Socioeconomic Disparities Affect Prefrontal Function in Children

Mark M. Kishiyama[1], W. Thomas Boyce[2], Amy M. Jimenez[3], Lee M. Perry[4], and Robert T. Knight[1]

Abstract

■ Social inequalities have profound effects on the physical and mental health of children. Children from low socioeconomic status (SES) backgrounds perform below children from higher SES backgrounds on tests of intelligence and academic achievement, and recent findings indicate that low SES (LSES) children are impaired on behavioral measures of prefrontal function. However, the influence of socioeconomic disparity on direct measures of neural activity is unknown. Here, we provide electrophysiological evidence indicating that prefrontal function is altered in LSES children. We found that prefrontal-dependent electrophysiological measures of atten-
tion were reduced in LSES compared to high SES (HSES) children in a pattern similar to that observed in patients with lateral prefrontal cortex (PFC) damage. These findings provide neurophysiological evidence that social inequalities are associated with alterations in PFC function in LSES children. There are a number of factors associated with LSES rearing conditions that may have contributed to these results such as greater levels of stress and lack of access to cognitively stimulating materials and experiences. Targeting specific prefrontal processes affected by socioeconomic disparity could be helpful in developing intervention programs for LSES children. ■

INTRODUCTION

Social inequalities have profound effects on the physical and mental health of children. For example, compared to children from higher socioeconomic status (SES) backgrounds, children from low SES (LSES) backgrounds have higher rates of mortality and are at greater risk for most forms of childhood morbidities, including injuries, chronic medical conditions, and behavioral disorders (Chen, Boyce, & Matthews, 2002). In addition, a growing body of evidence indicates that individual differences in adult health status are related to impoverished circumstances experienced during childhood (Rahkonen, Lahelma, & Huuhka, 1997; Smith, Hart, Blane, Gillis, & Hawthorne, 1997). Socioeconomic disparities thus not only exert health effects on children but they also contribute to health outcomes in adults.

Strong associations have also been found between SES and cognitive ability and achievement in childhood. That is, children from LSES backgrounds perform below children from higher SES backgrounds on tests of intelligence, language proficiency, and academic achievement (Bradley & Corwyn, 2002; Duncan, Brooks-Gunn, & Klebanov, 1994). In addition, LSES children are more likely to fail courses, be placed in special education, and drop out of school compared to high SES children (HSES) (McLoyd, 1998). Recent behavioral studies have reported a relationship between SES and specific neurocognitive systems. For example, LSES children have reduced performance on tests of language, long-term memory, and executive function compared to middle SES children (ages 10–13 years) (Farah et al., 2006). These findings extend those of a previous study that found differences on tests of language and executive function between low and middle SES kindergartners (Noble, Norman, & Farah, 2005). In addition, in a study using an Attentional Network Test (ANT) (Rueda et al., 2005), Mezzacappa (2004) found that LSES children were impaired in both speed and accuracy on measures of alerting and executive attention compared to HSES children. Taken together, these findings indicate that executive function is one of the primary neurocognitive systems associated with social inequalities in early experience. Moreover, the tests of executive function employed in these studies index cognitive processes that have been attributed to the prefrontal cortex (PFC) (Diamond, 1988; Goldman-Rakic, 1987).

Although these findings indicate that socioeconomic disparities affect prefrontal function in children, behavioral tests have a number of limitations. First, they provide only indirect measures of brain function. Second, many of these tests are multifactorial, and thus, performance could be disrupted for reasons other than frontal dysfunction (Stuss, Shallice, Alexander, & Picton, 1995).

[1]University of California, Berkeley, [2]University of British Columbia, Vancouver, BC, Canada, [3]University of California, Los Angeles, [4]Stanford University

In addition, correlations among these tests are low, and they vary in complexity such that it is sometimes difficult to separate task difficulty from impairment (Stuss & Alexander, 2000). In the current study, we addressed these limitations by using direct measures of neural activity and a simple target detection task that could be performed easily by all the children independent of SES level. In particular, we used electrophysiological methods to assess whether prefrontal function was altered in LSES children. The task involved detecting easily discriminable target stimuli embedded in streams of repetitive stimuli (Courchesne, Hillyard, & Galambos, 1975). In addition to the target events, task-irrelevant novel stimuli occurred randomly on 15% of the trials (see Figure 1). We predicted that certain event-related potential (ERP) components in this attention task would show a pattern similar to that observed in patients with structural PFC damage.

First, we predicted that differences would not be observed between LSES and HSES children in behavioral target responses because we expected both groups to perform the target detection task with a high degree of accuracy. Second, we predicted that group differences would not be observed for the P3b ERP component. The P3b is an index of voluntary detection of target events, and it is maximal in amplitude at centro-parietal electrode sites (Sutton, Braren, Zubin, & John, 1965). This component is dependent on the integrity of the temporal–parietal cortex, and it is not reduced in patients with PFC lesions in simple tasks such as the one employed in the current study (Knight, 1997). In contrast, we predicted that LSES children would have reduced extrastriate (P1 and N1) and novelty ERP (N2) responses relative to HSES

children. The P1 and N1 components are prefrontal-dependent, early latency brain potentials generated in ventral and dorsal extrastriate pathways (Clark, Fan, & Hillyard, 1995; Heinze et al., 1994). These components are modulated by the degree of voluntary attention and are under top–down control by the lateral PFC (Yago, Duarte, Wong, Barcelo, & Knight, 2004; Barcelo, Suwazono, & Knight, 2000). The novelty N2 component reflects the automatic response to novelty (Knight, 1984; Courchesne et al., 1975), and it is dependent on a distributed novelty processing network with the PFC serving as a critical component of this system (Knight & Scabini, 1998; Knight, 1997). The early extrastriate P1 and N1 components and the novelty N2 have been shown to be reduced in patients with PFC lesions (Yago et al., 2004; Barcelo et al., 2000; Knight, 1984, 1997).

