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PAPER

Differences in the neural mechanisms of selective attention in children from different socioeconomic backgrounds: an event-related brain potential study

Courtney Stevens,[1,2] Brittni Lauinger[1] and Helen Neville[1]

1. *Department of Psychology, University of Oregon, Eugene, OR, USA*
2. *Department of Psychology, Willamette University, Salem, OR, USA*

Abstract

Previous research indicates that children from lower socioeconomic backgrounds show deficits in aspects of attention, including a reduced ability to filter irrelevant information and to suppress prepotent responses. However, less is known about the neural mechanisms of group differences in attention, which could reveal the stages of processing at which attention deficits arise. The present study examined this question using an event-related brain potential (ERP) measure of selective auditory attention. Thirty-two children aged from 3 to 8 years participated in the study. Children were cued to attend selectively to one of two simultaneously presented narrative stories. The stories differed in location (left/right speaker), narration voice (male/female), and content. ERPs were recorded to linguistic and non-linguistic probe stimuli embedded in the attended and unattended stories. Children whose mothers had lower levels of educational attainment (no college experience) showed reduced effects of selective attention on neural processing relative to children whose mothers had higher levels of educational attainment (at least some college). These differences occurred by 100 milliseconds after probe onset. Furthermore, the differences were related specifically to a reduced ability to filter irrelevant information (i.e. to suppress the response to sounds in the unattended channel) among children whose mothers had lower levels of education. These data provide direct evidence for differences in the earliest stages of processing within neural systems mediating selective attention in children from different socioeconomic backgrounds. Results are discussed in the context of intervention programs aimed at improving attention and self-regulation abilities in children at-risk for school failure.

Introduction

Even before the first day of kindergarten, a child's academic prospects can be predicted based on characteristics of his or her parents, including their income, occupation, and level of education (e.g. Baydar, Brooks-Gunn & Furstenberg, 1993; Duncan, Brooks-Gunn & Klebanov, 1994; Walker, Greenwood, Hart & Carta, 1994). Collectively, these familial characteristics are considered part of a child's socioeconomic status (SES), with children from lower socioeconomic backgrounds at-risk for school failure. Indeed, a robust predictor of a child's classroom grades, standardized test scores, and likelihood of high-school graduation is her own mother's level of education (Baydar *et al*., 1993; Liaw & Brooks-Gunn, 1994; Walker *et al*., 1994). These intergenerational cycles of academic underachievement are embedded in a complex system of factors that covary with socioeconomic status, including school and neighborhood characteristics, parenting practices, and exposure to neurotoxins (Brooks-Gunn & Duncan, 1997; Duncan *et al*., 1994; Jimerson, Egeland, Sroufe & Carlson, 2000). Several lines of evidence suggest that these and other environmental covariates mediate at least part of the relationship between familial SES and children's academic outcomes (Brooks-Gunn & Duncan, 1997; Capron & Duyme, 1989; Duncan *et al*., 1994; Jimerson *et al*., 2000; Noble, McCandliss & Farah, 2007; Schiff, Duyme, Dumaret & Tomkeiwics, 1982).

Although previous research has examined the relationship between SES and broad academic indicators such as graduation rates and standardized test scores, recent research has shifted the focus of the question to whether SES is associated with differences in more *specific* neurocognitive systems, for example in aspects of language or attention (Farah *et al*., 2006; Mezzacappa, 2004; Noble *et al*., 2007; Noble, Norman & Farah, 2005). It has been proposed that academic underachievement among children from lower socioeconomic backgrounds might be related most strongly to the development of certain foundational skills or neural systems (Mezzacappa, 2004; Noble *et al.*, 2005). Under this hypothesis, atypical development of a foundational skill could have cascading consequences on later development and learning. Thus, if specific neurocognitive deficits could be identified in children from lower socioeconomic backgrounds early in development, it might be possible to develop more

Address for correspondence: Courtney Stevens, Department of Psychology, Willamette University, 900 State Street, Salem, OR 97301, USA; e-mail: cstevens@willamette.edu

focused interventions that target these systems or skills. As such, the long-term goal of this research is the identification of aspects of cognition that could be targetted by interventions for children from lower socioeconomic backgrounds, as part of larger programs of systemic change addressing the negative impacts of lower SES on children's cognition.

The present research, motivated in part by recent reports of behavioural deficits in aspects of attention as a function of familial SES (Farah *et al.*, 2006; Lipina, Martelli, Vuelta & Colombo, 2005; Lupien, King, Meaney & McEwen, 2001; Mezzacappa, 2004; Noble *et al.*, 2007; Noble *et al.*, 2005), examines the neurobiology of selective auditory attention in children from different socioeconomic backgrounds. Using maternal education as a proxy for SES, the present study examines whether children whose mothers have lower levels of education (defined as no college experience) versus higher levels of education (here defined as some college experience) differ in the effects of sustained, selective auditory attention on early (~100 ms) stages of perceptual processing indexed using event-related brain potentials (ERPs). If differences were observed at this early stage of neural processing, such differences would provide a possible mechanism whereby deficits in aspects of attention could influence the processing of information in a range of domains.

Attention in children from diverse socioeconomic backgrounds

A handful of recent studies have examined aspects of attention and executive function in children from diverse socioeconomic backgrounds (Farah *et al.*, 2006; Lipina *et al.*, 2005; Lupien *et al.*, 2001; Mezzacappa, 2004; Noble *et al.*, 2007; Noble *et al.*, 2005). These studies, described in detail below, reveal that children from lower socioeconomic backgrounds experience difficulties with aspects of attention as early as the first year of life (Lipina *et al.*, 2005) that persist at least through early adolescence (Farah *et al.*, 2006). The attention deficits observed appear most strongly linked to tasks that require filtering distracting information, managing response conflict, and regulating behaviour.

As early as infancy, differences in attentional precursors can be observed among individuals from different socioeconomic backgrounds. One recent study (Lipina *et al.*, 2005) tested a group of 280 Argentinian 6- to 14-month-old infants using the A-not-B task, which is associated with later executive functioning skills. The infants from lower socioeconomic backgrounds showed poorer performance on the task relative to their higher SES peers. The authors proposed that these early differences could be a precursor to later difficulties in executive function and attention in children from lower socioeconomic backgrounds.

