys, 70 girls) were able to be reached by telephone to answer a 5-minute questionnaire that included items on socioeconomic background, the child's medical and psychiatric history, and activities engaged in at home. These 150 children constitute the subjects in the analyses presented below.

Thirty-four per cent of children were identified by their parents as African-American; 6.7% were Asian; 22.7% were Latino; 22.7% were white; and 14.0% of children were identified as mixed or other. All children were native English speakers. Although English was the primary language spoken in the home, 68 children (45%) grew up in a family in which another language was also spoken by at least one family member part of the time. Results of relevant analyses accounting for second language exposure are presented below.

Seventeen children's parents reported some type of significant medical or psychiatric history. Of these, five children weighed less than 1500 g at birth. Three children were reported to have diagnoses of ADHD, and one child was taking Ritalin. No other children were taking psychotropic medications of any kind. No child had been diagnosed with a learning disability, although 14 children's parents reported a history of some other type of psychiatric or developmental problem. One child was reported to have suffered a head injury involving loss of consciousness for several hours. Analyses are presented both including and excluding children with significant medical and/or psychiatric histories. Although parental report is always subject to error, it was previously found that children's medical histories as reported by parents were reasonably accurate, and that results from the subset verified by children's pediatricians were the same as those from the whole sample (Noble *et al*., 2005).

Procedures

A battery of tasks parsed cognition into six broad neurocognitive systems: language, visuospatial processing, memory, working memory, cognitive control, and reward processing. The six systems cover a range of cognitive abilities, grouped into broad categories whose validity is supported by anatomical and information-processing considerations, discussed below.

Each neurocognitive system was assessed using two tasks that were superficially different, but that were designed to predominantly tax that system. The level of functioning of each of the six neurocognitive systems was measured by a composite score derived from that system's tasks. Although no task is pure, and some tasks undoubtedly engage multiple systems, the tasks were chosen to be relatively selective measures of particular neurocognitive systems in that they tax one system and place relatively light demands on the others, as based on evidence from the cognitive neuroscience literature. Whenever possible, we provide neurocognitive evidence from pediatric populations. Of course, behavioral measures alone cannot tell us with complete confidence whether a particular task engaged the hypothesized neural circuitry in our subject population.

The battery consisted of paper-and-pencil and computerized tasks, each lasting approximately 5–10 minutes, with the complete battery requiring two 45-minute sessions. Subjects were tested in a quiet room or hallway in school. Each session included tasks from multiple systems and the order of sessions was counterbalanced between subjects.

Data collection also included a questionnaire for parents documenting the education level, income, and occupation for all adults in the home (McLoyd, 1998). Parental education was defined as the average education of any parents, step-parents, or guardians in the home. The income-to-needs ratio was calculated for each family, defined as the total family income divided by the official poverty threshold for a family of that size, such that a family with an income-to-needs ratio of 1 is living at the poverty line (McLoyd, 1998). Finally, parental occupation was defined as the highest occupational score of any parent, step-parent, or guardian in the home, according to the 9-point Hollingshead Index Occupational Status Scale (Hollingshead, 1975, as cited in Bornstein, Hahn, Suwalsky & Haynes, 2003). Although the Hollingshead is frequently criticized for being oversimplified and out-of-date (Duncan & Magnuson, 2003), it is nonetheless the best-known and most widely used measure (Bornstein *et al.*, 2003). Occupations of all adults in the home were assigned to one of the nine categories, ranging from 'farm laborers/menial service workers' to 'higher executives/ proprietors of large businesses, and major professionals'. Modern-day urban occupations were assigned as seemed reasonable, with the best efforts made to stay true to the original scale. For instance, 'tailor' was assigned to the category of 'skilled manual workers, craftsmen, and tenant farmers', for a score of 4; 'office manager' was assigned to the category of 'smaller business owners, farm owners, managers, and minor professionals', for a score of 7; and 'teacher' was assigned to the category of 'administrators, lesser professionals, and proprietors of medium-sized businesses', for a score of 8. To ensure consistency, all assignments were made by one author (K.G.N.).

Parents were also asked to report the number of hours per week the child had spent in preschool and/or daycare prior to kindergarten, the frequency with which parents currently engage in pro-academic activities with children (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. For each activity, they were asked to choose whether they had engaged in the activity 'within the last week, month, six months, or less frequently'. Activity frequencies were coded as 1, 2, 3, or 4, respectively, such that a higher score indicated spending less time engaging in that activity.

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).

Peabody Picture Vocabulary Test (PPVT). This is a standardized test of lexical-semantic knowledge, used in our previous studies of SES and neurocognitive development. 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, 1997).

CTOPP – Blending words subtest. This 20-item subtest was taken from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen & Rashotte, 1999) and measures the child's ability to combine sounds to form words. The child listens to a series of tape-recorded sounds and puts the sounds together to make a whole word. 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, Shaywitz, Pugh, Mencl, Fulbright, Skudlarski, Constable, Marchione, Fletcher, Lyon & Gore, 2002).

Parietal/spatial cognition system

Spatial cognition involves the perception and mental manipulation of spatial relations (Macaluso & Driver, 2003), and plays a role in mathematics and technical subjects (Zago & Tzourio-Mazoyer, 2002) as well as artistic endeavors (Kirk & Kertesz, 1989).

Developmental Neuropsychological Assessment (NEPSY) (Korkman, Kirk & Kemp, 1998) arrows line orientation task. In this standardized test of spatial perception and cognition, the experimenter initially shows the subject a concentric target with two arrows, and demonstrates how the two arrows point to the center of the target. The subject is then shown another target with eight surrounding arrows, and is asked, 'Which two arrows point straight to the middle of the target?' The task continues for 15 trials, and the total score is the sum of points earned on all items, for a maximum of 30. Line orientation judgment is most impaired by lesions to the parietal cortex in humans (Walsh, 1987).