METHODS

Subjects

A total of 28 child subjects were tested. These subjects were recruited from the San Francisco Bay Area. The data from two children were not included in the data analysis due to excessive electroencephalogram (EEG) artifacts. One of these subjects was in the HSES group and one was in the LSES group. The subjects in the final analysis included 26 children (6 boys, 20 girls; age range = 7–12 years; mean age = 9.5 years, SD = 1.1 years). There were 13 subjects in the HSES group [3 boys, 10 girls; age range = 7–12 years; mean age = 9.2 years, SD = 1.2 years; child ethnicity: 10 Caucasian/European American, 1 Asian/Pacific Islander, and 2 biracial (1 Caucasian/Latino and

Figure 1. Examples of standard (upright triangles), target (tilted triangle), and novel (color IAPS image) stimuli included in the novelty oddball paradigm.
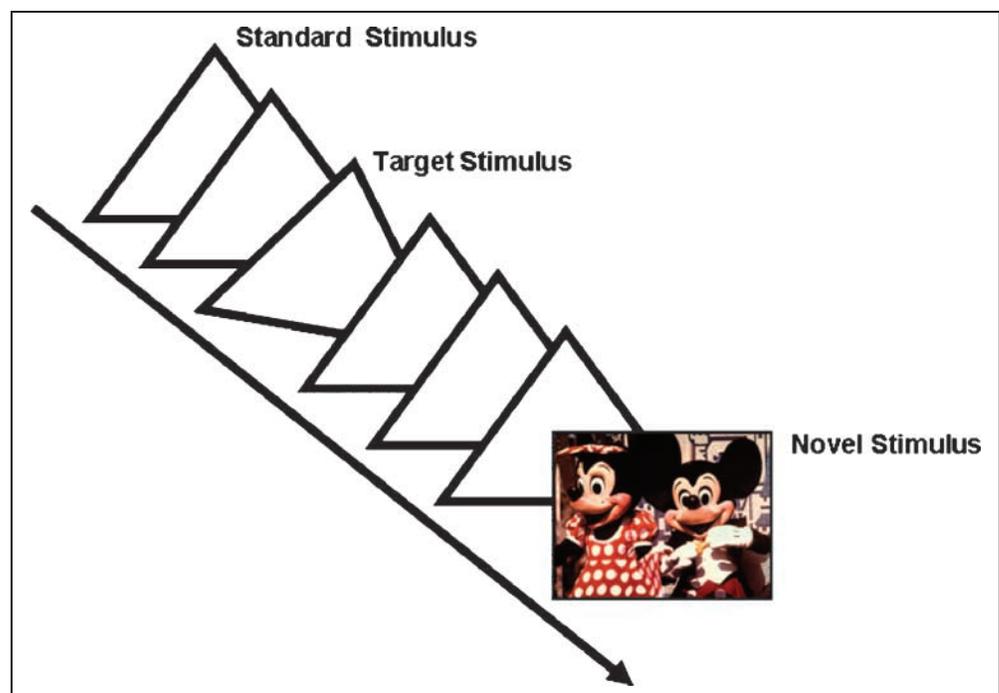
1 Caucasian/African American)] and 13 subjects in the LSES group [3 boys, 10 girls; age range = 8–11 years; mean age = 9.7 years, SD = 1.0 years; child ethnicity: 10 African American, 1 Caucasian/European American, 1 Latino/Hispanic, and 1 biracial (Asian/African American)]. The two groups did not differ in age (p = .36). The ethnic composition of the two groups differed, with SES confounded, to some degree, with child ethnicity. Distinguishing between socioeconomic and ethnicity effects is constrained by the size and heterogeneity of the current sample and by the sociodemographic characteristics of the San Francisco Bay Area, but the observed associations are more plausibly attributable to the neurodevelopmental consequences of early social experience—experience that strongly covaries with SES.

Measures of SES were acquired from primary caregiver responses on the MacArthur Sociodemographic Questionnaire. SES criteria were based on primary caregiver education, average family income, and income-to-needs ratio. Parental education is one of the most important and stable indicators of SES (Hoff-Ginsberg & Tardif, 1995; House, 1981). Primary caregivers of the HSES group had obtained at least a Bachelor's degree and completed at least 4 years of college (mean years of education = 18.2 years, SD = 1.5 years), whereas primary caregivers of the LSES group had not obtained a Bachelor's degree nor completed a minimum of 4 years of college (mean years of education = 12.9 years, SD = 3.2 years). The years of education were greater for primary caregivers in the HSES compared to the LSES group [$t(12)$ = 5.79, p < .0001]. Average income was assessed by asking respondents to report their total combined income for the past twelve months (before taxes). The mean average family income for the HSES group was $96,157 and the mean average family income for the LSES group was $27,192. The average family income for the HSES group was greater than the average family income for the LSES group [$t(12)$ = 12.37, p < .0001]. Family income-to-needs ratio is another measurement of economic well-being, and its use as an indicator of SES has become increasingly popular in contemporary research (McLoyd, 1998). Income-to-needs ratio was calculated by dividing family income by the federal poverty threshold (adjusted for family size) (Duncan et al., 1994). For example, an income-to-needs ratio of 1.0 indicates that family income is equal to the poverty threshold. The average family income-to-needs ratio was 4.87 for the HSES group and 1.47 for the LSES group. Income-to-needs ratio was greater in the HSES compared to the LSES group [$t(12)$ = 17.81, p < .0001].

The child subjects, as assessed by parental report, had no history of neurological or psychiatric disorders, drug abuse, or prenatal exposure to drugs or alcohol. In addition, no child was currently taking psychotropic medication. Each child subject and one of their parents gave written informed consent prior to being tested, and they were paid for their participation. The experimental procedures were approved by and conducted in compliance with the Committee for the Protection of Human Subjects for the University of California, Berkeley.

Design and Materials

The stimuli consisted of high-probability (75%) standard stimuli and low-probability target (10%) and novel stimuli (15%). Standard and target stimuli consisted of black triangles (7.3° × 5.3°) presented against a white background. The target triangles were tilted 10° clockwise relative to upright standard triangles. The novel stimuli consisted of digitized color images from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2005). The novel picture stimuli were selected in this study in order to facilitate robust novelty responses. That is, stimuli were selected on the basis of high valence ratings for pleasantness and moderate ratings of arousal. The mean pleasantness and arousal ratings for these picture stimuli were 7.1 (SD = 0.55) and 4.8 (SD = 1.0), respectively. All stimuli were centrally presented. Stimulus duration was 250 msec with an interstimulus interval of 1000 msec. Stimuli were presented in eight blocks of trials consisting of 120 items per block.

