

Socioeconomic Influences on Brain Development: A Preliminary Study

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The emergence of cognitive neuroscience in the final decades of the 20th century resulted from a number of technical and conceptual breakthroughs, and Michael Posner was behind many of them. From his fundamental contributions to the information processing framework in cognitive psychology to his pioneering uses of reaction time methods with neurological patients and his revolutionary adaptation of functional neuroimaging for the study of human cognition, he helped make cognitive neuroscience what it is today.

But that was all last century. In recent years, Posner has embarked on a new scientific quest, to understand individuality and development. Whereas cognitive neuroscience has made considerable progress toward understanding neurocognitive function in the typical adult brain, much less is known about the ways in which normal, healthy individuals differ or about the genetic and environmental factors that lead to these differences. Posner is at work again, this time with babies and school children, linking genes, behavior, and brain activity, and inspiring his colleagues to follow.

This chapter focuses on the relation between one aspect of children's life experiences and the resulting pattern of their individual cognitive strengths and weaknesses. That aspect of life experience is referred to as socioeconomic status. A child's socioeconomic status is generally estimated by measuring parental education and occupational status along with family income. It is a far more complex construct than the composite of these straightforward measures, however, with associated differences in health status, child-rearing practices, family structure (particularly the number of parents in home), and neighborhood characteristics, to name but a few correlated factors. Not surprisingly,

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given these factors, socioeconomic status has an effect on children's neurocognitive development.

Socioeconomic Status and Cognitive Development

Although the existence of socioeconomic status effects on development is not surprising, the magnitude of these effects is. For example, in one cohort of low-socioeconomic-status children, screened for a host of prenatal and neonatal complications including gestational cocaine exposure, and judged to be in good physical health in semiannual assessments, the average IQ at age 4 was 81 (Hurt et al., 1998). Beginning as early as preschool, and persisting throughout childhood and beyond, individuals of low socioeconomic status perform below their higher socioeconomic status counterparts on a variety of psychometric tests, including IQ and school achievement test scores (e.g., Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; McLoyd, 1998). Indeed, socioeconomic status has stronger associations with cognitive performance than with other seemingly more concrete outcomes, such as health and behavior (Duncan, Yeung, Brooks-Gunn, & Smith, 1998). As already noted, these effects are quite large. Furthermore, there is no single cause that fully accounts for the socioeconomic status gap in cognitive performance. In one study, for example, low- and middle-income 5-year-olds, matched on birth weight, gender, ethnicity, mother's education, and number of adults in the home, had IQs that differed by an average of 9 points, or over half a standard deviation (Duncan, Brooks-Gunn, & Kiebanov, 1994). In general, the effect of lowering income by one standard deviation, holding constant the other family and child variables, lowers performance on intelligence and school achievement tests by a third of a standard deviation (Brooks-Gunn, Duncan, & Britto, 1999). Of course, if one is interested in understanding how childhood poverty affects cognitive development, one ought not exclude these family and child variables as they are, in reality, a component of socioeconomic status.

The developmental gap between children of low and middle socioeconomic status has been studied within the disciplinary frameworks of sociology (e.g., Mercy & Steelman, 1982), psychology (e.g., Bradley & Corwyn, 2002), and behavior genetics (e.g., Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003). The goal of this chapter is to analyze the problem in terms of the framework of cognitive neuroscience. The empirical work reported here is more fully described in an article by Noble, Norman, and Farah (in press).

Socioeconomic Status and the Developing Brain: What Is Affected?

Intelligence tests and school achievement are relatively broad-band measures that could reflect either selective socioeconomic status effects on specific neurocognitive systems or global effects on brain development. Our initial goal was to characterize the effects of childhood poverty in terms of the specific neurocognitive systems affected. To characterize the effect of low versus middle socioeco-

conomic status on children's neurocognitive development in greater detail, and in terms that can be related to current cognitive neuroscience conceptions of mind and brain, we used a battery of behavioral tests to assess the neurocognitive profile of two groups of kindergarteners, differing in socioeconomic status.