Indeed, several studies of school-age children report deficits in aspects of attention in children from lower socioeconomic backgrounds. For example, Mezzacappa (2004) assessed a group of 249 children age 5 to 7 years old using the children's attention network test (ANT; Rueda *et al.*, 2004). Relative to their higher SES peers, children from lower socioeconomic backgrounds showed increased interference from peripheral flanker stimuli, indicating a reduced ability to filter distracting information and manage response conflict. Children from lower socioeconomic backgrounds also showed reduced influences of an alerting cue on accuracy and reaction times, suggesting that children from lower socioeconomic backgrounds might have an overall upregulation of attention vigilance.

A study by Lupien, King, Meaney and McEwen (2001) also suggested that attention is compromised in children from lower socioeconomic backgrounds, at least at early ages. In this study, separate comparisons were made of children from higher and lower socioeconomic backgrounds for each of six different age groups, ranging from early elementary school (mean age 6 years) to late high school (mean age 16 years). Children completed a visual detection task requiring selective attention. In the task, children indicated whether the number '2' appeared in a briefly presented four-item visual display containing either distractor letters (easy detection) or distractor numbers (difficult detection). In the youngest age group, children from lower socioeconomic backgrounds performed significantly worse than children in the higher SES group on this task. However, this pattern was reversed in children in the oldest age group and absent in children in the middle age groups. These data suggest possible attentional differences associated with SES early in development, though interpretation is confounded by possible differences in letter/number knowledge given the use of the alphanumeric stimuli and by probable differences in task difficulty across the age groups.

In a series of studies conducted by Farah and colleagues, aspects of attention and executive function were examined in elementary- and middle-school students from different socioeconomic backgrounds. An initial study of 60 African–American first-graders (Noble *et al.*, 2005) found that children from lower socioeconomic backgrounds showed large deficits (Cohen's $d = .68$) on an executive attention battery that included a go/no-go task, a test of spatial working memory, and false-alarm rates on three tasks from the other test batteries. The children from lower socioeconomic backgrounds also tended to have poorer performance both on a dimensional card-sort task that required shifting rule sets and on a theory-of-mind task that required taking the perspective of another individual. Similar results were obtained in two subsequent studies. One study (Farah *et al.*, 2006) included 60 middle-school children and reported that adolescents from lower socioeconomic backgrounds had poorer performance on a cognitive control composite including a go/no-go and number Stroop task. A second study (Noble *et al.*, 2007) included a larger sample of 150 first-grade children, in which familial SES was treated as a continuous variable. Significant, positive correlations were observed between familial SES and a composite measure of executive function that included a go/no-go task and the

NEPSY auditory attention response set task. In addition, in two of the three studies described above, the relationship between SES, executive function, and language was examined (Noble *et al.*, 2005, 2007). In both studies, the relationship between SES and executive function did not persist when performance on standardized measures of language and pre-literacy (which also differed between groups) were controlled for statistically. A similar analysis indicated that SES differences in language/pre-literacy scores were accounted for partially, but not completely, by differences in children's attention scores. The authors suggested that this pattern of findings could indicate that differences in language cause secondary deficits in aspects of attention.

Taken together, the results of these studies suggest that children from lower socioeconomic backgrounds have difficulty in some aspects of attention, at least during the early school years, and that these differences might be related to (i.e. co-occur with, cause, or be caused by) performance in other domains, including language and pre-literacy. Although it has been inferred from these behavioural studies that children from lower socioeconomic backgrounds have deficits in specific neurocognitive systems mediating attentional control and filtering (Farah *et al.*, 2006; Lupien *et al.*, 2001; Mezzacappa, 2004; Noble *et al.*, 2007; Noble *et al.*, 2005), little direct evidence exists on this point. Yet, such data would be useful in further characterizing the nature of group differences in aspects of attention. That is, these previous studies indicate a behavioural deficit in aspects of attention that are associated with later stages of processing indexed by a late (behavioural) measure of response selection. However, behavioural performance reflects the final output of multiple stages of processing, leaving it unclear whether difficulties in attention arise from earlier (e.g. perceptual) and/or later (e.g. response selection) processing stages. Examination of the neural mechanisms of attention can provide greater insight into the nature of group differences on behavioural indices of attention and, as a consequence, into the mechanisms whereby an attention deficit could influence other aspects of cognitive or socioemotional development.

Before proceeding, it is important to note that any investigation into the neural mechanisms of cognitive skills in children from different socioeconomic backgrounds should not be confused with an effort to identify genetic determinants of cycles of poverty and lower educational attainment. Indeed, the brain is highly plastic and modifiable by experience (e.g. Bavelier *et al.*, 2001; Castro-Caldas & Reis, 2003; Pascual-Leone, Armedi, Fregni & Merabet, 2005; Recanzone, Schreiner & Merzenich, 1993). Furthermore, the neural mechanisms investigated in the present study have been shown to be modifiable in response to interventions, including training with high-intensity computerized language programs (Stevens, Fanning, Coch, Sanders & Neville, 2008) or small-group interpersonal reading programs (Stevens, Currin *et al.*, 2008). As such, an understanding of the nature of attention deficits at a more precise level can guide efforts to develop interventions that can target the specific neurocognitive systems that are most in need.

Neural mechanisms of selective attention

Event-related brain potentials (ERPs) have been used to characterize the earliest neural mechanisms of sustained, selected attention in both adults (Hillyard, Hink, Schwent & Picton, 1973; Hillyard, Woldoff, Mangun & Hansen, 1987; Woldoff & Hillyard, 1991) and children (Coch, Sanders & Neville, 2005; Sanders, Stevens, Coch & Neville, 2006). Over thirty years ago, Hillyard *et al.* (1973) first used sensory-evoked potentials to study selective auditory attention. Subjects attended to rapid tones in one ear and ignored a separate stream of tones (different in pitch) presented in the other ear. The participants' task was to detect occasional target stimuli in a single ear, forcing them to restrict attention to one side at a time. ERPs were recorded to standard tone pips occurring in the attended and unattended channel. The first negative component of the evoked potential (N1, 80–110 ms after stimulus onset) was larger to tones in the attended, relative to the ignored, ear indicating attentional modulation of early sensory processing. This early amplification probably resulted from the joint processes of signal enhancement of the attended stimuli and suppression of the competing stimuli presented in the ignored channel. Several subsequent studies replicated and extended this basic ERP signature of selective attention using a variety of stimuli and paradigms (Hillyard *et al.*, 1973, 1987; Woldoff & Hillyard, 1991).