Mental rotation task. In this task, the experimenter uses laminated line-drawings of hands, similar to those used by Parsons, Gabrieli, Phelps and Gazzaniga (1998), to demonstrate that two identical right hands can be superimposed, but that a right hand and a left hand cannot be superimposed no matter how they are rotated. The child is then told that two hands will appear on the computer screen, and that as quickly as possible he is to press one button if the two hands are the same and another button if they are different. The buttons are marked with stickers, such that two of the same stickers (two stars) indicate the 'same' button, and two different stickers (a circle and a heart) indicate the 'different' button. Five practice trials with feedback ensue, followed by 30 test trials without feedback. The hand on the left is always a non-rotated right hand. The hand on the right is rotated either 0, 45 or 90 degrees clockwise from the reference hand on the left, and was a left hand in 50% of trials. Because of the speed–accuracy tradeoff involved in this task, the relevant score represents an average of the z-scores of accuracy and reaction time of correct trials. Both patient data (Ratcliff, 1979) and pediatric fMRI (Booth, MacWhinney, Thulborn, Sacco, Voyvodic & Feldman, 1999) have linked mental rotation to the parietal lobes.

Medial temporal/declarative 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 were tests of incidental memory, in that the children were not aware that their memory would be tested at the time they were exposed to the stimuli. Incidental memory is unaffected by differences in strategy or intention to learn. It affords a relatively pure measure of medial temporal memory processing, independent of prefrontally mediated strategy (Rugg, Fletcher, Frith, Frackowiak & Dolan, 1997).

NEPSY delayed memory for faces. In this standardized, incidental learning task, the child is presented with 16 children's faces, presented individually, each of which the child must classify as a boy or girl. During the test phase, presented about 20 minutes later, the child is presented with sets of three faces, and must choose which of the three faces she has seen before. 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).

Incidental picture pair learning task. In this task involving the incidental learning of arbitrarily paired associates, the child is shown 10 pairs of line-drawings from the Snodgrass and Vanderwart (1980) corpus (e.g. a book and a clock), and is asked to indicate which picture answers a simple question (e.g. 'Which one has pages?' with the correct answer being the book). Each set of paired associates is presented twice, once with the question referring to one picture of the pair, and once referring to the other. During the test phase, about 10 minutes later, the child is shown three pictures on a page, and is asked to indicate which two of the three had previously been paired. The task continues for 20 trials. Position of each picture on the page was randomized. Patients with medial temporal damage are impaired at recognition memory and their impairment is evident in incidental learning tasks (Mayes, Meudell & Neary, 1978). Functional neuroimaging studies support this localization (Squire, Ojemann, Miezin, Petersen, Videen & Raichle, 1992).

Lateral prefrontal/working memory system

Working memory involves the ability to retain and manipulate information over a short duration. It is essential for complex reasoning and problem solving (Klingberg, Forssberg & Westerberg, 2002).

Spatial working memory task. This computerized task, adapted from Klingberg *et al.* (2002), involves a storyline in which the child is told she has to 'help the squirrel find his acorns'. Acorns are serially presented in pseudo-random positions on a four-by-four grid. After the last acorn is presented, the screen turns green to indicate that the subject should point to the positions of the respective acorns in the order they appeared. The number of acorns in the sequence is successively increased after two trials at a given span level. The task proceeds until the child misses two trials at the same span level. Spatial working memory has been linked to prefrontal cortex function, particularly dorsolateral PFC, in lesion studies (Shimamura, 1994) and in functional neuroimaging, including fMRI of pediatric populations (Thomas, King, Franzen, Welsh, Berkowitz, Noll, Birmaher & Casey, 1999).

Delayed nonmatch to sample. This computerized task, adapted from Marks, Cyrulnik, Berwid, Santra, Curko and Halperin (2001), requires children to hold simple nonverbalizable figural stimuli in working memory. In the experimental condition, the child is presented with a single shape for 4 seconds, followed by a 1-second delay. A response screen containing the original figure and one new figure is then presented. The child is asked to 'point to the shape that is different from the one you just saw'. The task difficulty increases incrementally every three trials, such that the first three trials contain stimuli with a single figure and a response screen containing two figures; the second level contains two figural stimuli and three response options, and so on. In the control condition, the child must perform the same task without delay, such that the child views the stimulus and response figures simultaneously, and does not need to engage working memory. In both conditions, the task continues until the child gets fewer than two out of three trials correct within a given level. The score is the difference between the total correct in the experimental and control conditions. Since most children answer all items correctly on the control task but fewer items correctly on the experimental task, scores are generally negative. Similar tasks are impaired in rats with prefrontal lesions (Porter, Burk & Mair, 2000), and have been linked to ventrolateral prefrontal cortex in humans using fMRI (de Zubicaray, McMahon, Wilson & Muthiah, 2001).

Anterior cingulate/cognitive control system

The ability to suppress or override competing attentional or behavioral responses, and the ability to adjust the effort required to do so, are key components in the performance of many cognitive processes (Casey, Tottenham & Fossella, 2002). The ability to ignore competing sources of attention is crucial for success in the classroom environment.

Go/no-go task. In this task, also used in our study of SES in kindergarteners, 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. Items are pseudo-randomized, and the cat appears on 10 out of 60 trials. This task assesses the child's ability to inhibit a prepotent response, by measuring the number of false alarms made to the cat. This ability has been linked to the anterior cingulate in both lesion studies (Drewe, 1975) and pediatric and adult fMRI (Casey, Trainor, Orendi, Schubert, Nystrom, Cohen, Noll, Giedd, Castellanos, Haxby, Forman, Dahl & Rapoport, 1997).

NEPSY auditory attention and response set. The first part of this standardized task was used to set up a prepotent response. Red, yellow, and blue squares are placed alongside an empty box. An audiotape plays a list of words at the rate of one word per second. The child is told that every time he hears the word *red*, he is to place a red square in the box. The second part of this task is similar to the Stroop task, in that the child must inhibit a prepotent response while shifting to and maintaining a new set of contrasting instructions. Here, the child is told that he will hear some more words on the audiotape. However, this time, the child is to place a yellow square in the box every time he hears the word *red*, a red square in the box every time he hears the word *yellow*, and a blue square in the box every time he hears the word *blue*. Standard scores represent performance on the second half of the task, and take into account both accuracy and reaction time. Lesion studies (Swick & Jovanovic, 2002) and neuroimaging (Peterson, Kane, Alexander, Lacadie, Skudlarski, Leung, May & Gore, 2002) have implicated anterior cingulate cortex during performance of Stroop and Stroop-like tasks.

Orbitofrontal/reward processing system

The ability to learn the reward value of stimuli is essential for flexibly adapting to changing situations in the world. Orbitofrontal cortex has been shown to encode the context-specific reward value of stimuli, and has been linked to impulse control and stimulus–reward learning (Mesulam, 2002).