Procedure

Subjects were seated in a sound-attenuated booth facing a computer monitor at a distance of one meter. They were instructed to press a button upon detection of the low-probability targets embedded in streams of the task-irrelevant stimuli. All stimuli were presented in pseudorandom order with the constraint that two targets, two novels, or a target and a novel never appear sequentially. They were told that there would be pictures (i.e., photographs) presented throughout the experiment, but they were instructed to ignore these stimuli and focus on the target detection task. ERPs and reaction time (RT) to targets were recorded to all stimuli. A button press within 200 to 1000 msec after the target stimulus onset was considered a correct response, and an analysis epoch containing a correct response was defined as a hit.

Electrophysiological Recording

EEG signals were continuously recorded by an ActiView 2 system (BioSemi, the Netherlands), using 64 Ag/AgCl electrodes arranged according to the 10–20 system. The channels were referenced to averaged electrodes placed over the left and right earlobes. Eye movements were recorded using electrodes above and below the right eye, and near the left and right outer canthi. The EEG

signals were amplified (band-pass: 0.16–100 Hz) and digitized using a 512-Hz sampling rate.

Average ERPs locked to the presentation of the stimuli were computed from artifact free data epochs extending from 100 msec prior to 1000 msec poststimulus onset. EEG epochs with excessive muscle activity or eye blinks (peak-to-peak amplitude = 100 µV) were excluded from the analysis. Peak amplitudes for the ERP components were measured relative to the 100-msec prestimulus baseline. Early extrastriate components for standard stimuli were measured in windows of 50–150 msec for the P1 and 100–250 msec for the N1. Target-related activity was measured in the windows of 50–250 msec for the P2, 100–350 msec for the N2, and 200–800 msec for the P3b. Novelty-related components were measured in similar windows for the P2 and N2 and in a window of 300–800 msec for the late frontal negativity (LFN).

All measurements were analyzed using a within-subjects repeated measures analysis of variance (ANOVA). Greenhouse–Geisser corrections are reported for all analyses to correct for violation of the sphericity assumption. ERP component amplitudes were submitted to a 2 × 3 repeated measures ANOVA to examine early visual responses in standard stimuli. The between-subjects factor in this analysis was group (HSES, LSES) and the within-subjects factor was laterality [left hemisphere (LH) (P07), midline (POz), and right hemisphere (RH) (P08)]. To examine target processing, ERP component amplitudes were submitted to a 2 × 2 × 3 × 2 repeated measures ANOVA. The between-subjects factor was the same as the early visual analysis (i.e., group), and the within-subjects factors were stimulus (standard, target), laterality [LH (F3, C3), midline (Fz, Cz,), RH (F4, C4)], and caudality [frontal (F3, Fz, F4), central (C3, Cz, C4)]. In the novelty processing analysis, ERP component amplitudes were submitted to a 2 × 2 × 3 × 2 repeated measures ANOVA. All within-subjects factors in this analysis were identical to the target processing analysis except for the stimulus factor (standard, novel). Habituation analyses for target and novel stimuli included a factor for block (early block, late block); all other factors were identical to those described above.

Neuropsychological Tests

Neuropsychological tests were also administered to determine associations between SES and measures of language and executive function. These measures were part of a broader study investigating the affect of social disparity on cognitive development. Language was assessed using a vocabulary subtest (Wechsler, 1994). Tests of executive function included measures of working memory (Wechsler, 1994), visuomotor attention and cognitive flexibility (Reitan, 1971), inhibitory control (Golden, 1978), and semantic fluency (Halperin, Healey, Zeitchik, Ludman, & Weinstein, 1989).

RESULTS

Behavioral Results

Both LSES and HSES children were able to perform the target detection task without difficulty. For example, the average mean hit rate accuracy was 92.8% for all subjects. The mean hit rate was 94.9% (SD = 4%) for the HSES group and 90.8% (SD = 9.5%) for the LSES group. The mean RT for hits was 545 msec (SD = 72 msec) for the HSES group and 564 msec (SD = 65 msec) for the LSES group. Target behavioral responses did not differ across the two groups in either RT [$t(12)$ = 0.88, p = .40] (see Figure 2A) for hits or hit rate accuracy [$t(12)$ = 1.71, p = .11] (see Figure 2B).

Electrophysiological Results

ERP Results

Standard stimuli. Both the standard P1 [$F(1, 24)$ = 7.71, p < .05] and the standard N1 [$F(1, 24)$ = 14.86, p < .005] ERP component amplitudes were reduced in the LSES compared to the HSES group (see Figure 3A). In addition, the P1 was greater over left and right hemisphere compared to midline electrode sites [$F(2, 46)$ = 19.38, p < .001], and the N1 was largest over left hemisphere compared to right hemisphere and midline electrode sites [$F(2, 41)$ = 4.24, p < .05].

Target stimuli. No significant effects were observed for the P2 component. N2 amplitude was enhanced for target compared to standard stimuli [$F(1, 24)$ = 8.43, p < .01]. In addition, the N2 was most prominent over midline compared to left and right hemisphere electrode sites [$F(2, 39)$ = 7.75, p < .005]. Group differences were not observed for either the N2 amplitude in general (p = .08) or the target N2 in particular (p = .62).

Robust target ERP responses (P3b) were also observed in both groups. The P3b amplitude was found to be greater for target compared to standard stimuli in both groups [$F(1, 24)$ = 53.57, p < .001]. The target P3b was most prominent at midline [Stimulus × Laterality: $F(2, 44)$ = 6.02, p < .01] and central electrode sites [Stimulus × Caudality: $F(1, 24)$ = 38.28, p < .001]. In addition, group differences were not observed for either the overall P3b amplitude (p = .31) or the target P3b amplitude (p = .27) (see Figure 2C).