We recently adapted the classic spatial selective auditory attention ERP paradigm to be child-friendly for testing with young elementary-aged and preschool children (Coch *et al.*, 2005; Sanders *et al.*, 2006). Coch, Sanders and Neville (2005) measured attention in adults and typically developing children aged 6 to 8 years. Participants were instructed to listen to one of two narratives, which were played simultaneously from separate speakers located to the left or right of the participant. ERPs were recorded to 100-ms probe stimuli superimposed on the attended and unattended narratives. In both children and adults, probes in the attended story elicited larger-amplitude ERPs when attention was directed towards as compared with away from the story. This attentional enhancement began during early sensory processing, approximately 100 ms after probe onset. The similarity in the nature and timing of attentional modulation in adults and children was particularly striking in light of the differences in the underlying morphology of the auditory-evoked potential components. Whereas adults displayed an evoked response that included an early positivity (P1) followed by a negative component around 100 ms (N1), children showed a broad positivity from 100 to 300 ms in response to probe stimuli. This difference in morphology is consistent with developmental research showing that children's auditory-evoked potentials are dominated by a broad, positive response followed by a later negativity, particularly in acoustically crowded environments with short interstimulus intervals between stimuli (Ponton, Eggermont, Kwong & Don, 2000; Sharma, Kraus, McGee & Nicol, 1997). We later replicated this work and extended it to children as young as 3 years of age (Sanders *et al.*, 2006). Similar to 6- to 8-year-old children, typically developing 3- to 5-year-old children also showed a broad positivity in response to probe stimuli that was enhanced with attention by 100 ms after probe onset. However, in 3- to 5-year-olds, the duration of the attention effect extended into the 200–300-ms time window, whereas the attention effect in 6- to 8-year-olds was complete by roughly 200 ms. This extended attention effect in the younger children could reflect a prolonged effect of attention on neural processing and/or variability between or within individual children in the latency of attention effects.

These studies suggest that ERPs can be used to index the early neural mechanisms of selective attention in very young children. Importantly, because ERPs can be recorded continuously and non-invasively, they provide an online index of the neural mechanisms of selective attention without requiring overt behavioural responses. We have used this paradigm to examine the neural mechanisms of sustained, selective attention in young children with specific language impairment (SLI) who, along with children with reading impairment, are reported to have behavioural deficits in aspects of attention (Asbjørnsen & Bryden, 1998; Atkinson, 1991; Cherry, 1981; Sperling, Lu, Manis & Seidenberg, 2005; Ziegler, Pech-Georgel, George, Alario & Lorenzi, 2005). Unlike typically developing children, children with SLI do not show ERP evidence of early attentional modulation, even when performing the task as directed (Stevens, Sanders & Neville, 2006). Furthermore, the deficits in children with SLI are linked specifically to reduced amplification of the neural response to probes in the attended channel (i.e. signal enhancement) rather than to difficulties in the suppression of responses to probe stimuli in the ignored channel (i.e. distractor suppression) (Stevens *et al.*, 2006). This suggests that the ERP paradigm described above is sensitive to group differences in the neural mechanisms of attention and can be used to index different processes of early, spatial selective attention (signal enhancement and distractor suppression) in young children.

Overview of the present study

In the present study, 32 children aged 3 to 8 years completed the ERP measure of sustained, selective auditory attention described above and used in our previous research (Sanders *et al.*, 2006; Stevens *et al.*, 2006). The children were divided into two groups based on their mother's level of education: 16 children lived with mothers who had completed at least one year of college (higher maternal education) and 16 children lived with mothers who had no college experience (lower maternal education). It was predicted that children in the lower maternal education group would show reduced or absent effects of attention on early stages of neural processing.

Method

Participants

Thirty-two children aged 3 to 8 years participated in the present study (range = 3.8 years to 8.7 years, $M = 6.1$ years, $SD = 1.4$, 16 girls). Of the participants providing information on race/ethnicity, the majority (90%) were White/Caucasian. All participants met the following criteria for participation in the study: (1) monolingual English speakers, (2) no history of neurological or language disorders, and (3) normal hearing, vision, and oral-motor performance on standard screenings. In addition, because our previous research indicated marked deficits on this task in children with specific language impairment (Stevens *et al.*, 2006), only children scoring above the 25th percentile on the receptive language composite were included in the study.

The children in the final sample represent a subset of those reported on previously in our study of 53 typically developing children age 3 to 8 years of age (Sanders *et al.*, 2006). This subset of children was selected to maximize differences based on socioeconomic background (see below), while keeping all experimental conditions balanced across the two groups.

Although information on education and occupation concerning the mother, father and any step-parents or guardians was collected using the Hollingshead questionnaire (Hollingshead, 1975), maternal education alone was used as a proxy for SES. This decision was based on the variable family structure observed in the sample of young children. Specifically, whereas all children currently lived with their mother and had done so since birth, the presence and number of years of contact with fathers, step-parents and other guardians were highly variable. Thus, in order to apply a consistent coding scheme to all children, data on the mother alone were utilized. As previous research has noted the temporal instability of maternal occupational status and its lack of correlation with children's cognitive outcomes (Gottfried, Gottfried, Bathurst, Wright Guerin & Parramore, 2003), only maternal education scores were used. The use of maternal education is consistent with previous research showing that maternal education alone correlates with children's cognitive outcomes (Baydar *et al.*, 1993; Gottfried *et al.*, 2003; Liaw & Brooks-Gunn, 1994; Noble *et al.*, 2007; Walker *et al.*, 1994).

Thus, children were divided into two groups based on the level of education completed by their mother. 'Higher maternal education' was defined as at least one year of college experience, whereas 'lower maternal education' was defined as no more than high school. Of the 16 children in the lower maternal education group, 15 had parents who had completed high school. Of the 16

Table 1 *Demographic characteristics of participant groups. None of the differences was statistically significant*

	Higher maternal education	Lower maternal education
N	16	16
No. of males	8	8
Race/ethnicity	12 White 1 American Indian 1 Hispanic 2 Declined to answer	14 White 1 White/Black 1 Declined to answer
Age in years (*SD*)	6.0 (1.4)	6.2 (1.3)
Receptive language SS (*SD*)	109 (15)	103 (11)

children in the higher maternal education group, 10 had mothers who had completed partial college (at least one year), four had mothers with four-year degrees, and two had mothers with graduate degrees. Table 1 summarizes the demographic characteristics of each group.

Behavioural testing

All participants completed the receptive language composite from the Clinical Evaluation of Language Fundamentals (CELF; Semel, Wiig & Secord, 1995). Behavioural and ERP testing occurred in different sessions separated by no more than 35 days.