Reversal learning task. In this task, adapted from Fellows and Farah (2003), subjects play a computerized card game, in which they are dealt two cards at a time from decks of different colors. One deck consistently conceals a 5-point win, the other a 5-point loss. Subjects are told to pick a card from one deck, and to try to get as many points as possible. Feedback is provided after each trial. After the learning criterion of eight consecutive cards chosen from the winning deck is met, the contingencies are switched, constituting the reversal phase of the task. If eight cards are again picked consecutively from the winning deck, the contingencies are switched again, for a total of 40 trials, allowing for up to five reversals. The number of errors following each reversal is scored. Both lesion (Fellows & Farah, 2003) and neuroimaging (Elliott, Dolan & Frith, 2000) data suggest that this aspect of reward processing involves orbitofrontal cortex.

Delay of gratification. In this task, the child is told that the experimenter has a present for her, but that she has to remain turned around while it is wrapped, similar to Carlson and Moses (2001). The experimenter then proceeds to noisily wrap the present for up to 5 minutes. Starting at 2 minutes, the experimenter makes a noise with a noisemaker every 30 seconds. The child's score is the amount of time elapsed before she turns around, with a maximum of 300 seconds. The ability to delay gratification has been shown to be 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

SES index

A stable measure of SES incorporates education, occupation, and income (McLoyd, 1998). Although ideally all parents would provide data pertaining to all three components of SES, in reality, parents are often more willing to provide education and occupation than income data (Bornstein & Bradley, 2003). In our sample, 150 parents provided education and occupation information, whereas only 130 of these were willing to disclose income. So as to avoid discarding the data from the remaining 20 children (and therefore potentially biasing our results towards those families who, for whatever reason, were willing to provide income information), a regression equation was constructed to predict the income-to-needs ratio from the other two variables in the subjects for whom all three variables were available. However, because of the nature of the income-to-needs ratio, there tend to be positive, but not negative, outliers: that is, all families living below the poverty line are distributed between values of zero and one, whereas very wealthy families may, in theory, be extreme outliers with very high income-to-needs ratios. To illustrate this point, the mean income-to-needs ratio in our sample of 130 parents who provided this information was 3.36 (SD 3.78); however, whereas the minimum ratio was only 0.23 (less than one standard deviation from the mean), the maximum was 19.5 (over 4 standard deviations from the mean). To eliminate the skewing effect that these positive outliers would have on predicting the missing data, the nine families who had income-to-needs ratios greater than 10 were eliminated, at which point the standardized residuals displayed a normal distribution. A regression equation was then calculated from the remaining 121 families (income-to-needs = 0.358 (parental education) + 0.344 (parental occupation) – 4.097; $R^2 = .545$; $p < .0001$), and this equation was used to impute the income-to-needs scores for the 20 children whose parents did not provide income information, using the education and occupation information that those children's parents provided. An SES index score was then determined for each child by entering the three variables (parental education, occupation, and income-to-needs or imputed income-to-needs) into a factor analysis, using the maximum likelihood method of extraction. A single factor was extracted, explaining 73.5% of the variance across the three variables. This factor loading was then used as the SES index score for each child.

Cognitive measures

For all cognitive tasks in all subjects, a total of 13 individual scores fell more than 3 standard deviations on either side of the mean of the sample and were eliminated from the data set. These included one high performance on PPVT, one low performance on NEPSY-arrows, four outliers on hand rotation (two with low accuracy and two with high reaction time), five low performances on reversal learning (including three subjects who scored a high number of reversal errors, plus two additional children who never reached the learning criterion of eight in a row correct), as well as one low performance each on memory-pictures and go/no-go. In addition to the outliers, other data points were eliminated or missing, either because the child refused to participate in a particular game (one data point for go/no-go), the child was unable to complete the testing session (one data point each for arrows, hand rotation, memory-faces, memory-pictures, and present wrapping), or due to computer difficulties (6 data points each for go/no-go and reversal learning, 4 data points for acorns, and 2 data points for delayed non-match to sample). The number of remaining participants for each task, as well as the means and standard deviations of the analyzed scores for each task are shown in Table 1.

Scores were converted to z-scores relative to the entire distribution of 150 children, thus putting all task

Table 1 *Means and standard deviations of tasks*

System	Task	*N*	Mean	SD
Language	PPVT[a] (standard score)	149	93.7	15.0
	CTOPP blends[b] (standard score)	150	8.9	2.3
Visuospatial	Arrows (line orientation)[b] (standard score)	148	9.4	3.0
	Hand rotation-accuracy (# correct)	145	26.4	4.2
	Hand rotation-reaction time (ms)	145	2104.7	646.7
Declarative memory	Memory-faces[b] (standard score)	149	10.4	3.2
	Memory-picture pairs (# correct)	148	17.6	2.4
Executive-working memory	Acorns (spatial working memory) (span)	146	4.3	1.6
	Delayed non-match to sample (span, experimental condition minus control condition)	148	–5.4	2.69
Executive-cognitive control	Go/no-go (# false alarms)	142	2.1	1.4
	Auditory attention and response set[b] (standard score)	150	7.8	3.1
Executive-reward	Reversal learning (reversal errors)	139	6.1	1.0
	Present wrapping (ms)	149	197.3	107.1

Note: See text for maximum and minimum possible scores on non-standardized tasks. PPVT = Peabody Picture Vocabulary Test. CTOPP = Comprehensive Test of Phonological Processing.
[a] Nationally normed mean standard score of 100, with a standard deviation of 15.
[b] Nationally normed mean standard score of 10, with a standard deviation of 3.

performances on a common scale. A composite score for each neurocognitive system was then constructed by averaging the relevant *z*-scores. Regression analyses of the relation between the SES index and neurocognitive systems were conducted, as well as further regressions including these measures and measures of early childhood experience.