Novel stimuli. Novel stimuli generated a sustained negativity beginning with a fronto-central N2 component (100–350 msec) and ending with an LFN (300–800 msec). The LFN component, also known as Nc (Courchesne, 1977), has previously been observed in children in response to novel stimuli (Gumenyuk et al., 2001; Courchesne, 1978). This pattern of novelty ERP response has also been observed in children by other investigators (Friedman, Brown, Cornblatt, Vaughan, & Erlenmeyer-Kimling, 1984).
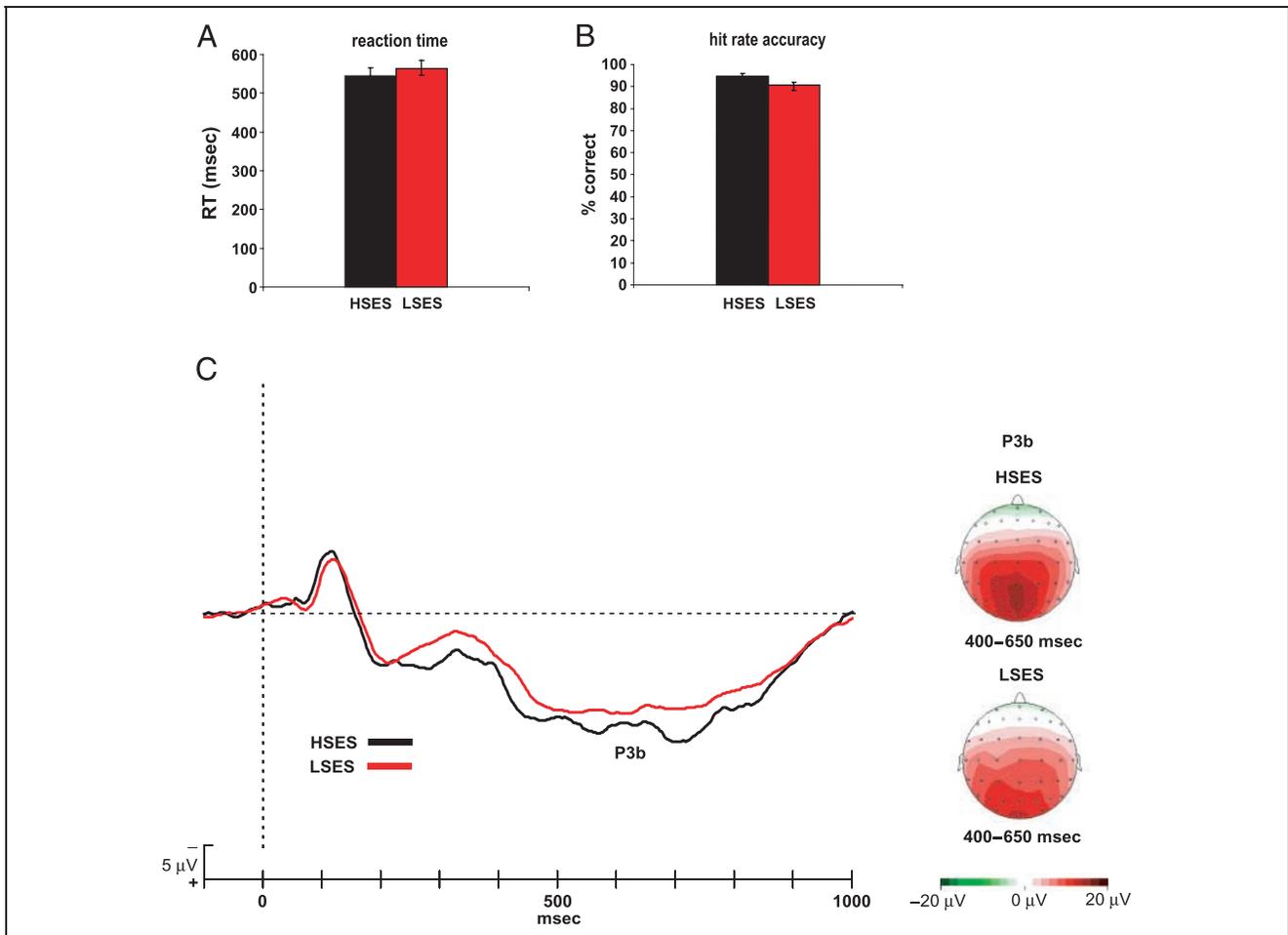
Figure 2. (A) Comparison of mean RTs for correct hits for the HSES and LSES groups. (B) Comparison of mean hit rates for the HSES and LSES groups. (C) Grand-averaged target P3b ERP components for the HSES (black) and LSES (red) groups for a composite of centro-parietal electrodes (C3, Cz, and C4). Topographic maps (top view) of peak amplitude ranges (400–650 msec) for the target P3b for the HSES and LSES groups are shown to the right.

Although a main effect for stimulus was not observed for the P2 ($p = .51$), the novelty P2 was found to be most prominent over frontal electrode sites [$F(1, 24) = 6.90, p < .05$]. The N2 amplitude was greater for novel compared to standard stimuli in both LSES and HSES children [$F(1, 24) = 146.47, p < .001$]. In addition, both the overall N2 amplitude [$F(1, 24) = 20.17, p < .001$] and the novelty N2 amplitude were reduced in the LSES compared to the HSES group [$F(1, 24) = 14.84, p < .005$] (see Figure 3B and C).

The LFN component amplitude was found to be greater for novel compared to standard stimuli in both groups [$F(1, 24) = 149.62, p < .001$], and it was most prominent at frontal electrode sites [$F(1, 24) = 5.96, p < .05$]. Group differences were not observed for the novelty LFN ($p = .23$).

Habituation ERP Results

Additional analyses were conducted in an effort to determine the effects of habituation on target (P3b) and novelty (N2 and LFN) ERP components. In particular,

target and novelty responses were examined in the early blocks (EB; Blocks 1–2) and late blocks (LB; blocks 7–8). Similar results from the ERP Results section will not be reported here (i.e., findings not relevant to habituation).