One hypothesis is that socioeconomic status affects all neurocognitive systems equally, across the board. Alternative hypotheses are that socioeconomic status affects certain systems more than others. There is already reason to believe that the development of the left perisylvian language system is influenced by socioeconomic status, as a number of relatively pure tests of language development have revealed a robust socioeconomic status gap (Whitehurst, 1997). What other systems undergo prolonged postnatal development and would they also show specific sensitivity to socioeconomic status? Prefrontal cortex is a brain region that continues to mature throughout childhood, with pronounced cellular changes in the preschool and early childhood years (Johnson, 1997). It is also a region on which many of the cognitive achievements of early childhood depend (Case, 1992; Diamond, 1990; Diamond, Prevor, & Callender, & Druin, 1997); Johnson, 1997; Posner & Rothbart, 1998). A disproportionate effect of socioeconomic status on prefrontal function is therefore a hypothesis of particular interest.

Participants

Sixty children were recruited from Philadelphia schools, 30 of whom met criteria for middle socioeconomic status and 30 of whom met criteria for low socioeconomic status. Specifically, the middle group was limited to children whose families had income-to-needs ratios (total family income divided by the official poverty threshold for a family of that size) greater than 1.5. In addition, at least one adult in the household was required to have at least 2 years of college education, and the occupation of at least one adult was required to fall into Hollingshead occupational status categories (Hollingshead, 1975) corresponding 1 to 4, ranging from higher executives to technical or clerical occupations. The low-socioeconomic-status group was limited to children whose family income-to-needs ratio was less than 1.2, with no college-educated adults in the household and occupations rated from 4 to 7, in other words from technical or clerical occupations to unskilled. Exclusionary criteria for all children included low birth weight (<1500 grams); maternal alcohol or drug use reported during pregnancy; history of head injury, attention-deficit/hyperactivity disorder (ADHD), learning disability, developmental delay, or other neurological or psychiatric problems. Twenty-six low-socioeconomic-status and 24 middle-socioeconomic-status parents provided consent to contact their pediatrician's office; of pediatricians who were contacted, we received responses from 90% from the consenting middle sample and 49% from the consenting low 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). Key predictions were also tested with the data from the subset of children with pediatrician-verified medical histories, as reported below. All participating children in both groups were Black native English speakers. Table 10.1 shows the demographics of the two samples.

Table 10.1. Demographics of Low- and Middle-Socioeconomic-Status Samples

	Low socioeconomic status	Middle socioeconomic status
Mean age	5 years, 10 months	5 years, 10 months
Gender	17 male, 13 female	13 male, 17 female
Mean birth weight	111 oz.; 3 known NICU stays	111 oz.; 2 known NICU stays
Race	Black	Black
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

Note. NICU = neonatal intensive care unit.

Neurocognitive Systems and Tasks Used to Assess Them

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.

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 to 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 research participants.

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 nonverbal cognitive abilities.

SHAPE DETECTION TASK. The Shape Detection Task 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 participants 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. The Color Imagery Task is a visualization task that 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, and plays a role in mathematics and technical subjects as well as artistic endeavors.

LINE ORIENTATION TASK. The Line Orientation Task is a modified version of the classic clinical neuropsychology test (Benton, Varney, & des Hamsher, 1978) in which a participant 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. Because 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 participant 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, 1978).

MENTAL ROTATION TASK. In the Mental Rotation 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 0, 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 functional magnetic resonance imaging (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. The critical feature of incidental learning paradigms is that the participant does not know that memory will be tested during presentation of the to-be-remembered stimuli.

INCIDENTAL PICTURE LEARNING TASK. In the Incidental Picture Learning 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 were the first set of named pictures, and the other half were novel pictures; the child is asked which pictures were seen before. Patients with medial temporal damage are impaired at recognizing stimuli presented in incidental learning tasks (Mayes, Meudell, & Neary, 1978); functional neuroimaging studies support this localization (Squire, 1992).

INCIDENTAL FACE LEARNING TASK. The Incidental Face Learning 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, 2002).

Left Perisylvian-Language System

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

PEABODY PICTURE VOCABULARY TEST. Peabody Picture Vocabulary Test (PPVT) is a 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 et al., 1998).