Regression analyses

The SES index was entered into regressions to examine whether SES could statistically account for the variance in performance of each system. Results are presented in Figure 1. SES statistically accounted for a portion of the variance in each system except for reward processing. Specifically, SES accounted for 32.0% of the variance in the language composite (Beta = .556; $p < .0001$); 16.7% of the variance in the visuospatial composite (Beta = .409; $p < .0001$); 10.2% of the variance in the memory composite (Beta = .32; $p < .0001$); 5.5% of the variance in the working memory composite (Beta = .239; $p < .002$), and 5.5% of the variance in the cognitive control composite (Beta = .234; $p < .004$). Using the test for correlated correlations (Meng, Rubin & Rosenthal, 1992), it was found that SES accounted for statistically more variance in the language composite than in the next highest system composite ($p < .03$). The variance explained in the other systems did not significantly differ from one another, though the difference in the variance accounted for in the visuospatial system as compared to that in both the cognitive control and working memory systems was borderline significant ($p < .06$).

SES is generally considered to comprise education, occupation and income (McLoyd, 1998). However, because

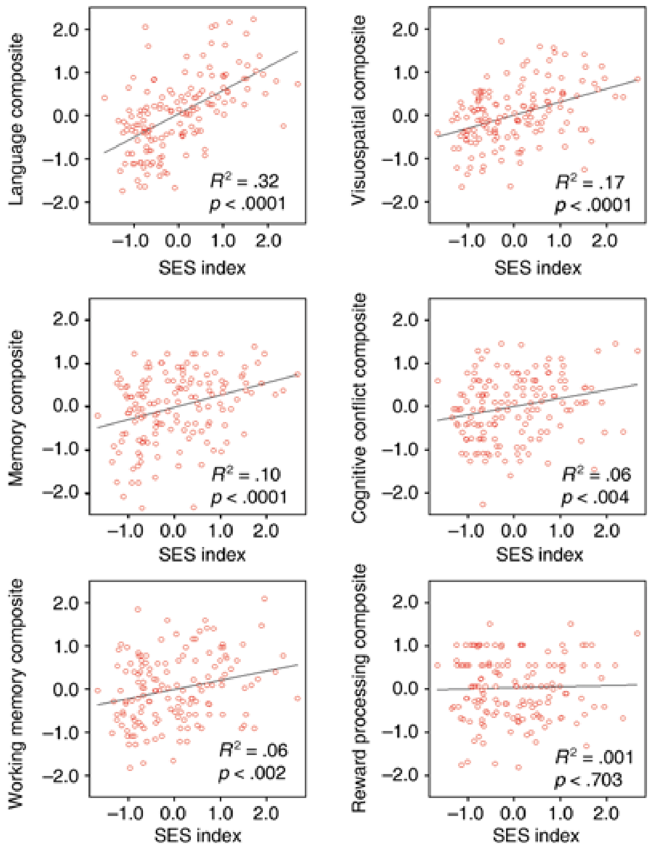

Figure 1 *SES accounts for variance in all neurocognitive composites except reward processing. SES accounts for statistically more variance in the language composite than in all other composites, which do not statistically differ from each other.*

our SES index used imputed income-to-needs ratios for the 20 subjects whose families declined to provide income data, we verified our results by re-running the above regression analyses using several other proxies for SES for which we had information from all families surveyed, including (1) maternal education, and (2) both parents' education and occupational status. Results in both cases were nearly identical to those found when using the SES index. For the language composite, maternal education accounted for 27.0% of the variance (Beta = .520; $p < .0001$). When both parental education and occupation were included in the language model, 30.6% of the variance was accounted for, and both education (Beta =.360; $p < .0001$) and occupation (Beta = .256; $p < .003$) accounted for unique variance. For the visuospatial composite, maternal education accounted for 15.0% of the variance (Beta = .387; $p < .0001$). Parental education and occupation together accounted for 15.7% of the variance in the model; education contributed unique variance (Beta = .263; $p < .007$), while occupation did not (Beta = .177; $p < .066$). In the memory composite, maternal education accounted for 5.7% of the variance (Beta = .238; $p < .004$). Together, parental education and occupation accounted for 9.9% of the variance; in this case, only occupation was significant (Beta = .240; $p < .016$), while education was not (Beta = .104; $p < .294$). For working memory, maternal education accounted for 4.7% of the variance (Beta = .216; $p < .009$). Parental education and occupation together accounted for 6.1% of the variance; education was significant (Beta = .225; $p < .029$) and occupation was not (Beta = .032; $p < .758$). Finally, in the cognitive control composite, 8.7% of the variance was accounted for by maternal education (Beta = .294; $p < .0001$). Parental education and occupation together accounted for 5.9% of the variance; once again, education was significant (Beta = .261; $p < .010$) while occupation was not (Beta = –.034; $p < .737$). As above, neither maternal education nor the combination of parental education and occupation accounted for variance in reward processing.

These results are generally consistent with our previous findings. As before, language shows the strongest association with SES. Also as before, executive functions are related to SES. The present results indicate that both working memory and cognitive control are associated with SES, whereas reward processing is not. This is also consistent with our previous findings, although the ages of the children and the tasks used to measure these abilities were different. In the study of middle schoolers, working memory and cognitive control were assessed with different tasks from those used here, but nevertheless showed significant SES disparities. That study also operationalized reward processing using different tasks and, in agreement with the present study, found no SES disparity. The executive function task most relevant to reward processing in the study of kindergarteners, a delayed gratification task requiring the children to choose between one sticker now and more stickers later, was also performed equivalently well by low and middle SES children.

The present study clarifies two ambiguous findings from previous research on SES and neurocognitive development. The first concerns spatial cognition. In both of the two previous studies, low and middle SES children differed in this ability, but in each case the difference failed to reach statistical significance. Our hope was that, with a larger sample size, we would disambiguate the relation between SES and spatial cognition, and indeed the present study found a clearly significant association. Recently, Levine, Vasilyeva, Lourenco, Newcombe and Huttenlocher (2005) also reported SES disparities in spatial cognition.

The second finding clarified by the present study concerns new learning and memory. In our previous study of kindergarteners, memory ability was equivalent across SES groups, but this may have been due to the short interval between exposure and test in that study. When memory was assessed in low and middle SES middle schoolers using a longer retention interval, it was found to differ substantially between groups. The results of this study confirm that, when tested after a sufficient interval, SES is associated with recognition memory performance.

So far we have examined the relation between SES and neurocognitive systems, rather than performance on specific tasks. By focusing on the neurocognitive system composite measures, which are based on pairs of tasks that differ from one another as much as possible, we can sample the functioning of each system somewhat more broadly. For example, the memory composite assesses both face memory and memory for verbally described pictures, and the language composite assesses both lexical-semantic and phonological aspects of language ability. Nevertheless, it is also of interest to measure the strength of association between SES and performance on individual tasks. Table 2 shows these results. Among tasks within systems that showed a significant statistical influence of SES, only the go/no-go and delayed non-match to sample tasks did not themselves demonstrate variance accounted for by SES. SES did not account for variance in either of the two reward tasks.