Materials

Eight 2.5–3.5-minute stories were digitally recorded (16 bit, 22 kHz) using an Electro Voice 1750 microphone connected to a Macintosh computer running a sound-editing program (SoundEdit 16, Version 2). The set of stories comprised four stories from the *Blue Kangaroo* series (Clark, 1998, 2000, 2002, 2003) and four stories from the *Harry the Dog* series (Zion & Graham, 1956, 1960, 1965, 1976). The story series were different in style and content, and each was recorded by both a male and a female narrator, reading in a child-directed manner. Pauses were edited to be less than 1 second, and the mean amplitude of the files was normalized to 60 dB SPL (A-weighted). Following editing, stereo files were created that presented one story from each series in a separate channel (right/left speaker). The two audio channels always differed in story series (*Harry the Dog* or *Blue Kangaroo*) and narrator voice (male or female). A monitor in front of the participant (57 inches away) presented 2.5-inch scanned images of the story in one of the two channels (corresponding to the attended channel, see Procedure below) and was small enough to prevent eye movements. A small green arrow pointing to the left or the right was at the bottom of every image as a reminder of which channel to attend to (Figure 1).

Linguistic and non-linguistic probe stimuli were superimposed on the stories in each channel. The linguistic probe was a 100-ms digitized (16 bit, 22 kHz) syllable /ba/ spoken in a female voice (different than the female storyteller's). The non-linguistic probe was an edited version of the /ba/ stimulus, in which 15–20-ms segments of the stimulus were reordered to create a buzz-like sound that nonetheless preserved many of the acoustic characteristics of the /ba/. The rise-times of the linguistic and non-linguistic probes differed. An equal number ($N \sim$ 180–206) of linguistic and non-linguistic probes were presented in each channel. The probes were presented randomly every 200, 500 or 1000 ms in one of the two auditory channels.

Procedure

After arrival and a short orientation, a parent or caregiver signed a consent form, and the child provided either verbal or written assent. Before the data were recorded, the participant heard instructions in a practice session that introduced the child to the two voices and probe stimuli. During the practice, children received instruction on attending to a single story while ignoring the distracting story presented in the opposite audio channel. A researcher sat next to the child at all times to monitor behaviour, to ensure that the child remained equidistant between the two speakers, and to administer comprehension questions following each story. A camera transmitted the session so that other researchers and the caregiver(s) could observe from outside the booth.

Children were instructed to attend selectively to one story, while ignoring the story presented in the opposite audio channel. Half of the children began attending to the right audio speaker, and half of the children began attending to the left audio speaker. Children attended to a total of four narratives, attending twice to the story on the right side and twice to the story on the left side (order either RLLR or LRRL). For each child, the attended narrator and story set remained constant across the four stories. After each story, the experimenter asked the child three basic comprehension questions about the attended story. The comprehension questions always had two alternatives. (A response of 'I don't know' was counted as an incorrect response.) At the end of all four stories, the experimenter asked one general question regarding the unattended stories. The majority of the questions focused on the attended story in order to encourage the child to maintain focus on a single story.

The higher and lower maternal education groups were matched for all stimulus factors, including attended story, start side and narration voice.

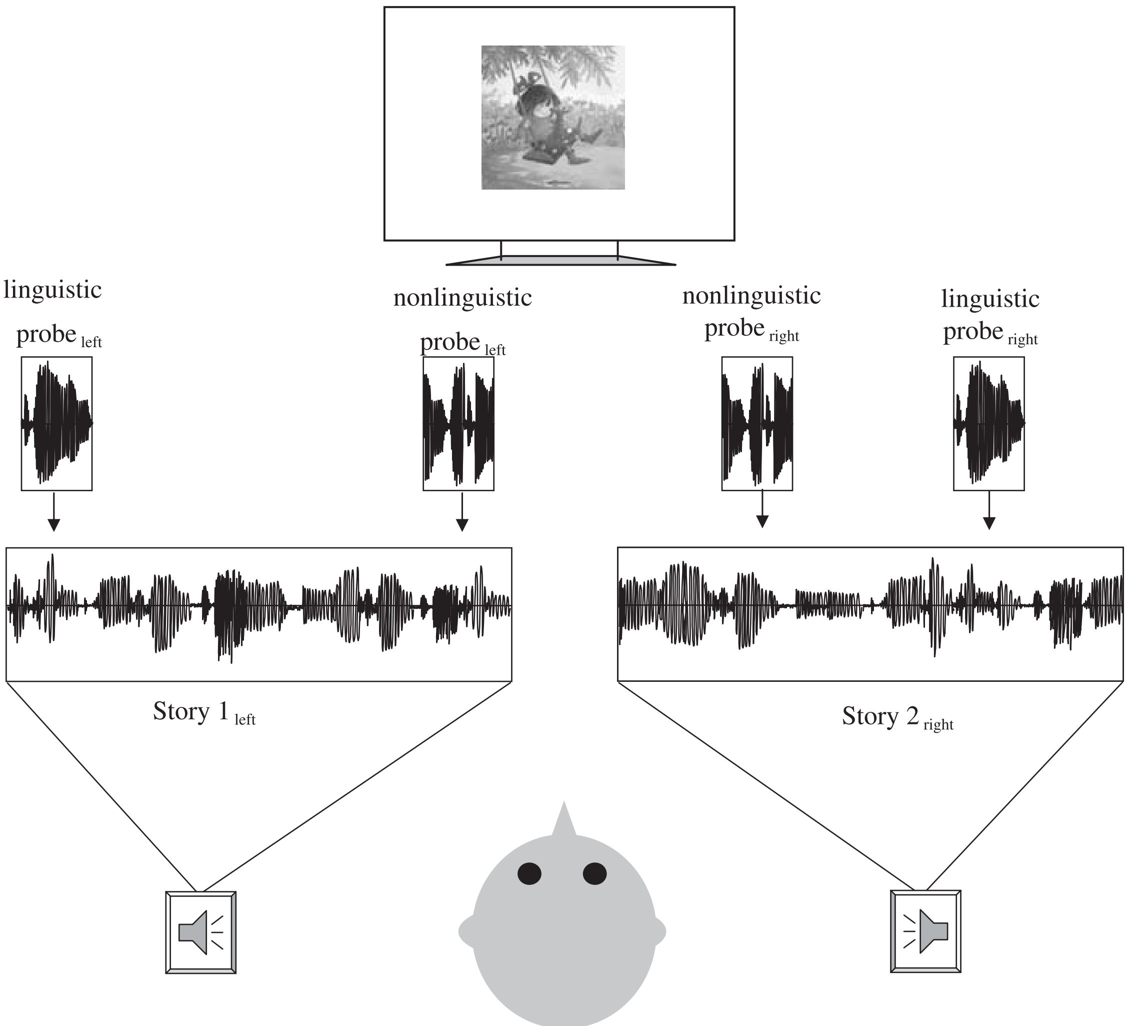

Figure 1 *Schematic representation of the experimental paradigm. Children were instructed to attend to the story presented from either the left or the right speaker. Event-related brain potentials were recorded to probe stimuli superimposed on both the attended and the ignored narrative.*

ERP recording and analysis

The electroencephalogram (EEG) was recorded from 29 silver-chloride electrodes (Figure 2) mounted in an elastic cap (Electro-Cap International). Electrodes were also placed horizontally next to each eye and beneath the right eye in order to monitor eye movements and blinks. Online, electrodes were referenced to the left mastoid. Offline, data were referenced to the averaged left and right mastoids. Eye channel impedances were maintained below 10 kΩs, mastoids below 3 kΩs, and all other sites below 5 kΩs.