TEST OF PHONOLOGICAL AWARENESS-KINDERGARTEN, SUBTESTS 1 AND 2. The Test of Phonological Awareness (TOPA) is a standardized test that assesses phonological awareness, a crucial predictor of reading ability. Subtests 1 and 2 consist of 10 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 (Pugh et al., 1996).

TEST OF RECEPTION OF GRAMMAR. The Test of Reception of Grammar (TROG) 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, 1994; Diamond, 1990), structural imaging (Giedd et al., 1999; Klingberg et al., 1999), functional imaging (Casey et al., 2000; Chugani, Phelps, & Mazziotta, 1987) and human autopsy (Huttenlocher & Dabholkar, 1997) suggests that prefrontal cortex continues to undergo extensive development, including synaptogenesis (Huttenlocher & Dabholkar, 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 et al., 2000; 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 noncontinuous measures not suitable for incorporating into a continuous composite measure.

GO-NO-GO TASK. In the go-no-go task, children are told that they will see pictures of different animals on the computer screen, and that they should press the space bar every time they see an animal, but never when they see the cat. 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 prefrontal cortex (PFC) in both lesion studies (Drewe, 1975) and pediatric and adult fMRI (Casey et al., 1997).

SPATIAL WORKING MEMORY TASK. The Spatial Working Memory 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 he or 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 (Pigott & Milner, 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 errors at any given level of performance is indicative of prefrontal executive function, with a preponderance of false alarms consistent with dysfunction (Parkin, Bindschaedler, Harsent, & Metzler, 1996; Schacter, Curran, Galluccio, Milberg, & Bates, 1996).

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 noncontinuous nature of their dependent measures.

DIMENSIONAL CHANGE CARD SORT TASK. In the Dimensional Change Card Sort 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 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 participants in fMRI (Konishi et al., 1999).

THEORY OF MIND. The theory of mind 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 and colleagues (Frye, Zelazo, & Palfai, 1995). The understanding of appearance as opposed to reality (Flavell, Green, & Flavell, 1990) was tested using the following task: a band-aid box containing crayons is shown 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 for delay of gratification, after the first task, the child is shown a variety of stickers. 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 (Newman, Gorenstein, & Kelsey, 1983) with lesions to the orbital PFC and is noted clinically in patients with prefrontal damage (Stuss & Benson, 1984).

Result

Means and standard deviations of the scores for each task and each socioeconomic status group are shown in Table 10.2, 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.

The composite scores from the five neurocognitive systems were submitted to repeated measures MANOVA with factors socioeconomic status and gender. This showed a main effect for socioeconomic status, $F(1, 57) = 13.6, p < 0.0005$, replicating the well-documented socioeconomic status gap in global measures of cognitive performance. There was no main effect of gender, $F(1, 57) = 1.7, p = 0.19$, nor did gender interact with neurocognitive system, $F(4, 54) = 1.12, p = 0.35$.

The question of whether socioeconomic status equally predicts the variance in performance of all neurocognitive systems or else disproportionately explains the variance in certain systems was answered by testing the socioeconomic status by neurocognitive system interaction. This interaction was significant, $F(4, 54) = 2.77, p < 0.036$.

Five independent *t* tests were then carried out on the composite scores for each system, comparing the performance of low and middle-socioeconomic-status children. To correct for the effect of multiple tests on the likelihood of a type I error, a significance cutoff of $p < 0.01$ was adopted. The two neurocognitive systems for which differences were predicted showed highly significant effects of socioeconomic status. For the left perisylvian-language system, $t(58) = -4.3$,

Table 10.2. Raw Scores, Effect Sizes, *t* and *p* Values for Tasks, and Composite Measures

Task	Mean (<i>SD</i>) low socioeconomic status / Mean (<i>SD</i>) middle-socioeconomic status	Effect size	<i>t</i>	<i>p</i>
Left perisylvian-language		1.10	-4.3	<0.0001
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
Prefrontal-executive		0.68	-2.8	0.007
Go-no-go correct no-gos (10)	7.4 (1.8) / 8.2 (1.2)	0.56	-2.2	0.03
Spatial-working memory	# correct trials (15): 11.1 (2.5)/11.1 (2.8) # trials till 1st error: 4.9 (1.5)/ 6.3 (1.6)	0.31	-1.2	0.23
False alarms	Shape detection: 0.3 (0.6) / 0.2 (0.4) Picture memory: 1.7 (2.1) / 0.9 (0.9) Face memory: 2.9 (4.5) / 1.2 (2.1)	0.58	-3.0	0.004
Occipitotemp-visual		0.48	-1.8	0.08
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
Parietal-spatial		0.48	-1.9	0.07
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
Medial temporal-memory		0.04	-0.16	0.87
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. Significant differences were observed on language and executive composites, but not visual, visuospatial, or memory composites. PPVT = Peabody Picture Vocabulary Test; TOPA = Test of Phonological Awareness; TROG = Test of Reception of Grammar.