Although one might expect high correlations between the tasks within a system, our attempt to sample different aspects of each system nonredundantly would be expected to reduce intrasystem correlations. Table 3 shows that the two tasks in each of the language, visuospatial, memory, and working memory systems are correlated with each other, whereas the cognitive control and reward tasks were not. Further, several tasks correlate with members of different systems.

Table 2 *SES variance in individual tasks*

System	Task	R^2	p
Language	PPVT	.439	.0001
	CTOPP blends	.091	.0001
Visuospatial	Arrows (line orientation)	.182	.0001
	Hand rotation-accuracy	.084	.0001
	Hand rotation-reaction time	.000	.857
Declarative memory	Memory-faces	.074	.001
	Memory-picture pairs	.049	.007
Executive-working memory	Acorns (spatial working memory)	.081	.001
	Delayed non-match to sample	.012	.194
Executive-cognitive control	Go/no-go false alarms	.009	.274
	Auditory attention and response set	.157	.0001
Executive-reward	Reversal learning (reversal errors)	.009	.262
	Present wrapping	.003	.490

Note: SES accounts for variance in all tasks other than Go/no-go, Delayed non-match to sample, and the two reward system tasks.

To better assess the specificity of our *a priori* groupings of tasks, whose mean standardized scores were termed 'system composites', we conducted a post-hoc principal components analysis with varimax rotation on the subset of tasks that showed intra-system correlation (i.e. eight tasks in the language, visuospatial, memory and working memory composites). This allowed us to extract loading scores on four principal components, which we term 'factors'. Table 4 shows the results of this analysis. The two visuospatial skills loaded most strongly on factor 1 (which we will term the 'visuospatial factor') and the two language tasks loaded most strongly on factor two ('linguistic factor'). Factor 3 ('declarative memory factor') shows strong loadings from both the memory tasks, and factor 4 ('working memory factor') is nearly exclusively representative of the working memory tasks. Though the specificity is not perfect – factors 1 and 3 show some contamination from other tasks – it can nonetheless be seen that four of the six *a priori* systems show reasonable orthogonality. Further, the SES index shows a similar relationship to each post-hoc factor loading as described previously for the *a priori* system composites. Specifically, SES accounted for 20% of the variance of the linguistic principal component (Beta = .442; $p < .0001$). SES also accounted for a significant but substantially smaller portion of the variance for the visuospatial ($R^2 = .12$, Beta = .350, $p < .0001$) and declarative memory ($R^2 = .07$, Beta = .271, $p < .001$) principal components. Interestingly, SES did not significantly account for any unique variance in the working memory principal component.

Potential mediating factors

In a preliminary attempt to unpack the relationship between SES and the neurocognitive measures examined here, we statistically controlled for several potential SES-related health, cognitive and environmental influences. Such factors could represent the underlying mechanisms by which SES is associated with cognitive outcome. Although prospective experimental studies are necessary to test such hypotheses directly, the following analyses can put useful constraints on the likely mechanisms. Note that when a factor reduces or eliminates the association between SES and a particular cognitive ability, this does not imply that the factor is an alternative to SES; rather, the factor may be part of the complex construct of SES, for which the easily quantifiable measures of parental education, occupation and income serve as a proxy.

Physical and mental health

Because health factors vary systematically with SES (Klein, Hack & Breslau, 1989; Needleman, Schell, Bellinger, Leviton & Allred, 1990), and are likely to play a role in creating and sustaining the SES gap in cognitive performance and achievement (Bornstein & Bradley, 2003), we reanalyzed the data excluding the 17 children who had any significant medical or psychiatric history. The results were essentially unchanged. The SES index accounted for 33.7% of the variance in the language composite (Beta = .581; $p < .0001$); 15.5% of the variance in the visuospatial composite (Beta = .394; $p < .0001$); 9.2% of the variance in the memory composite (Beta = .303; $p < .0001$); 6.3% of the variance in the working memory composite (Beta = .251; $p < .004$); and 6.0% of the variance in the cognitive control composite (Beta = .245; $p < .004$). Again, SES did not significantly account for any variance in reward processing performance. It is notable that the variance accounted for by SES in the language, working memory, and cognitive control composites actually increased after excluding children with a significant medical or psychiatric history, suggesting that health factors are unlikely to be mediating the associations between SES and these systems.

Table 3 *Correlations between tasks*

System	Tasks	PPVT	CTOPP	Arrows	Hand rotation	Mem-faces	Mem-pictures	Acorns	DNMS	GNG	AARS	Present wrap	Reversal learning
Language	PPVT	–	**.423****	.485**	.185*	.326**	.306**	.347**	.014	.158	.538**	.028	–.181*
	CTOPP		–	.284**	.195*	.106	.054	.174*	–.058	.122	.428**	.046	–.176*
Visuo-spatial	Arrows			–	**.243****	.326**	.141	.374**	.043	.068	.396**	–.039	–.171*
	Hand rotation				–	.070	.097	.401**	.154	–.035	.327**	.199*	–1.44
Declarative memory	Memory-faces					–	**.192***	.165*	.140	.084	.200*	.238**	.002
	Memory-picture pairs						–	.139	–.009	.105	.117	–.093	–.044
Working memory	Acorns							–	**.274****	.015	.394**	.078	–.115
	Delayed non-match to sample								–	.098	.022	.028	–.147
Cognitive control	Go/no-go									–	.031	–.139	–.028
	Aud. attn. and response										–	.172*	–.147
Reward	Present wrapping											–	–.009

** $p < .01$.
* $p < .05$.

We found similar results when applying the same exclusionary criteria and regressions to the post-hoc factors, as well. The SES index accounted for 22% of the variance in the linguistic factor (Beta = .464; $p < .0001$), 10% of the visuospatial factor (Beta = .316; $p < .0001$) and 6.8% of the variance in the declarative memory factor (Beta = .260; $p < .004$). Once again, SES did not account for unique variance in the working memory factor. Together, these results suggest that physical and mental health factors do not play a large role in mediating the associations found between SES and certain cognitive skills in our sample.