Target stimuli. The P3b amplitude was larger in the early blocks compared to the late blocks [$F(1, 24) = 17.35, p < .001$]. In addition, target P3b amplitudes were significantly reduced from the early to the late blocks compared to standard P3b amplitudes [Block × Stimulus: $F(1, 24) = 14.59, p < .005$]. However, there was no difference between the groups in terms of overall P3b habituation (Block × Group, $p = .61$) and specific target P3b habituation (Block × Stimulus × Group, $p = .98$). Thus, there was evidence of habituation for the P3b component including specific target P3b responses, but group differences in habituation were not observed.

Novel stimuli. The N2 amplitude was larger in the early blocks compared to the late blocks [$F(1, 24) = 7.02, p < .05$]. Novelty N2 responses were significantly
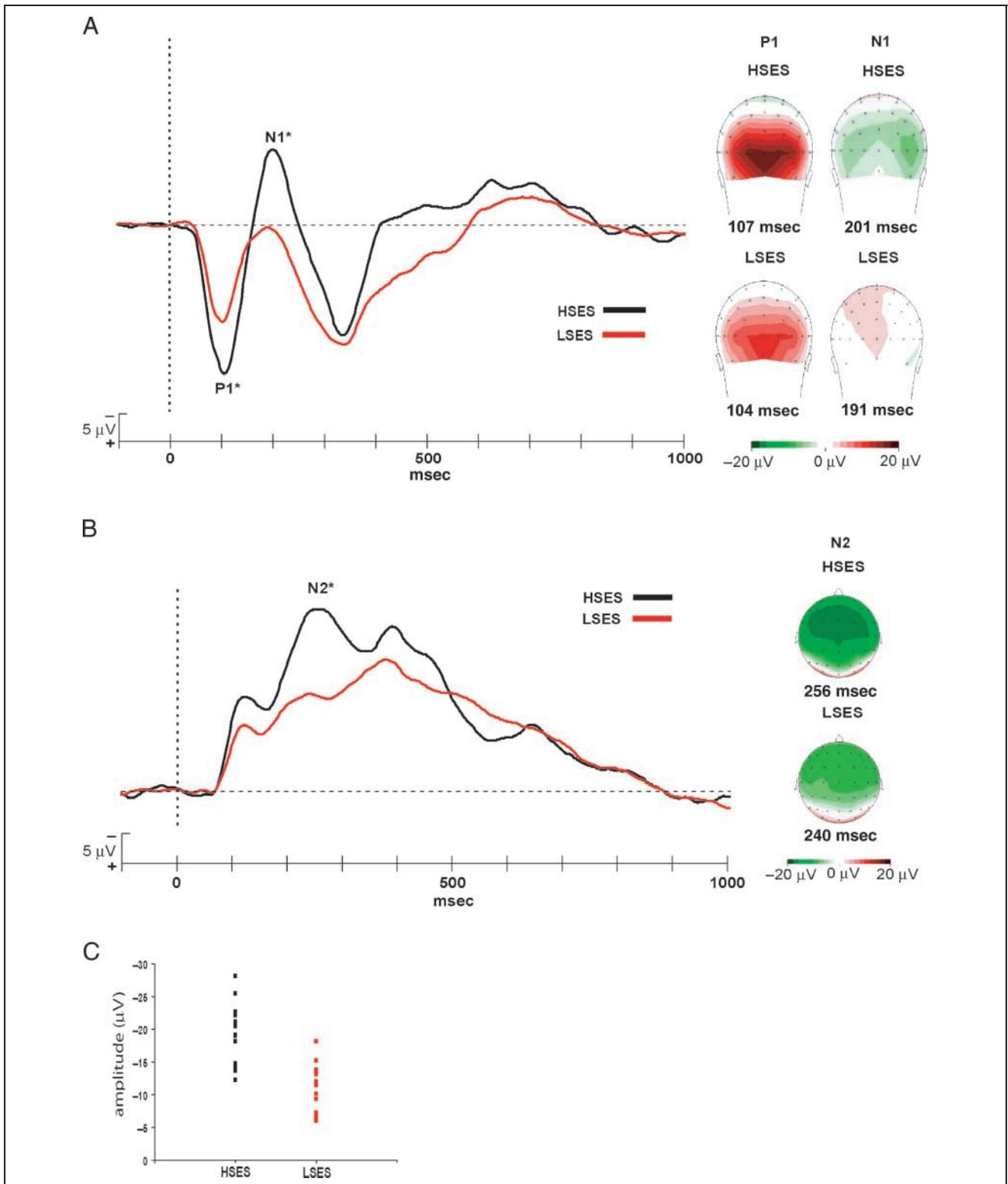
Figure 3. (A) Grand-averaged standard P1 and N1 ERP components for the HSES (black) and LSES (red) groups at the PO8 electrode. Topographic maps (back view) of peak amplitude times for the standard P1 and N1 for the HSES and LSES groups are shown to the right. (B) Grand-averaged novelty ERP components for the HSES (black) and LSES (red) groups at the Cz electrode. Topographic maps (top view) of peak amplitude times for the novelty N2 for the HSES and LSES groups are shown to the right. (C) Scatterplot for novelty N2 amplitudes at electrode Cz for individual subjects in the LSES and HSES groups.

reduced from the early to the late blocks relative to standard N2 amplitudes [Block × Stimulus: $F(1, 24) = 4.82, p < .05$]. There was no difference between the groups for overall habituation (Block × Group, $p = .52$) and specific novelty N2 habituation (Block × Stimulus × Group, $p = .45$). Habituation effects were found for the N2 component including specific novelty N2 responses, but group differences in habituation were not observed. Effects of habituation were not observed for the LFN component ($p = .72$).

Neuropsychological Test Results

Prefrontal-dependent Executive Function Tasks

Digit span. Working memory was measured using the digit span subtest of the Wechsler Intelligence Scale for Children III (WISC-III) (Wechsler, 1994). In the digit span subtest, children were presented with increasingly long strings of numbers and asked to repeat these numbers back to the experimenter in the original order (digit forward, DF) and in reverse order (digit backward, DB). The total score for the digit span subtest is the sum of the DF and DB scores. The average digit span total scores were 16.9 for the HSES group (scaled score = 14) and 12.2 for the LSES group (scaled score = 9). The subtest scaled scores ($M = 10, SD = 3$) were derived from the age ranges most representative of the average age of each group [i.e., 9.0–9.3 years for the HSES group ($M = 9.2$ years); 9.4–9.7 years for the LSES group ($M = 9.7$ years)]. The scaled score for the HSES group was more than one standard deviation above the mean, whereas the scaled score for the LSES was close to the mean. In addition, the raw digit span total scores were greater for the HSES group compared to the LSES group [$t(12) = 5.52, p < .0005$].