The EEG was amplified with Grass 7P511 amplifiers (–3-dB cutoff, band pass .01 to 100 Hz) and digitized online (4-ms sampling rate). Offline, separate ERPs to the four types of probe stimuli (linguistic attended, linguistic unattended, non-linguistic attended, non-linguistic unattended) were averaged for each subject at each electrode site over a 500-ms epoch, using a 100-ms pre-stimulus-onset baseline. Individual artifact rejection parameters were selected for each subject on the basis of visual inspection of the raw EEG to identify the smallest-amplitude changes associated with eye movements or blinks. Following artifact rejection, there were no differences between maternal education groups in the number of ERP trials available for analysis in any bin, which is an indirect measure of motor and eye movements, largest $t(30) < 1$, $p = .35$. All children had at least 78 trials, and on average 163 trials, available for analysis in each of the four bins.

ERP data were analysed using a $2 \times 2 \times 2$ mixed design analysis of variance (ANOVA) on the mean amplitude of the ERP from 100 to 200 ms post-stimulus onset, averaged over the anterior four rows of 16 electrodes (F7/8, FT7/8, F3/4, FC5/6, C3/4, C5/6, CT5/6, T3/4; see Figure 2). Within-subject factors included attention (attended/unattended) and probe type (linguistic/non-linguistic). The between-subject factor was group (higher/lower maternal education). This set of electrodes was selected based on past research using the auditory attention

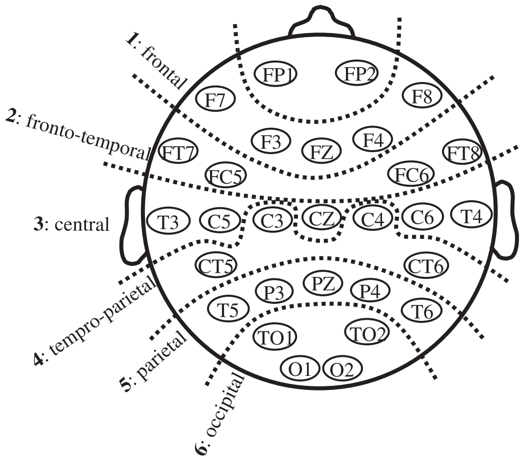

Figure 2 *Electrode configuration for event-related brain potential recording. The 16 electrodes included in analysis are specified in the text.*

Table 2 *Mean amplitude response (in V) from 100 to 200 ms to probe stimuli as a function of attention condition, separately for children in the two maternal education groups. Data are collapsed across the linguistic and non-linguistic probe types*

	Higher maternal education	Lower maternal education
Attended probes (*SD*)	3.2 (1.0)	2.9 (0.9)
*Unattended probes (*SD*)	1.4 (0.8)	2.3 (0.9)
*Attention effect, Attended – Unattended (*SD*)	1.7 (0.7)	0.6 (1.1)

* Significant difference, $p < .05$.

paradigm with both typically developing children (Coch *et al.*, 2005; Sanders *et al.*, 2006) and children with specific language impairment (Stevens *et al.*, 2006). The 100–200-ms time window was selected because, in our ongoing analyses with typically developing children (Sanders *et al.*, 2006), we find a reliable effect of attention for children age 3–5 and 6–8 years during this early time window, although younger children continue to show an effect from 200 to 300 ms.

Results

Behavioural testing

On average, standard scores on the CELF receptive language scores were 109 ($SD = 15$) in the higher maternal education group and 103 ($SD = 11$) in the lower maternal education group. However, this 6-point difference in standard scores between groups was not statistically significant, unpaired $t(30) = 1.3$, $p = .2$.

ERP results

In response to probe stimuli, children in both the higher and the lower maternal education group showed a single, broad positivity peaking around 150 ms post-stimulus onset (see Figure 3). The main effect of group was not significant, $F(1, 30) = 1.0$, $p = .32$, nor was the interaction between group and probe type, $F(1, 30) < 1$, $p = .70$. Across groups and probe types, the positivity was larger to probes in the attended compared with the unattended channel, main effect of attention $F(1, 30) = 52.4$, $p < .001$; interaction between attention and probe type, $F(1, 30) < 1$, $p = .49$.

Crucial to the hypothesis of the study, the group × attention interaction was significant, $F(1, 30) = 13.4$, $p = .001$, indicating that the effect of attention differed for children in the higher and lower maternal education groups (see Figure 3 and Table 2). As the group difference in attention did not vary as a function of probe type (group × attention × probe type, $F(1, 30) < 1$, $p = .63$), simple effect tests for the difference between attended and unattended stimuli were conducted for each maternal education group, collapsed across probe type. The means for each group are presented in Table 2. Children in the higher maternal education group showed a larger positivity to probes in the attended versus the unattended channel, paired-samples $t(15) = 10.0$, $p < .001$. Children in the lower maternal education group also showed attentional modulation during this time window, paired samples $t(15) = 2.1$, $p < .05$. However, the magnitude of the effect of attention was significantly larger in the higher than in the lower maternal education group, unpaired $t(30) = 3.6$, $p = .001$ (mean effect of attention 1.7 and 0.6 V for the higher and lower maternal education groups, respectively).

Attentional modulation involves two processes: enhancement of attended stimuli and suppression of distracting, competing stimuli. Following previous research (Stevens *et al.*, 2006), supplemental analyses compared the higher and lower maternal education groups directly on these two processes. If the magnitude of the evoked response to attended and unattended stimuli is taken as an index of each of these processes, respectively, direct comparison of the two groups could identify whether group differences in the magnitude of the attention effect arose primarily from differences in one or both attentional mechanisms. This analysis indicated that, whereas the two groups did not differ in response to probe stimuli in the attended channel, independent samples $t(30) < 1$, $p = .40$, the groups did differ in response to probe stimuli in the unattended channel, independent samples $t(30) = -2.87$, $p < .01$; see Figure 4 and Table 2. The pattern of means revealed that children in the higher maternal education group had a smaller-amplitude response to probes in the unattended channel than did children in the lower maternal education group, indicating a better ability to suppress the response to distracting information in the unattended channel.