Language

Although all children were native English speakers, a large number had at least some exposure to a second language in the home. We therefore examined what effect, if any, this may have on the development of cognitive abilities. Second language exposure itself did not account for variance in any system. Furthermore, after controlling for second language exposure, the associations with SES were quite similar to those reported above. Specifically, when the SES index is added to the model, 33.3% of the variance in the language composite is explained (Beta = .589; $p < .0001$), as well as 16.9% of the variance in the visuospatial composite (Beta = .418; $p < .0001$); 10.2% of the variance in the memory composite (Beta = .319; $p < .0001$); 6.7% of the variance in the working memory composite (Beta = .235; $p < .005$); and 5.9% of the variance in the cognitive control composite (Beta = .249; $p < .003$). Again, SES did not significantly account for any of the variance in reward processing. Thus, the presence or absence of second language exposure does not appear to be mediating the associations between SES and cognitive abilities.

When controlling for second language exposure in the post-hoc principal components, results were again quite similar to those reported earlier. After accounting for second language exposure, the SES index explained 21% of the variance in the linguistic factor (Beta = .467; $p < .0001$); 12% of the variance in the visuospatial factor (Beta = .349; $p < .0001$); and 7% of the variance in the declarative memory factor (Beta = .293; $p < .001$). Again, SES did not account for unique variance in the working memory factor. Together, these results suggest that the presence or absence of second language exposure does not appear to be mediating the associations between SES and the neurocognitive abilities examined here.

Previously, we reported that language abilities statistically mediated the association between SES and executive function (Noble *et al.*, 2005). In the present study, the language composite accounts for 10.6% of the variance

Table 4 *Principal components analysis of tasks*

	Task	Factor 1 (Visuospatial)	Factor 2 (Language)	Factor 3 (Memory)	Factor 4 (Working memory)
Language tasks	PPVT	.250	**.700**	.427	.039
	CTOPP-blends	.125	**.890**	−.086	−.026
Visuospatial tasks	Hand rotation	**.739**	.199	−.186	.022
	Arrows (line orientation)	**.668**	.270	.185	−.050
Declarative memory tasks	Memory-faces	.621	−.108	**.332**	.009
	Memory-picture pairs	.046	.077	**.889**	−.001
Executive-working memory tasks	Acorns (spatial w.m.)	.693	.151	.003	**.318**
	Delayed non-match to sample	.092	−.020	.004	**.973**

in the cognitive control composite ($p < .0001$). Similar to the results of the previous study, the SES index does not account for any unique variance in cognitive control after controlling for language ability (R^2 change = .004; $p < .436$), although language ability retains significance (Beta = .284; $p < .003$). To explore this phenomenon further, the effects of the semantic and phonological subcomponents of the language composite were examined separately. Table 2 shows that the SES index is much more strongly correlated with the PPVT (semantic processing) than with the CTOPP (phonological processing). Interestingly, however, both tasks are individually nearly identically correlated with the cognitive control composite (PPVT $R^2 = .079$; $p < .001$, and CTOPP $R^2 = .074$; $p < .001$). This represents non-overlapping variance when both tasks are entered into the model together. (PPVT Beta = .201; $p < .021$ and CTOPP Beta = .189; $p < .030$). The question is then raised as to whether one or both tasks are primarily accounting for the SES effect on cognitive control. When controlling for CTOPP performance, the SES index continues to account for some residual variance in cognitive control (R^2 change = .026; $p < .043$). On the other hand, when controlling for PPVT performance, SES no longer accounts for variance in the cognitive control composite (R^2 change = .007; $p < .281$). Further, when the two language tasks and the SES index are entered in the model together, only the CTOPP displays unique variance (Beta = .187; $p < .032$). Thus, though both semantic and phonological processing are correlated with cognitive control performance, it is semantic processing that mediates the majority of the association between SES and cognitive control.

Although the language composite score also accounts for some variance in performance in visuospatial skills ($R^2 = .225$; $p < .0001$), memory ($R^2 = .095$; $p < .0001$), and working memory ($R^2 = .039$; $p < .017$), the SES index accounts for unique variance in these systems after controlling for language ability (for visuospatial, memory, and working memory systems respectively, R^2 change = .044; $p < .003$; R^2 change = .031; $p < .024$; and R^2 change = .028; $p < .042$). Language skills significantly account for a portion of the variance in reward processing (R^2 = .033; $p < .016$); however, SES continues not to account for variance in this skill.

Of course, principal components are by definition orthogonal to one another, and so the linguistic factor is, in effect, already covaried from the other factors. However, when entering the language composite score into the regressions, we find that the SES index still accounts for variance in the visuospatial (R^2 change = .06; $p < .003$) and memory (R^2 change = .04; $p < .022$) factors, but not the working memory factor.

Home and school environment

A great deal of work has examined how home and school effects mediate socioeconomic differences in academic achievement. In order to begin investigating the relationship between these mediating factors and specific neurocognitive systems, participants' parents were asked a number of questions about the home environment, including the frequency of literacy-related activities (parental reading of newspapers and books, reading with the child, and practicing writing letters or words with the child), and frequency of physical punishment. Responses were subjected to principal components analysis with Varimax rotation. Two factors with Eigenvalues greater than 1 were extracted, together accounting for 57.3% of the variance of the initial variables. The first loaded predominantly on the factors related to the home literacy environment, and the second loaded heavily on reported frequency of physical punishment.

In addition, a number of variables pertaining to the quality of children's early education were examined. Based on information made publicly available by the New York City Department of Education, the average attendance, average dollar allotment per student, and percent of students meeting New York State and City English Language Arts standards was collected for each school from which participants were recruited. We also calculated the number of hours per week each child spent in preschool or daycare prior to kindergarten, as reported by parents.

We then entered each of these early education variables into a principal components analysis with Varimax rotation, which revealed two factors with Eigenvalues greater than one, together accounting for 84.3% of the total variance. One factor loaded heavily on all school environment factors, while the other loaded heavily on time spent in daycare or preschool.

Because we did not have *a priori* hypotheses about which home or school environment variables would account for variance in different cognitive systems, we entered all four factor loadings into a single regression step, followed by the SES index, for each system composite. The final step of each regression, presented in Table 5, indicates that in many cases, these variables significantly reduced or eliminated the unique variance accounted for in cognitive performance by the SES index.