Visuomotor attention and cognitive flexibility. The Trail Making Test (TMT) is one of the most widely used neuropsychological tests (Lezak, 1995; Reitan, 1971). The TMT has two parts. Part A is a measure of visuomotor attention and Part B is a measure of cognitive flexibility (Baron, 2004). Part B is sensitive to both set shifting and inhibitory control. Part A requires the child to draw a line in sequence between numbered circles scattered across a page, whereas Part B requires the child to draw a line while alternating between numbers and letters in sequence. Scores are determined by time-to-completion in seconds (including time for errors, pointed out by the examiner, and subsequent corrections implemented by the child).

Average scores on Part A of the TMT for both the HSES ($M = 20.0$ sec) and the LSES ($M = 22.6$ sec) groups were within the normal range of Part A scores for children in a similar age group (i.e., 9 years) ($M = 25.1$ sec, $SD = 8.8$ sec) (Spreen & Gaddes, 1969). Although the average score in seconds on Part B for the LSES group ($M = 58.2$ sec) was within the normal range for Part B scores of children in a similar age group (9 years) ($M = 54.6$ sec, $SD = 19.0$ sec) (Spreen & Gaddes, 1969), the average score for the HSES ($M = 33.3$) fell below this norm (i.e., reflecting a faster time to completion). In addition, significant differences were observed between the two groups on Part B of the TMT [$t(12) = 3.47, p < .005$] and in the B–A difference scores [$t(12) = 3.21, p < .01$] (Part B–A difference scores are considered to be another index of cognitive efficiency) (Wheeler & Reitan, 1963). However, group differences were not observed in Part A of the TMT ($p = .25$).

Inhibitory control. The Stroop Color and Word Test (SCWT) (Golden, 1978) is a measure of focused attention, set shifting, and response inhibition (Lezak, 1995; Lowe & Mitterer, 1982). This test is based on the Stroop effect (Stroop, 1935), and it requires children to inhibit an automatic reading response while producing a competing color-naming response. Children were given 45 sec trials of word reading of black typed words (word), color naming of "XXXX" in randomized color sequences (color), and color naming of words printed in nonmatching colored ink (e.g., the word "red" printed in green ink with the correct response being "green") (color/word). Scoring consisted of the number of items successfully completed during each trial. Average scores of both groups were compared to normative data obtained from children of a similar age group ($M = 9.93$ years): word ($M = 67.1, SD = 16.2$); color ($M = 54.3, SD = 13.9$); color/word ($M = 32.8, SD = 7.0$); color–color/word scores ($M = 21.4, SD = 7.1$) (Golden & Golden, 2002). For the word trial, the scores from both the HSES ($M = 78.0$) and the LSES ($M = 75.4$) groups fell within the normal range, and no significant difference was observed between the two groups for this trial ($p = .56$). Similar results were observed for the color trial (HSES: $M = 54.2$, LSES: $M = 47.1, p = .14$), the color/word trial (HSES: $M = 31.7$, LSES: $M = 27.6, p = .19$), and for the color–color/word scores (HSES: $M = 22.5$, LSES: $M = 19.5, p = .31$).

Semantic fluency. Verbal fluency tests involve speeded lexical production and aspects of executive function, such as working memory, set shifting, and inhibition (Baron, 2004). Verbal fluency tests include tests of letter fluency and semantic fluency. Semantic fluency tests assess the child's ability to produce words in response to a category cue.

The semantic fluency test consisted of three 1-min trials. In particular, children were asked to name all the words they could think of in three different categories (i.e., animals, food, and words beginning with the sound "sh"). Average scores for both groups were compared to normative data from children of a similar age group (i.e., 9 years): animals ($M = 13.8, SD = 3.7$), food ($M =$

14.1, $SD = 3.9$), and sh ($M = 6.0$, $SD = 2.4$) (Halperin et al., 1989). The average score for the LSES group ($M = 12.5$) in the animals category fell within the normal range, but the average score for the HSES group ($M = 18.6$) exceeded this range (i.e., beyond one standard deviation). In addition, a significant difference was observed between the scores of the two groups for this category [$t(12) = 4.01$, $p < .005$]. In the food category, the average score for the LSES group ($M = 13.7$) fell within the normal range, but the average score for the HSES group ($M = 20.8$) exceeded this range. A significant difference between the scores of the two groups was also observed for this category [$t(12) = 4.79$, $p < .0005$]. In the "sh" category, the average scores for the LSES ($M = 4.8$) and HSES ($M = 5.8$) groups fell within the normal range, and no significant difference was observed between the two groups ($p = .08$).

Language

Language performance was measured using the vocabulary subtest of the WISC-III (Wechsler, 1994). In this test, children were read words, and they had to verbally define each word to the examiner. The average raw score for the HSES group was 34.5 (scaled score = 16) and the average raw score for the LSES group was 19.0 (scaled score = 7). The scaled scores for the vocabulary subtest were derived in the same manner as the scores for the digit span total scores of the WISC-III (see above). The scaled score for the HSES group was two standard deviations above the mean, whereas the scaled score for the LSES group was one standard deviation below the mean. In addition, performance on this subtest, as reflected in the raw scores, was significantly greater for the HSES compared to the LSES group [$t(12) = 5.48$, $p < .0005$].

