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# Towards a Cognitive Science of Social Inequality: Children's Attention-related ERPs and Salivary Cortisol vary with their Socioeconomic Status

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## Abstract

We investigated the relationships between socioeconomic status (SES) and the neural correlates of selective attention by comparing event-related potentials (ERPs) in low- and high-SES preadolescents during an auditory selective attention task. Salivary cortisol levels were also determined before and after the task. ERP difference waveforms between attended and unattended auditory stimuli (Nd, *difference negativity*) were significant in the high-SES group but not in the low-SES group. However, post-ERP cortisol levels were elevated only for low-SES children and there were no differences between the groups in reaction times and accuracy. We conclude that low-SES children have reduced attentional selectivity, but at the cost of heightened executive control which allows them to inhibit responding to attended distracters and perform the task as well as high-SES children.

Socioeconomic status reflects living conditions associated with differences or "inequalities" in a series of outcomes during different periods of the life-course (e.g., Graham & Power, 2004). In the last 30 years, research has established that family income and other indicators of *socioeconomic status of origin* (SES), such as parental occupation or education, are highly associated with cognitive and achievement outcomes in childhood (review in Bradley & Corwyn, 2002).

Several environmental variables, including physical health, home environment, early education and neighbourhood characteristics, co-vary systematically with SES and are likely to influence the SES gap in children's cognitive performance and achievement. In particular, low-

SES children generally live in environments that are more crowded, chaotic, noisy and dangerous (e.g., Evans, 2004) than high-SES children and thereby they experience more stressful, unpredictable life events and less sense of control (McLoyd, 1998). Research attempting to clarify how SES may exert its influence on health and well-being shows that stress and SES are associated (Baum, Garofalo & Yali, 1999). For example, compared to high-SES individuals, low-SES individuals are more likely to be exposed to environmental challenges that elicit hyper-vigilance (Kristenson et al., 2004). If low- and high-SES children live in environments with different characteristics, this may be regarded as a particular instance in which children develop different ways of integrating cognitive and emotional aspects involved in adaptation and self-regulation (Blair, 2002). Accordingly, it is reasonable to expect children from different SES backgrounds to develop experience-dependent patterns of neural activity and self-regulation that are differentially associated with attention and executive cognitive processes depending on the types of environmental challenges they normally encounter.

Although the relationship between SES and development may influence some of the most important, and evolutionarily recent functions associated with frontal brain activity such as selective attention and executive control (Farah, Noble, & Hurt, 2004), there has been little direct study of the brain processes that mediate the effects of childhood experiences associated with living conditions, as reflected by proxy SES indicators, on executive performance.

Like other cognitive abilities required at school, at home, or in the community, children's *selective attention* may be expected to be subject to the potent influences of

family SES (Bradley & Corwin, 2002). A few studies (e.g., Ardila & Rosselli, 1994; Lupien et al., 2001) have indeed shown a correlation between SES and children's performance on behavioural tests of selective attention. Other research has shown correlations between SES and other executive cognitive processes that are indirectly connected to selective attention, (Breznitz & Norman, 1998; Noble, McCandliss, & Farah, 2007; Waber, et al., 2006). One limitation of this research is that it employed composite variables that were not designed to characterize which specific underlying neural processes might be involved in the observed outcomes. Without evidence from neuroimaging of subjects' concurrent task performance, inferences on the relationship between SES and brain functions are indirect.

There has been very little investigation of the relationship between SES and the neural responses underlying selective attention in childhood. Preliminary ERP reports (e.g., Lauinger, Sanders, Stevens, & Neville, 2006) suggest that, while high-SES children "filter out" irrelevant information, low-SES children of various ages attend to it as much as they attend to the relevant information, without apparent differences or consequences in terms of task performance. The primary purpose of the present ERP study was to further investigate the pattern of relationships between SES and ERP performance in preadolescent children. Specifically, we examined the possibility that the level of selectivity in auditory attention in low- and high-SES children may be associated with the ability to regulate cognitive resources as well as the behaviour required for correctly carrying out an attention task. In the paradigm we used, the challenge for the children was controlling and monitoring attentional allocation as well as response inhibition to distracters that are partially or fully attended; hereafter, we will refer to these components of self-regulation as *executive control*.