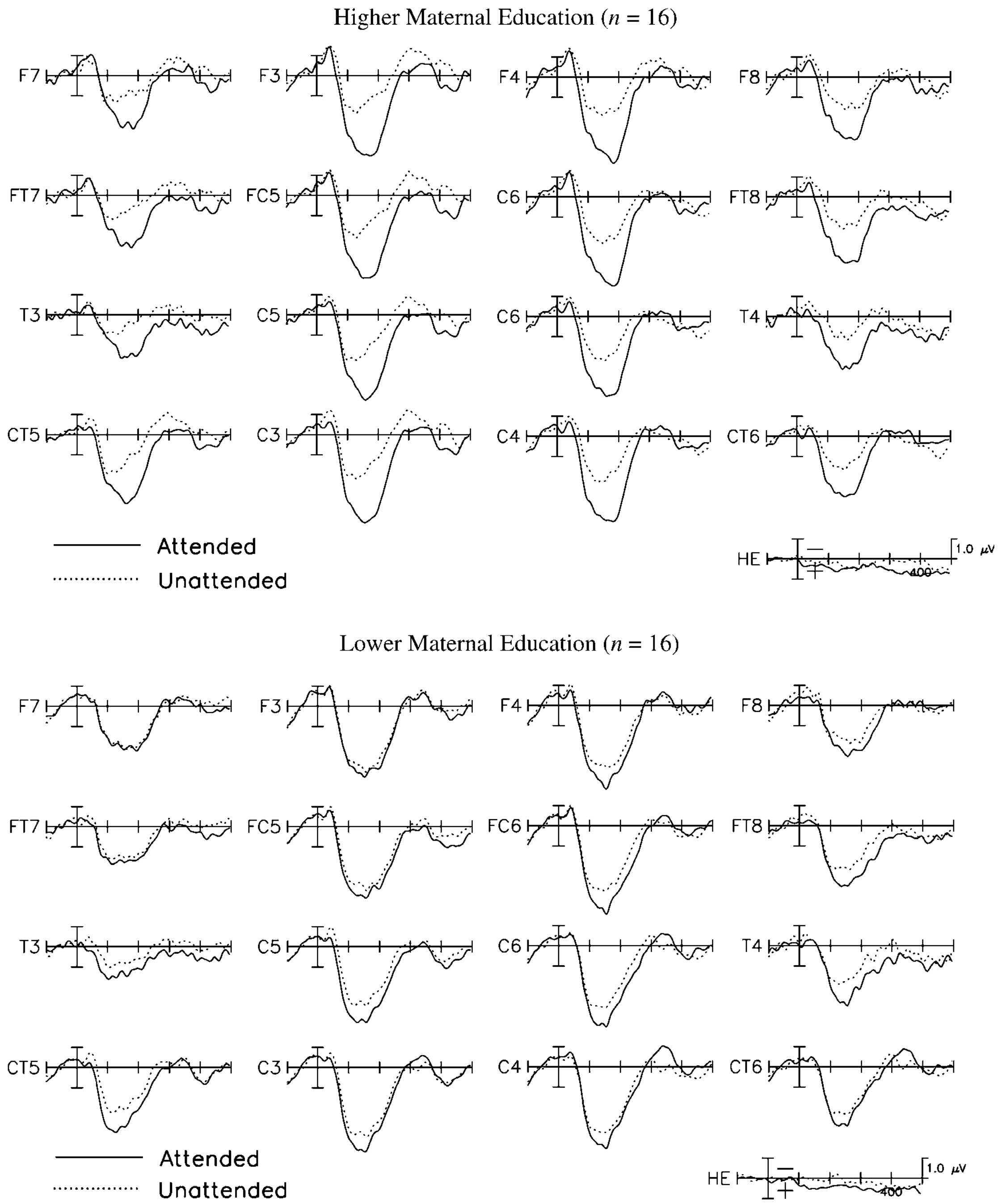

Figure 3 *Grand average evoked potentials for attended and unattended stimuli, collapsed across linguistic and non-linguistic probes, in children in the higher maternal education group (upper panel) and in the lower maternal education group (lower panel).*

As noted previously, the two groups did not differ significantly in receptive language scores. However, it was still possible that the 6-point mean difference in receptive language mediated part or all of the relationship between maternal education and attentional modulation. To control for this possibility, a supplemental analysis of covariance (ANCOVA) was conducted that compared the effects of attention on sensorineural processing (Attended – Unattended difference score, collapsed across probe type) across groups, with children's receptive language standard score included as a covariate. Even when controlling for children's receptive language scores, the two maternal education groups differed significantly in the effects of attention on sensorineural processing ($F(1, 29) = 14.2$, $p = .001$). Receptive language scores did not significantly predict the effect of attention on sensorineural processing ($F(1, 29) < 1$, $p = .36$). Thus, the group differences in the effects of attention on sensorineural processing could not be accounted for by differences in receptive language scores between groups, or vice versa.

To explore whether the group differences in early attentional modulation could be explained by on-task

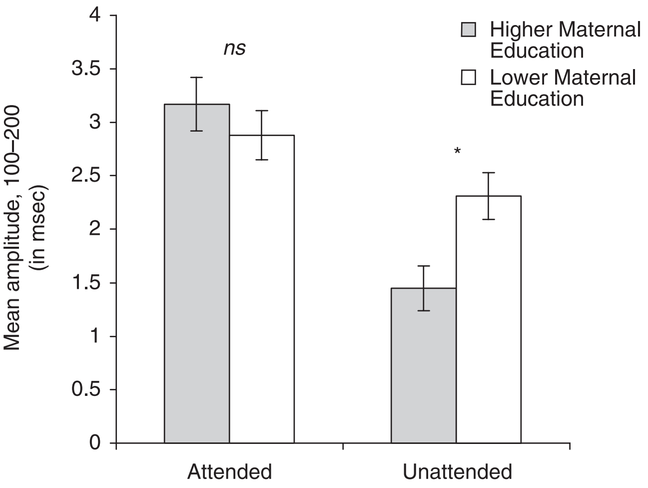

Figure 4 *Mean amplitude response (in V) to probe stimuli in the attended and the unattended channel, separately for children in the higher and lower maternal education groups.*

performance, responses to the 12 comprehension questions about the attended story were also compared across groups. All children answered at least half of the questions correctly. There were no significant differences between the higher and lower maternal education groups in the number of comprehension questions correctly answered about the attended stories, $t(30) = -.17$, $p = .87$, higher maternal education $M = 10.1$, $SD = 1.1$, lower maternal education $M = 10.2$, $SD = .9$. Responses to the single question about the unattended story were at chance levels for both groups, largest one-sample $t = 1.6$, $p = .14$, and also did not differ between groups, Fischer's exact $p = 1.0$.