In the first step of the language composite regression, home and school environment variables together account for 24% of the variance in performance ($p < .0001$). In this step, elementary school environment accounts for a unique portion of the variance in language skills (Beta = .432; $p < .0001$). As seen in Table 5, after adding the SES index in the second step, 34.7% total variance is accounted for, such that the SES index accounts for an additional 10.7% unique variance ($p < .0001$). That is, home and school variables together account for over 20% of the variance in language performance previously accounted for by the SES index. Both elementary school environment and the SES index account for unique variance, suggesting that school environment partially mediates the association between SES and language abilities, and that school environment accounts for some residual portion of language performance even after controlling for SES.

Table 5 *Final regression steps: home and school environment and SES*

System	Model	R^2	Beta	p
Language composite	Home – lit,	.347	–.083	.243
	Home – punish,		–.019	.785
	School – elem.,		.219	**.009**
	School – day/pre,		.034	.634
	SES		.410	**.0001**
Visuospatial composite	Home – lit,	.230	–.037	.631
	Home – punish,		.034	.653
	School – elem.,		.203	**.026**
	School – day/pre,		.065	.408
	SES		.310	**.001**
Declarative memory composite	Home – lit,	.113	.081	.331
	Home – punish,		–.050	.535
	School – elem.,		.087	.371
	School – day/pre,		.085	.311
	SES		.261	**.011**
Working memory composite	Home – lit,	.128	–.162	.055
	Home – punish,		–.112	.179
	School – elem.,		.133	.176
	School – day/pre,		.163	.055
	SES		.107	.291
Cognitive control composite	Home – lit,	.076	–.083	.326
	Home – punish,		.105	.204
	School – elem.,		–.030	.760
	School – day/pre,		–.037	.670
	SES		.238	**.022**
Reward processing	Home – lit,	.017	.122	.163
	Home – punish,		–.014	.871
	School – elem.,		.021	.834
	School – day/pre,		.043	.629
	SES		.038	.719

Note: Environmental factors mediate some variance accounted for by SES in language, visuospatial skills, memory and working memory. See text for definitions of variables.

Similar results are found when examining the post-hoc linguistic factor. In this case, home and school variables together account for 16.4% of the variance in the factor loading score ($p < .0001$), while the SES index accounts for an additional 5.7% of the variance ($p < .003$). Thus, home and school environment appear to largely mediate the association between SES and performance on tasks relying on linguistic skill.

A similar pattern emerges when visuospatial skills are examined. In the first step of the regression, home and school environment variables together account for 16.9% of the variance in the visuospatial composite ($p < .0001$), with time spent in daycare or preschool accounting for unique variance (Beta = .133; $p < .0001$). When the SES index is added in the next step, 23% total variance is accounted for, such that the SES index accounts for 6.1% unique variance ($p < .001$) – a marked reduction from the 17% of variance originally accounted for by the SES index alone. This reduction is largely statistically mediated by time spent in daycare or preschool, and Table 5 shows that this variable does not account for unique variance once the SES index is controlled in the second step. Similarly, the principal components analysis reveals that home and school variables account for 10.7% of the variance in the visuospatial factor ($p < .006$), with the SES index contributing an additional 3.8% ($p < .019$).

In the memory composite, home and school variables account for 7% of the variance in performance ($p < .04$), with elementary school environment accounting for unique variance (Beta = .223; $p < .008$). In the second step, the SES index accounts for an additional 4.3% of variance in memory skill ($p < .011$). Elementary school environment is thus partially mediating the association with SES, although when all variables are entered in the second step, only the SES index explains unique residual variance. Home and school variables do not significantly account for any variance in the memory factor, and when these variables are controlled the SES index continues to account for 6.4% unique variance ($p < .004$).

Finally, some interesting dissociations can be observed among the three executive measures. First, home and school variables together account for 12.1% of the variance in the working memory composite ($p < .002$). Home literacy environment (Beta = –.179; $p < .03$), school environment (Beta = .190; $p < .022$), and time in daycare/preschool (Beta = .186; $p < .024$) each account for unique variance. Table 5 shows that, in the second step, the SES index no longer statistically accounts for variance in this composite. Further, no variables account for unique variance in the second step, suggesting that home and school environment variables entirely mediate the association between SES and working memory abilities. As stated above, SES does not account for variance in the post-hoc working memory factor.

In contrast to working memory, none of the home or school environment variables significantly accounts for variance in the cognitive control composite. In the second step, the SES index continues to account for approximately the same variance as originally reported (R^2 change = 3.6%; $p < .022$). Finally, neither the home and school environment variables nor the more global SES index statistically account for unique variance in the reward composite.

Discussion

Socioeconomic background has long been associated with large differences in cognitive achievement. We asked which specific neurocognitive systems underlie this association, and found that language, spatial cognition, memory, and some but not all executive abilities vary continuously with SES in our sample of first-grade children.

SES and neurocognitive performance

SES accounted for over 30% of the variance in performance in language tasks, with a statistically smaller portion of the variance accounted for in other systems. One possible explanation of the strong association between SES and language is that the perisylvian brain regions involved in language processing have been shown to undergo a more protracted course of maturation *in vivo* than any other neural region (Sowell *et al.*, 2003). It is thus possible that a longer period of development leaves the language system more susceptible to the myriad environmental influences that covary with SES (though it should be noted that some postmortem studies have implicated other regions of protracted development, including prefrontal regions; e.g. Huttenlocher, 1997). Alternatively, different systems may be differentially reliant on the types of enculturation processes that differ across SES; variation in language exposure relating to cognitive development may be particularly tied to differences in SES (Whitehurst, 1997; Hart & Risley, 1995). Notably, SES was more strongly associated with the measure of receptive vocabulary than with the measure of phonological processing. It is possible that this is related to differences in the amount of cultural knowledge necessary to perform the two tests. Future work could further explore this by including additional measures of the semantic and phonological subsystems for a finer-grained analysis. In addition, other areas of language development, such as syntax, might be explored as well.

A post-hoc principal components analysis of a subset of the composites revealed four orthogonal factors among our tasks, comprising linguistic skills, visuospatial skills, declarative memory, and working memory. SES once again accounted for unique variance in the linguistic factor, and to a lesser extent, in the visuospatial and declarative memory factors, providing additional evidence that linguistic processes are particularly susceptible to SES differences.