DISCUSSION

The PFC is thought to play an important role in the top–down attentional modulation of early visual processing (Barcelo et al., 2000), and it is a critical region in the novelty processing network (Knight, 1984, 1997). For example, early, extrastriate attention-sensitive components (P1 and N1) and novelty ERP responses are reduced in patients with lateral PFC lesions (Yago et al., 2004; Barcelo et al., 2000; Knight, 1997). Such a pattern was predicted and observed in the current study in LSES children. That is, early extrastriate (P1 and N1) and novelty-related (N2) ERP responses were reduced in the LSES compared to the HSES group. We predicted that differences between the groups would not be found for either behavioral or ERP (P3b) target responses, and no such differences were observed. Similar to prior studies (Farah et al., 2006), neuropsychological tests revealed that LSES children had reduced performance compared to HSES children on measures of executive function that index processes associated with the PFC (Diamond, 1988; Goldman-Rakic, 1987), such as working memory, cognitive flexibility, and semantic fluency. Taken together, the current behavioral and electrophysiological results indicate that factors associated with social inequalities contribute to altered function of the PFC in LSES children.

The human PFC has a prolonged period of postnatal development (e.g., Fuster, 2002; Casey, Giedd, & Thomas, 2000), and major stages of cognitive development are associated with development of the PFC (Johnson, 1997). Evidence from a number of animal studies indicates that experience can affect brain development. For example, findings from several studies have shown that environmental complexity can augment brain development (e.g., van Praag, Emperman, & Gage, 2000; Rosenweig & Bennett, 1996). In contrast, environmental deprivation and stress have been shown to adversely affect behavior (Clarke & Schneider, 1993; Higley et al., 1993), performance on cognitive tests (Francis, Szegda, Campbell, Martin, & Insel, 2003), and PFC development (Braun, Lange, Metzger, & Poeggel, 2000). Moreover, susceptibility to stress can be transmitted across generations (Francis & Meaney, 1999), and stressful rearing conditions have even been shown to predict behavior more reliably than genes (Francis et al., 2003).

There are multiple factors associated with LSES rearing conditions that might plausibly exert influence on behavior and normal brain development. For example, LSES children often live in cognitively impoverished environments. LSES children have limited access to cognitively stimulating materials and experiences, and they receive less attention from adults than children from higher SES backgrounds (Bradley & Corwyn, 2002; McLoyd, 1998; Hart & Risley, 1995). Access to cognitively stimulating materials mediates the relation between SES and their academic and intellectual achievement (Bradley & Corwyn, 2002). Children from LSES backgrounds also experience greater levels of stress. For example, LSES children are exposed to a greater number of family chronic stressors, and they tend to live in more stressful environments than children from higher SES backgrounds (McLoyd, 1998). In addition, LSES children tend to have higher basal levels of the stress hormone cortisol and poorer selective attention than HSES children (Lupien, King, Meaney, & McEwen, 2001).

Factors shown to adversely affect PFC development in animals (e.g., environmental deprivation and stress) also appear to be associated with the early life experiences of LSES children. It is possible that such factors contributed to the disparity in prefrontal function we observed in the current study. Identifying specific prefrontal cognitive processes affected by social inequalities could be helpful in developing intervention programs for LSES children, given that such programs have been found to improve both intellectual development and academic achievement

in at-risk children (Diamond, Barnett, Thomas, & Munro, 2007; Ramey, Campbell, & Ramey, 1999).

REFERENCES

Barcelo, F., Suwazono, S., & Knight, R. T. (2000). Prefrontal modulation of visual processing in humans. *Nature Neuroscience, 3,* 399–403.

Baron, I. S. (2004). *Neuropsychological evaluation of the child*. New York: Oxford University Press.

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology, 53,* 371–399.

Braun, K., Lange, E., Metzger, M., & Poeggel, G. (2000). Maternal separation followed by early social deprivation affects the development of monoaminergic fiber systems in the medial prefrontal cortex of Octodon degus. *Neuroscience, 95,* 309–318.

Casey, B. J., Giedd, J. N., & Thomas, K. M. (2000). Structural and functional brain development and its relation to cognitive development. *Biological Psychology, 54,* 241–257.

Chen, E., Boyce, W. T., & Matthews, K. A. (2002). Socioeconomic differences in children's health: How and why do these relationships change with age? *Psychological Bulletin, 128,* 298–329.

Clark, V. P., Fan, S., & Hillyard, S. A. (1995). Identification of early visual evoked potential generators by retinotopic and topographic analyses. *Human Brain Mapping, 2,* 170–187.

Clarke, A. S., & Schneider, M. L. (1993). Prenatal stress has long-term effects on behavioral responses to stress in juvenile rhesus monkeys. *Developmental Psychobiology, 26,* 293–304.

Courchesne, E. (1977). Event-related brain potentials: Comparison between children and adults. *Science, 197,* 589–592.

Courchesne, E. (1978). Neurophysiological correlates of cognitive development: Changes in long-latency event-related potentials from childhood to adulthood. *Electroencephalography and Clinical Neurophysiology, 45,* 468–482.

Courchesne, E., Hillyard, S. A., & Galambos, R. (1975). Stimulus novelty, task relevance and the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology, 39,* 131–143.

Diamond, A. (1988). The abilities and neural mechanisms underlying AB performance. *Child Development, 59,* 523–527.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science, 318,* 1387–1388.

Duncan, G. J., Brooks-Gunn, J., & Klebanov, P. K. (1994). Economic deprivation and early childhood development. *Child Development, 65,* 296–318.

Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., et al. (2006). Childhood poverty: Specific associations with neurocognitive development. *Brain Research, 1110,* 166–174.

Francis, D. D., & Meaney, M. J. (1999). Maternal care and the development of stress responses. *Current Opinion in Neurobiology, 9,* 128–134.

Francis, D. D., Szegda, K., Campbell, G., Martin, W. D., & Insel, T. R. (2003). Epigenetic sources of behavioral differences in mice. *Nature Neuroscience, 6,* 445–446.

Friedman, D., Brown, C., Cornblatt, B., Vaughan, H. G., & Erlenmeyer-Kimling, L. (1984). Changes in the late task-related brain potentials during adolescence. *Annals of the New York Academy of Sciences, 425,* 344–352.

Fuster, J. M. (2002). Frontal lobe and cognitive development. *Journal of Neurocytology, 31,* 373–385.

Golden, C. J. (1978). *Stroop Color and Word Test: Manual for clinical and experimental uses*. Chicago: Stoelting.