Discussion

In the present study, children whose mothers had lower levels of education (no college experience) showed reduced effects of selective attention on neural processing relative to children whose mothers had higher levels of education (at least some college). These differences were related specifically to a reduced ability to filter irrelevant information (i.e. to suppress the response to ignored sounds) and could not be accounted for by differences in receptive language skill. These data provide direct evidence for differences in the neural systems mediating selective attention in young children from different socioeconomic backgrounds and reveal that such differences affect neural processing within 100 ms of stimulus presentation.

Nature of attentional differences

Previous behavioural studies indicate that children from lower socioeconomic backgrounds experience difficulty with selective attention, and particularly in tasks of executive function and in those tasks that require the filtering of irrelevant information or the suppression of prepotent responses (Farah *et al.*, 2006; Lupien *et al.*, 2001; Mezzacappa, 2004; Noble *et al.*, 2007; Noble *et al.*, 2005). The results from this study help to clarify the nature of these group differences. First, the present data indicate that group differences in sustained selective attention can be traced to early stages of processing (within 100 ms of stimulus presentation). This suggests that group differences in selective attention and filtering arise, at least in part, from differences in attentional modulation of the early stages of perceptual processing. Second, the nature of the group difference in early attentional modulation was linked specifically to differences in *distractor suppression* of stimuli in the unattended channel. Whereas children in the two groups did not differ in response to probe stimuli in the attended channel, children whose mothers had lower levels of educational attainment displayed reduced suppression of distracting information presented in the competing channel. It is interesting to note that the mechanism implicated in attention deficits in children from lower socioeconomic backgrounds (i.e. distractor suppression) is not the same as the mechanism implicated in previous research on attention deficits in children with SLI, who show a deficit in signal enhancement of stimuli in the attended channel (Stevens *et al.*, 2006). Thus, examination of the neural systems underlying a particular cognitive ability can identify different mechanisms that give rise to similar impairments in behavioural performance.

To our knowledge, only one other study has compared the neural mechanisms of selective auditory attention in individuals from diverse socioeconomic backgrounds (D'Angiulli, Herdman, Stapells & Hertzman, 2008). Unlike the present research, the study by D'Angiulli and colleagues examined older adolescents, aged 12–14 years. The adolescents performed a non-spatial auditory attention task, in which they attended to tones at one of two pitches presented binaurally. Participants responded to targets of the attended pitch that were longer in duration. Whereas adolescents from higher SES backgrounds showed attentional modulation of ERPs around 300 ms after stimulus onset and again from ~600 to 800 ms, adolescents from lower SES backgrounds did not show attentional modulation of the ERPs during either time window. In contrast, only the adolescents from lower socioeconomic backgrounds showed attention effects on theta activity: increased frontal theta activity was elicited by tones in the ignored frequency channel from 200 to 700 ms after tone onset in children from lower SES backgrounds. Because there were no differences between groups in behavioural performance on the target detection task, the authors suggested that the two groups of adolescents were using different attentional mechanisms to perform the selection task. Thus, in both the present study and the study by D'Angiulli and colleagues, individuals from lower socioeconomic backgrounds exhibit reduced attentional modulation of ERP components.

The present study examined sustained, selective auditory attention using an online measure of neural activity and a task that did not require overt behavioural responses. Indeed, this was one of the primary advantages of using ERPs: the methodology was well-suited to indexing cognitive processes online while minimizing extraneous task demands. In the present study, the children in both the higher and lower maternal education groups were willing and able to complete the task, as indicated by the high overall performance on the comprehension questions about the attended story and the lack of group differences in this measure. At the same time, in the face of these data, it is reasonable to speculate whether there are behavioural consequences of a reduced effect of attention on sensorineural processing.

One possibility, suggested by D'Angiulli and colleagues (2008), is that children from lower socioeconomic backgrounds may use different neural mechanisms to achieve similar behavioural performance on a given task. Another possibility is that group differences in performance do exist, but only become apparent when processing demands increase. Indeed, previous research has associated the magnitude of the ERP attention effect with improved behavioural performance on detection tasks, as measured by response accuracy, reaction time, and d-prime (Neville & Lawson, 1987; Roder *et al*., 1999; Squires, Hillyard & Lindsay, 1973; Teder-Salejarvi & Hillyard, 1998; Teder-Salejarvi, Pierce, Courchesne & Hillyard, 2005). The possibility that behavioural deficits only arise when task demands are sufficiently difficult could explain why one previous behavioural study of attention found behavioural deficits in children from lower SES backgrounds only in the youngest age group (Lupien *et al.*, 2001).

The present study localizes the timing (100 ms) and mechanism (distractor suppression) of selective attention deficits in children from lower socioeconomic backgrounds. However, the poor spatial resolution of ERPs means that strong conclusions cannot be drawn about the identity of the specific neural networks that mediate these group differences. Previous studies (Farah *et al.*, 2006; Mezzacappa, 2004; Noble *et al.*, 2005, 2007) have speculated that differences in behavioural measures of executive attention and filtering reflect deficits in prefrontal neural systems. It has been noted that the prefrontal cortex shows a protracted time course of development and might be influenced by differences in stress hormones, including cortisol, which are present at higher levels in children from lower SES backgrounds (Lupien, King, Meaney & McEwen, 2000; Lupien *et al.*, 2001).

Potential implications of an attention deficit

Difficulties in suppressing irrelevant information could have profound impacts on a child's development in other domains. At the most general level, difficulty filtering distracting sounds could render the typical environment poorly suited for learning. For example, an early task for the infant or child is to focus selectively on particular input for further processing, including speech in the environment (Vouloumanos & Werker, 2004). In addition, a mechanism similar to selective attention appears to facilitate an early amplification of the neural response to word-initial syllables relative to word-medial syllables, even when matched for acoustic characteristics (Astheimer & Sanders, 2009; Sanders & Neville, 2003; Sanders, Newport & Neville, 2002). Difficulties with selective attention could impede these processes. Likewise, the typical classroom environment, which is replete with auditory and visual distractions, may make it difficult for a child to focus on a teacher's instructions or on an assignment at hand.