$p < 0.0001$. For the prefrontal-executive system, $t(58) = -2.8$, $p < 0.007$. In contrast, there were nonsignificant trends in the occipitotemporal-visual cognition system and the parietal-spatial system composites, $t(58) = -1.8$, $p < 0.08$ and $t(58) = -1.9$, $p < 0.07$, respectively, and no difference in the medial temporal-memory composite, $t(58) = -0.16$, $p < 0.87$. The same pattern held among the subset of children for whom a pediatrician verified the parent-reported medical history: large differences were observed across socioeconomic

status in performance of tasks comprising the language ($t(28) = -3.4$; $p < 0.002$) and executive ($t(28) = -3.2$; $p < 0.003$) composites, whereas no differences were seen in the visual ($t(28) = -1.7$; $p < 0.11$), visuospatial ($t(28) = -1.1$; $p < 0.32$) or memory ($t(28) = -1.6$; $p < 0.13$) composites. The lack of socioeconomic status effect on memory performance cannot be attributed to a ceiling effect. However, the retention interval was brief, in that the test was administered immediately following the learning phase, and it would be of interest to assess incidental retention over a longer duration.

The size, as well as the significance level, of socioeconomic status effects on the different neurocognitive system composites suggest disproportionate effects on language and executive function: As shown in Table 10.2, the effect size for the left perisylvian–language system was 1.1 standard deviations between the means of the groups and 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 (nonsignificant) effects of socioeconomic status on 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 effect on the language and executive systems is manifest at the individual task level, rather than emerging artifactually from a more thorough sampling of those systems. Table 10.2 summarizes the inferential statistics on socioeconomic status differences for the 13 individual tasks with continuous measures. Of the posterior brain systems, one of the occipitotemporal–visual cognition tasks showed a significant socioeconomic status 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 socioeconomic status effect can be interpreted as depressed performance for the low-socioeconomic-status children rather than enhanced performance for the middle-socioeconomic-status 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 dysfunction in children with early treated phenylketonuria (Diamond, 1990).

Turning next to the noncontinuous measures of prefrontal–executive function, we continue to find trends suggestive of a socioeconomic-status disparity in two of the three tasks. In the dimensional change card sort task, the majority of children scored either five or zero correct on each trial (i.e., either all correct or all incorrect), requiring ordinal regression analysis. In the first rule change block there was a nonsignificant trend for better performance by the middle-socioeconomic-status children (22 of 30 vs. 15 of 30 children with errorless blocks, for middle and low socioeconomic status respectively; pseudo R -squared = 0.051; $p < 0.075$). In the second rule change block, performed only by children who made errors in the first, three of eight middle-socioeconomic-

status children and four of 15 low-socioeconomic-status 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 near-significant (pseudo R -squared = 0.06; $p < 0.054$).

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 socioeconomic status overall. However, for false belief alone, ordinal regression analysis showed a borderline difference, such that middle-socioeconomic-status children were more likely to perform more accurately (pseudo R squared = .059; $p < 0.056$).

In contrast to most of the other prefrontal-executive tasks, the delay of gratification task showed no socioeconomic status effect at all. The two groups were equally inclined to delay their sticker reward to get more stickers (mean delay choices 22.6 for both low and middle-socioeconomic-status children), and this was true even for the most tempting delay problem, of one sticker now or just two later (18 vs. 20 children, out of 30, choosing to delay gratification for low and middle socioeconomic status, respectively, Chi-square = 0.287, $p < 0.59$). Note that this null result, which cannot be attributed to floor or ceiling effects, conflicts with the reported finding of a socioeconomic status difference in this characteristic in adults (Goodman, 1992). Although null results are always ambiguous, this is consistent with the preference for smaller immediate rewards in low socioeconomic status adults emerging as a pragmatic adaptation to the contingencies of their adult lives rather than as a result of childhood socioeconomic status influences on the maturation of prefrontal cortex.