Golden, Z. L., & Golden, C. J. (2002). Patterns of performance on the Stroop Color and Word Test in children with learning, attentional and psychiatric disabilities. *Psychology in the Schools, 39,* 489–496.

Goldman-Rakic, P. S. (1987). Circuitry of primate prefrontal cortex and regulation of behavior by representational memory. In V. B. Mountcastle, F. Plum, & S. R. Geiger (Eds.), *Handbook of physiology*. *The nervous system*: *Higher functions of the brain* (pp. 373–417). Bethesda, MD: American Physiological Society.

Gumenyuk, V., Korzyukov, O., Alho, K., Escera, C., Schröger, E., Ilmoniemi, R. J., et al. (2001). Brain activity index of distractibility in normal school-age children. *Neuroscience Letters, 314,* 147–150.

Halperin, J. M., Healey, J. M., Zeitchik, E., Ludman, W. L., & Weinstein, L. (1989). Developmental aspects of linguistic and mnestic abilities in normal children. *Journal of Clinical and Experimental Neuropsychology, 11,* 518–528.

Hart, T., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore, MD: Brookes.

Heinze, H. J., Mangun, G. R., Burchert, W., Hinrichs, H., Scholz, M., Munte, T. F., et al. (1994). Combined spatial and temporal imaging of brain activity during visual selective attention in humans. *Nature, 372,* 543–546.

Higley, J. D., Thompson, W. W., Champoux, M., Goldman, D., Hasert, M. F., Kraemer, G. W., et al. (1993). Paternal and maternal genetic and environmental contributions to cerebrospinal fluid monoamine metabolites in rhesus monkeys (*Macaca mulatta*). *Archives of General Psychiatry, 50,* 615–623.

Hoff-Ginsberg, E., & Tardif, T. (1995). Socioeconomic status and parenting. In M. H. Bornstein (Ed.), *Handbook of parenting* (Vol. 3, pp. 161–187). Mahwah, NJ: Erlbaum.

House, J. (1981). Social structure and personality. In M. Rosenberg & R. Turner (Eds.), *Social psychology: Sociological perspectives* (pp. 525–561). New York: Basic Books.

Johnson, M. H. (1997). *Developmental cognitive neuroscience*. Cambridge, UK: Blackwell.

Knight, R. T. (1984). Decreased responses to novel stimuli after prefrontal lesions in man. *Electroencephalography and Clinical Neurophysiology, 59,* 9–20.

Knight, R. T. (1997). Distributed cortical network for visual attention. *Journal of Cognitive Neuroscience, 9,* 75–91.

Knight, R. T., & Scabini, D. (1998). Anatomic bases of event-related potentials and their relationship to novelty

detection in humans. *Journal of Clinical Neurophysiology, 15,* 3–13.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2005). *International affective picture system (IAPS): Digitized photographs, instruction manual and affective ratings. Technical report A-6.* University of Florida, Gainesville, FL.

Lezak, M. (1995). *Neuropsychological assessment* (3rd ed.). New York: Oxford University Press.

Lowe, D. G., & Mitterer, J. O. (1982). Selective and divided attention in a Stroop task. *Canadian Journal of Psychology, 36,* 684–700.

Lupien, S. J., King, S., Meaney, M. J., & McEwen, B. S. (2001). Can poverty get under your skin? Basal cortisol levels and cognitive function in children from low and high socioeconomic status. *Development and Psychopathology, 13,* 653–676.

McLoyd, V. C. (1998). Socioeconomic disadvantage and child development. *American Psychologist, 53,* 185–204.

Mezzacappa, E. (2004). Alerting, orienting, and executive attention: Developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child Development, 75,* 1373–1386.

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science, 8,* 74–87.

Rahkonen, O., Lahelma, E., & Huuhka, M. (1997). Past or present? Childhood living conditions and current socioeconomic status as determinants of adult health. *Social Science & Medicine, 44,* 327–336.

Ramey, C. T., Campbell, F. A., & Ramey, S. L. (1999). Early intervention: Successful pathways to improving intellectual development. *Developmental Neuropsychology, 16,* 385–392.

Reitan, R. (1971). Trail Making Test results for normal and brain-damaged children. *Perceptual and Motor Skills, 33,* 575–581.

Rosenweig, M. R., & Bennett, E. L. (1996). Psychobiology of plasticity: Effects of training and experience on brain and behavior. *Behavioural Brain Research, 78,* 57–65.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., et al. (2005). Development of attentional networks in childhood. *Neuropsychologia, 42,* 1029–1040.

Smith, G. D., Hart, C., Blane, D., Gillis, C., & Hawthorne, V. (1997). Lifetime socioeconomic position and mortality: Prospective observational study. *British Medical Journal, 314,* 547–552.

Spreen, O., & Gaddes, W. H. (1969). Developmental norms for 15 neuropsychological tests age 6 to 15. *Cortex, 5,* 171–191.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662.

Stuss, D. T., & Alexander, M. P. (2000). Executive functions and the frontal lobes: A conceptual view. *Psychological Research, 63,* 289–298.

Stuss, D. T., Shallice, T., Alexander, M. P., & Picton, T. (1995). A multidisciplinary approach to anterior attentional functions. *Annals of the New York Academy of Sciences, 769,* 191–212.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates stimulus uncertainty. *Science, 150,* 1187–1188.

van Praag, H., Emperman, G., & Gage, F. H. (2000). Neural consequences of environmental enrichment. *Nature Reviews Neuroscience, 1,* 191–198.

Wechsler, D. (1994). *Wechsler Intelligence Scale for Children* (3rd ed.). London: Psychological Corporation.

Wheeler, L., & Reitan, R. (1963). Discriminant functions applied to the problem of predicting cerebral damage from behavioral tests: A cross validation study. *Perceptual and Motor Skills, 16,* 681–701.

Yago, E., Duarte, A., Wong, T., Barcelo, F., & Knight, R. T. (2004). Temporal kinetics of prefrontal modulation of the extrastriate cortex during visual attention. *Cognitive, Affective & Behavioral Neuroscience, 4,* 609–617.