Mediating factors

Characterizing the associations between SES and different neurocognitive systems is not an end in itself, but rather an intermediate step toward longer range goals including a more mechanistic understanding of the relation between SES and neurocognitive development. A preliminary extension of the present study in this direction involved the examination of various SES-related factors as possible mediators for SES-cognition associations. Our analyses suggested that none of the associations between SES and cognitive performance were mediated by the physical health factors we tested or by exposure to a second language. In contrast, several other linguistic and environmental factors did statistically mediate such effects. Previously we reported that language ability statistically mediated the association between SES and executive function (Noble *et al.*, 2005). Here, controlling for language ability eliminated the association between SES and cognitive control, and reduced the association between SES and all other systems. Thus, language ability may mediate the association between SES and cognitive control, and may partially mediate the association between SES and visuospatial skills, memory, and working memory. On further probing, it was found that the SES association with cognitive control was largely accounted for by semantic as opposed to phonological abilities. Future neuroimaging studies could explore this further to understand the mechanism underlying this association.

Several home and school environment variables also statistically mediated associations between SES and cognitive performance. In particular, school environment accounted for variance in language, memory, and working memory performance. In addition, attendance in daycare or preschool accounted for variance in visuospatial skills. Finally, home literacy environment accounted for additional variance in working memory performance. It should be noted that a portion of the school environment loading score consisted of a report on the percentage of children who passed city- or state-wide Language Arts tests. Thus, strictly speaking, we do not have evidence that school quality *per se* influences individual differences in cognitive development. We could argue, however, that a school's success and ability to provide resources is associated with individual differences in language, memory and working memory.

After controlling for all home and school environment factors, the association between SES and working memory was eliminated, whereas the respective associations between SES and language and visuospatial skills were markedly reduced. In contrast, these factors did not account for variance in cognitive control or in reward processing.

Dissociation of executive functions

Previously, we found that SES differences were associated with differences in several measures of executive function. Consistent with our earlier work, we found that SES accounts for significant and statistically indistinguishable amounts of variance in the working memory and cognitive control composites, whereas no association was found between SES and reward processing. However, although SES is associated with both cognitive control and working memory, the factors that statistically mediate these associations are quite different. Working memory skill was statistically mediated by a variety of home and school variables, including home literacy environment, daycare/preschool attendance, and elementary school quality. This suggests the possibility that targeting these factors may lead to an improvement in the ability to store and manipulate 'online' information, though again, a prospective study is necessary to make formal claims about causation. In contrast to working memory, language abilities (particularly receptive vocabulary) accounted for the association between SES and cognitive control, in line with our previous report (Noble *et al.*, 2005). This suggests the possibility of a causal pathway in which differences in SES influence language development (Whitehurst, 1997; Hart & Risley, 1995), which then independently drives cognitive control. This too could be tested by a prospective, experimentally designed intervention study. Interestingly, SES did not account for any variance in reward processing. This finding is in line with previous work that did not find SES differences in the ability to delay gratification (Noble *et al.*, 2005), delay response, or reverse stimulus–reward associations (Farah *et al.*, 2006). These dissociations, observed across studies, indicate the complexity of the interplay between SES and neurocognitive development and the feasibility, nevertheless, of generalizing about the process.

Potential implications for intervention, caveats and conclusions

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). Although critics often conclude that the benefits of early intervention wane shortly after termination of the program (e.g. Haskins, 1989), other studies have shown sustained (Brooks-Gunn, McCarton, Casey, McCormick, Bauer, Bernbaum, Tyson, Swanson, Bennett, Scott, Tonascia & Meinert, 1994) and cost-effective (Barnett, 1998) effects.

An as-yet untested approach to maximizing the efficacy of interventions is to focus programs on those neurocognitive abilities that vary most steeply with SES. In addition, neurocognitive analysis may reveal different SES-related factors playing different mediating roles across neurocognitive systems. By examining which underlying factors are associated with which cognitive abilities, we can design and test interventions with increased efficacy.

This study made a preliminary attempt at disentangling the experiential factors that may mediate SES differences in neurocognitive performance. Several factors limit its conclusiveness, however. First, we relied heavily on retrospective parental report. Parents may not accurately remember, or may feel pressured to answer a certain way, biasing results. Second, more detailed information about childhood experience is needed. For instance, not only the amount but also the type of shared literacy activities have been shown to be important in skill development (Evans, 2000; Raz & Bryant, 1990).

Third, our data were correlational. Experimental designs are ultimately necessary to systematically test predictions about the effects of various factors that may mediate neurocognitive development. Finally, our data were behavioral, and inferences regarding brain function were indirect. Without imaging the subjects as they are performing the tasks, it is impossible to infer from behavior alone whether tasks within a composite are truly involving the same system. Such ambiguities are partially resolved by choosing task types for which both the lesion and neuroimaging literatures have demonstrated a good degree of neural specificity. Additionally, post-hoc analyses showed reasonable correlations between tasks within four of the composites, and orthogonal principal components behaved much like their counterparts in the simple composite structure. Importantly, however, behavioral correlation alone is not necessarily the best predictor of neural specificity, as it is possible for two tasks to use different systems but to be highly correlated (i.e. if system A drives system B); alternatively, it is possible for two tasks to engage the same system in different ways, such that behavioral correlation of performance between tasks is actually quite low. Ultimately, hypotheses regarding neural function must be investigated by incorporating assessments of SES into functional neuroimaging studies using pediatric populations.

Finally, an assumption was made that the neural systems engaged during certain cognitive tasks are consistent across SES. In fact, the cognitive neuroscience literature is largely based on studies of subjects of average to high socioeconomic background. A rigorous examination of the degree to which SES plays into the relationships between cognitive processing and neural function is therefore necessary. It is possible or even likely that differences in cognitive performance and/or associated brain activity are influenced by cultural and educational factors like familiarity, knowledge, practice, and test-taking skills that vary with SES.

In sum, SES accounts for individual differences in performance on a variety of tasks that were designed to tap particular neurocognitive systems, with a particularly strong association with language abilities. These associations are statistically mediated by different cognitive, home and school factors. By more precisely understanding the associations between SES and cognitive achievement, we may ultimately develop more specific interventions, with educational strategies targeted at cognitive outcomes and social strategies targeted at underlying mediating factors.

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