Taken together, the results from the individual continuous and noncontinuous measures generally affirm the conclusions drawn from the composite measures, namely that socioeconomic status differences may be apparent in multiple systems, but that socioeconomic status differences are most pronounced in the functioning of the left perisylvian-language and prefrontal-executive systems. Whether or not socioeconomic status effects might be found in memory tasks with longer delays, and whether or not the trends toward socioeconomic status effects in parietal-spatial and temporo-occipital vision would remain and attain significance in a larger sample are open questions.

An important limitation of behavioral tests as assays for specific neurocognitive systems is that they always engage multiple systems, most commonly language and prefrontal-executive function regardless of the system of interest. Thus, it is possible that the socioeconomic status differences in nonlinguistic and nonexecutive tasks, such as the color imagery task that showed a significant difference between groups in the present study, result from the linguistic and executive demands implicit in the task. It is also possible that socioeconomic status influences many neurocognitive systems. Although the present data do not allow us to conclude that socioeconomic status effects are confined to particular neurocognitive systems, they do demonstrate that socioeconomic status effects are significantly disproportionate for those systems as tested here.

Socioeconomic Status and Neurocognitive Development: From Correlation to Causality

The research just described shows an association between socioeconomic status and performance on tests of language and executive function. So far we have been referring to the effect of socioeconomic status on these functions, but the data are equally consistent with the reverse direction of causality. Perhaps families with higher innate language and executive abilities tend to acquire and maintain a higher socioeconomic status. Note that the direction of causality is an empirical issue. It should not be confused with the ethical issue of society's obligation to help children of any background become educated, productive citizens.

Direction of Causality

Given that the direction of causality is an empirical issue, are there data that bear on the issue? The methods of behavioral genetics research can, in principle, tell us about the direction of causality in the association between socioeconomic status and the development of specific neurocognitive functions, although these methods have yet to be applied to the question. They have been applied to a related question, however, namely the heritability of IQ and socioeconomic status. Cross-fostering studies of within—and between—socioeconomic status adoption suggest that roughly half the IQ disparity in children is experiential (Capron & Duyme, 1989; Schiff & Lewontin, 1986). If anything, these studies are likely to err in the direction of underestimating the influence of environment because the effects of prenatal and early postnatal environment are included in the estimates of genetic influences. A recent twin study by Turkheimer and colleagues (2003) showed that, within low-socioeconomic-status families, IQ variation is far less genetic than environmental in origin. Additional evidence comes from studies of when, in a child's life, poverty was experienced. Within a given family that experiences a period of poverty, the effects are greater on siblings who were young during that period (Duncan et al., 1994). In sum, multiple sources of evidence indicate that socioeconomic status does indeed have an effect on cognitive development, although its role in the specific types of neurocognitive system development investigated here is not directly known.

Mechanisms of Causation: Somatic

The environments of low and middle-socioeconomic-status children differ in innumerable ways, many of which could affect brain development. Some of these would affect brain development by their direct effects on the body. Three somatic factors have been identified as significant risk factors for low cognitive achievement by the Center for Children and Poverty (1997): Inadequate nutrition, substance abuse (particularly prenatal exposure), and lead exposure.

Malnutrition can effect brain development and brain function, permanently and acutely, prenatally and postnatally. Few people in the United States