Efficient reading, in particular, requires the ability to focus on selective letters, words, or phrases. Previous research indicates that poor readers show an attentional bias for focusing on word-initial or word-final letters when reading. Interventions that train children to focus attention on all individual letters – including word medial letters – are associated with improvements in decoding skill (McCandliss, Beck, Sandak & Perfetti, 2003). In addition, when reading new words, children must be able to suppress prepotent responses based on already-learned words with a similar, but not identical, spelling. For example, when encountering the word *cot* for the first time, the child must be able to suppress reading the word as *cat*, a more frequently occurring word that is likely to be learned earlier in the reading process. Thus, learning to read might be expected to depend on the ability to focus on relevant dimensions of spelled words, as well as on the ability to suppress overlearned responses for early-sight words, such that a child can observe and appreciate meaningful differences between newly learned words. Indeed, recent research indicates that preschool measures of aspects of executive function correlate more strongly than IQ with several aspects of academic performance in kindergarten (e.g. Blair & Razza, 2007).

Although attention may have a role in these different aspects of learning, it is important to note that the present study was not designed to answer causal questions about the relationship between the neural mechanisms of selective attention and skill in other domains. Indeed, receptive language scores did not show a significant relationship to the attention index when entered as a covariate in the analysis. This lack of a relationship could indicate that attention skills, as measured with this ERP index, are orthogonal to language development within the normal range of abilities represented in the present study (children below the 25th percentile were excluded from the study). However, it is also possible that the attentional index in the present study is poorly suited for correlational analysis. The ERP attention index represents a difference score (Attended – Unattended), which will be less reliable than an index of attention based on either a single measurement or a composite of several different measures tapping the same construct (Bonate, 2000; Zimmerman, 1994). It will take a different type of study to address the question of causality and interrelationships among skills more directly. However, two studies (Noble *et al.*, 2005, 2007) that used composite measures of language and executive function found significant relationships between executive function and language scores. The difference between these previous studies and the current study could be attributable to the different natures of the tasks used and/or to the smaller range of language ability represented in the present study, in which all children scored at or above the 25th percentile.

Even if the association between childhood SES and attentional skills represents a causal relationship, the mechanism underlying this relationship is unknown. A number of studies examining other cognitive domains suggest that at least part of the relationship between SES and cognitive outcomes is mediated by environmental differences associated with lower socioeconomic status (Brooks-Gunn & Duncan, 1997; Capron & Duyme, 1989; Duncan *et al.*, 1994; Jimerson *et al.*, 2000; Noble *et al.*, 2007; Schiff *et al.*, 1982). Indeed, the malleability of cognitive outcomes to instructional interventions (Diamond, Barnett, Thomas & Munro, 2007; McCandliss *et al.*, 2003; Rueda, Rothbart, McCandliss, Saccomanno & Posner, 2005; Stevens, Fanning *et al.*, 2008; Torgesen *et al.*, 2001) provides one powerful indicator that attention deficits are shaped by environmental factors and are amenable to training. Thus, regardless of the pathway underlying this relationship, when there are socioeconomic differences in achievement or cognitive outcomes, it can be asked whether the outcome is amenable to intervention.

Attention interventions

As alluded to previously, if attention represents a core system vulnerable to deficit in children from lower socioeconomic backgrounds, interventions might be designed to target attention skills. In his *Principles of Psychology*, William James raised the idea of attention training for children, proposing that this would be '*the* education *par excellence*' (James, 1890, p. 424, italics original). Although James went on to say that such an education is difficult to define and bring about, attention training has recently been implemented in curricula for preschool and school-age children. For example, the Tools of the Mind curriculum, which is based on Vygotskian principles, assists preschool and kindergarten children in developing planning and self-regulation skills (Bodrova & Leong, 2007). The Tools of the Mind curriculum has been used in several federal Head Start programs serving children from lower socioeconomic backgrounds and is reported to improve multiple academic outcomes as well as measures of executive function (Diamond *et al.*, 2007). A separate group of researchers has developed a computerized preschool attention training curriculum that is associated with improvements in IQ scores and in a neurophysiological measure of attention (Rueda *et al.*, 2005). Finally, a recent study reports greater effectiveness of a remedial writing intervention for adolescents with dyslexia when the program is preceded by an attention training program (Chenault, Thomson, Abbott & Berninger, 2006). Prior attention training appears to allow the students to benefit more from the targetted writing intervention. These studies suggest that attention can indeed be trained and that effective interventions exist for improving attention in children of all ages. Furthermore, at least two studies (Rueda *et al.*, 2005; Stevens, Fanning *et al.*, 2008) report that behavioural improvements in attention, nonverbal intelligence, and/or language and pre-literacy are accompanied by changes in the neural mechanisms of attention, including the electrophysiological index described above (Stevens, Currin *et al.*, 2008; Stevens, Fanning *et al.*, 2008). These data suggest that modifications in behaviour can arise alongside changes in the early neural mechanisms of attention.

In line with previous suggestions (Noble *et al.*, 2005), we hypothesize that interventions targetting attention skills may serve as a force-multiplier, leading to improvements in domains outside attention. It will be important for future research and intervention studies to investigate the viability of training programs to improve selective attention and self-regulation skills among children from lower socioeconomic backgrounds. Such training programs, if implemented as part of larger efforts of systemic change, may aid in closing the socioeconomic gap in children's academic achievement. However, such an intervention should not be perceived as a 'quick fix' to the impacts of persistent poverty and low socioeconomic status on children's development. The learning trajectories of children from lower socioeconomic backgrounds, which consistently undershoot those of their peers from higher socioeconomic backgrounds (NAEP, 2005a, 2005b), occur in the context of differences in access to resources (including basic nutrition), home environments, family interaction patterns, and neighborhood and school systems (Brooks-Gunn & Duncan, 1997; Capron & Duyme, 1989; Duncan *et al.*, 1994; Jimerson *et al.*, 2000; Schiff *et al.*, 1982). Thus, although early childhood programs for children in lower socioeconomic backgrounds may include training in foundational systems, including attention regulation and control, to be maximally effective such interventions should occur within comprehensive programs addressing socioeconomic and class divide.

Conclusions

The present data support previous reports of deficits in selective attention and attentional control, and in particular in the filtering of distracting stimuli, among young children from lower socioeconomic backgrounds. These attention deficits impact very early stages of perceptual processing and could have cascading consequences on the development of other skills, including language and reading.

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