suffer severe malnutrition. The more common problems are mild-to-moderate protein-energy malnutrition (PEM), which involves shortages of both protein and calories, and iron deficiency. There is disagreement whether mild-to-moderate PEM has a significant effect on children's neurocognitive development (e.g., see Ricciuti, 1993; Sigman, 1995). The issue has been difficult to resolve for two reasons. First, unlike severe malnutrition, which causes easily measurable differences in body size and other clinical and biochemical indices, mild-to-moderate PEM is difficult to detect. Researchers must therefore rely on intrinsically less reliable data from family reports of food intake. Second, nutritional status is strongly correlated with a host of other family and environmental variables likely to affect neurocognitive development, including all of the potential mechanisms of causation to be reviewed. Supplementation programs have the potential to deconfound these variables, but are often coupled with other, nonnutritional forms of enrichment or simply affect children's lives in nonnutritional ways which perpetuate the confound (e.g., children given school breakfast are absent and late less often). A report from the Center on Hunger, Poverty and Nutrition Policy (CHPNP, 1998) concludes that it is possible that mild-to-moderate PEM has little effect on its own. Iron-deficiency anemia afflicts about one quarter of low income children in the United States (CHPNP, 1998) and is known to impair brain development when severe. Numerous correlational studies have shown an association between iron-deficiency anemia and lower cognitive performance, although the confounding between nutrition and other aspects of the environment make it difficult to assess the impact of iron deficiency per se. Supplementation studies have shown that normalizing iron levels increases motor and behavioral development in severely anemic infants. It has been suggested that nutritional effects on cognitive development may be mediated, at least in part, by an indirect mechanism whereby lethargy of parent as well as child results in less interaction, support and stimulation (Valenzuela, 1997). In sum, the consensus regarding the role of nutrition in the cognitive outcomes of poor children has shifted over the past few decades, from primary cause to a factor that contributes indirectly and through synergies with other environmental disadvantages (CHPNP, 1998).

Lead is a neurotoxin that accumulates in the bodies of low-socioeconomic-status children at far greater levels, on average, than in the middle-socioeconomic-status children (Brody et al., 1994). Lead-containing paint is present in most older homes, and when walls and woodwork are not well maintained the resulting peeling and powdered paint is ingested and inhaled by young children. A meta-analysis of low-level lead exposure on IQ indicates estimated that every 10 ug/dL increase in lead is associated with a 2.6 point decrease in IQ (Schwartz, 1994). As with nutrition, the effect of lead synergizes with other environmental factors and is more pronounced in low-socioeconomic-status children (Bellinger, Leviton, Waternaux, Needleham, & Rabinowitz, 1987). For example, low iron stores render children more susceptible to environmental lead (CHPNP, 1998).

Prenatal substance exposure is a third factor that affects low-socioeconomic-status children disproportionately. Maternal use of alcohol, tobacco and marijuana have all been associated with adverse cognitive outcomes in children (Chasnoff et al., 1998). The sharpest socioeconomic status differences

in prenatal substance exposure involve cocaine. Although animal models indicate general effects on fetal well-being because of dopaminergic restriction of blood flow and specific effects on brain development (Mayes, 2002), epidemiological studies have found the effects on cognitive performance to be subtle (Hurt et al., 1998; Mayes, 2002; Vidaeff & Mastrobattista, 2003). For example, the low-socioeconomic-status 4-year-olds of Hurt's cohort, whose average IQ was 81, served as control research participants for a cohort with prenatal cocaine exposure, whose average IQ was a statistically indistinguishable 79. This lack of difference contrasts with the substantial difference between both low socioeconomic-status groups' scores and those of typical middle-socioeconomic-status children.

The set of potentially causative factors just reviewed is far from complete. There are socioeconomic status gradients in a wide variety of physical health measures, many of which could affect children's neurocognitive development through a variety of different mechanisms (Adler et al., 1997). Having briefly reviewed the most frequently discussed factors, we turn now to a consideration of the psychological differences between the experiences of low and middle-socioeconomic-status children that could affect neurocognitive development.

Mechanisms of Causation: Psychological

As with potential physical causes, the set of potential psychological causes for the socioeconomic status gap in cognitive achievement is large, and the causes are likely to exert their effects synergistically. Here we will review research on differences in cognitive stimulation, parenting styles, and stress levels.

One difference between low- and middle-socioeconomic-status families that seems predictable, even in the absence of any other information, is that low-socioeconomic-status children are likely to have fewer toys and books and less exposure to zoos, museums, and other cultural institutions because of the expense of such items and activities. This is indeed the case (Bradley, Corwyn, McAdoo, et al., 2001) and has been identified as a mediator between socioeconomic status and measures of cognitive achievement (Bradley & Corwyn, 1999; Brooks-Gunn & Duncan, 1997; McLoyd, 1998). Such a mediating role is consistent with the results of neuroscience research with animals, showing that complex environments that afford exploration and activity to young animals have a favorable effect on brain development (Greenough, Black, & Wallace, 1987).

Other types of cognitive stimulation are also less common in low-socioeconomic-status homes, for example parental speech designed to engage the child in conversation (Adams, 1998). The average number of hours of one-on-one picture book reading experienced by children before kindergarten entry has been estimated at 25 for low-socioeconomic-status children and between 1000 and 1700 for middle-socioeconomic-status children (Adams, 1990). Thus, in addition to material limitations, differing parental expectations and concerns also contribute to differences in the amount of cognitive stimulation experienced by low and middle-socioeconomic-status children.

There is a huge literature on socioeconomic status differences in parenting attitudes and behavior, with certain findings robust across geographic and

ethnic variation (Bradley, Corwyn, Burchinal, et al., 2001). These include a greater middle-socioeconomic-status emphasis on verbal skills, independence, achievement and creativity and a greater low-socioeconomic-status emphasis on obedience and staying out of trouble (Adams, 1990). Physical punishment is more common in low-socioeconomic-status homes, and harsh physical punishment has been associated with lower IQ (Brooks-Gunn, 1999).

The lives of low-socioeconomic-status individuals tend to be more stressful for a variety of reasons, some of which are obvious: concern about providing for basic family needs, dangerous neighborhoods, and little control over one's work life. Recent research in neuroscience with animal models has uncovered mechanisms by which such psychological stress is transduced into neurochemical changes involving cortisol and other stress hormones (McEwen, 2001). High levels of stress in early life, such as prolonged maternal separation, impacts the development of medial temporal and prefrontal brain systems involved in the regulation of the stress response (Meany et al., 1996). Lupien and colleagues (Lupien, King, Meany, & McEwen, 2001) extended the study of stress and neuroendocrine function to children and socioeconomic status by assessing salivary cortisol levels in 6-year-olds and found higher levels in children of lower socioeconomic status.

Conclusion

Children's neurocognitive development is affected by their socioeconomic status. We know that the effects are large and that they have real world importance, insofar as they influence school and job success. We also know some of the ways in which socioeconomic status influences neurocognitive development, although the list of potential factors is long and synergisms among factors are likely to be as important as any individual factor's contribution.

The present study was an attempt to add to our understanding of the effect of socioeconomic status on neurocognitive development by asking: What systems of the developing brain are affected by socioeconomic status? The conclusion of this preliminary study is that the left perisylvian-language system and prefrontal-executive system are most sensitive to childhood socioeconomic status. This conclusion has implications for basic science and for the well-being of low-socioeconomic-status children.

The basic science implications of our research concern the influences of the environment on human brain development. The animal literature on environmental influences on brain development typically contrasts plain laboratory cages with so-called enriched environments, but both types of environment are unnatural for the animals and it is difficult to say whether the contrast is between an impoverished versus normal environment, normal versus enriched, or impoverished versus enriched. The present results concern our species in its normal environment. The less advantaged children here were not raised in isolated orphanages or subjected to socially unacceptable abuse or neglect. They were among the estimated 12 million American children living below the poverty line. Our results show that variation in childhood environment, within the normal range for our society, leads to large and significant effects on the

development of at least two brain systems important for language and executive function. Additional studies are under way to address some of the new questions raised by these preliminary findings. For example, prefrontal cortex is a large region with distinct subsystems. How is the development of each of these subsystems influenced by socioeconomic status? Which of the many differences between low and middle-socioeconomic-status children's lives contribute to the differences observed in language and executive function?

At a practical level, our approach to the study of socioeconomic status has the potential to inform a number of real-world issues. As we learn more about the neurocognitive profile of socioeconomic status, we become better equipped to counteract its negative effects through more targeted intervention programs. Knowledge of the specific neurocognitive effects of socioeconomic status also allows a more specific and hence more sensitive search for causal factors which can then be addressed directly. Finally, by framing the socioeconomic status gap in cognitive achievement in terms of brain development, we can see it as a matter public health in addition to economic opportunity.

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