Posner and Rothbart (1998) have argued that the anterior attention system, which includes areas of the midprefrontal cortex, underlies executive control capabilities. The electrical brain activity in the range of 4 to 8 Hz, also known as theta activity, is generally believed to be reflective of processes of selective attention, focused attention, expectancy and attentional orienting (Onton, Delorme & Makeig, 2005). Its appearance over the frontal cortical regions has been especially correlated with performance on tasks requiring complex information processing. Therefore, in addition to ERP analysis of the EEG signal we also conducted power analysis to confirm the involvement of midline frontal areas. This system is believed to be involved in the regulation of the hypothalamic-pituitary-adrenal (HPA) axis, which secretes the hormone cortisol in response to stress. Research has shown that low-SES individuals generally have higher basal concentrations of the hormone, believed to reflect higher sensitivity of these individuals to the acute stress response as a result of greater exposure to adverse environmental challenges. Accordingly, we examined patterns of salivary cortisol over the school day and tested the extent to which the performance of the

attention task would be associated with changes in cortisol pre- versus post-ERP measurements. Our predictions were that basal cortisol levels of low-SES children would be higher compared with the high-SES children and that the former would have higher post-ERP cortisol levels.

## Method

**Participants.** Twenty-eight preadolescent children (*mean age* = 13.2, *SD* = 1.4) half with low-SES and half with high-SES background, all Caucasian, with no hearing impairments, were recruited from two different schools: one attended predominantly by students with high SES and the other attended predominantly by students with low SES. All of the participants were typically-developing children with no history of medication or referral to disability assessment or services. The two groups did not differ significantly in average school grade.

**SES measurement.** For each student, SES scores were computed using an adapted version of Hollingshead's (1975) four-factor index of social status. The highest occupation of either parent was rated using the Hollingshead categories 1-4, ranging from 'higher executives' to 'laborers/mental workers'. On the composite SES scale (highest = I, lowest = V), the high-SES parents ranked II (corresponding to college graduates and managers/professionals) whereas the low-SES parents ranked IV (corresponding to high school graduates and skilled workers). The percentage of single parents was 40% in the low-SES group versus 16% in the high-SES group. The percentage of unemployed parents was 35% in the low-SES group versus 0% in the high-SES group. The percentage of developmental vulnerability (as defined by Kershaw et al., 2005) in the low-SES versus the high-SES neighbourhood was 43% versus 7%. The low-SES neighbourhood ranked first for vulnerability, whereas the high-SES neighbourhood ranked last in the context of a large urban area.

**Design.** Children were seen individually across an entire ordinary school day. Saliva was collected six times, four times before and two after the ERP experiment. To exclude possible confounds (food intake, sleep patterns and intense physical activity), children completed a diary – there were no systematic reliable differences in relation to these confounding variables between the two groups.

## EEG/ERP data collection

**Stimuli.** The stimuli were four pure tones, two frequencies (800 Hz and 1200 Hz) by two durations (100 ms and 250 ms). EEG was recorded during 2 blocks in which both 800- and 1200-Hz tones and durations were presented. In a block, the children were instructed to attend to tones of either 800 or the 1200 Hz, which defined the "attended channel", and to ignore tones with the other frequencies. There were 30 (10%) *attended target-duration (250 ms) tones* (targets), 30 (10%) *unattended target-duration tones* with the same duration as targets but the other frequency (distracters), 120 (40%) *attended non-target duration tones* with the same frequency as targets but the other duration (150 ms), and

120 (40%) *unattended non-target duration tones* with the other frequency and duration.

The four types of tones were presented binaurally with an inter-stimulus interval of 1 second. Stimulus presentation followed different random orders for each block of trials and for each child; the different orders were randomly assigned to a given block and child, except that they were pre-selected so that a target tone would not appear immediately after the next in the presentation sequence. Children were asked to press a button as fast and as accurately as possible to the longer (250 ms) tones (i.e., targets) of one of the two presented frequencies, which was designated as the attended channel. For half of the children within each SES group, in the first block the attended channel was 800 Hz whereas in the second block it was 1200 Hz. For the other half, the order was reversed. Reaction times and accuracy were measured for behavioural analyses.

**Data acquisition and recording procedures.** EEG recordings were made at F3, F4, Fz, FC3, FC4, Cz, and Pz sites during a binaural standard selective attention task (Hillyard, Hink, Schwent & Picton, 1973). All electrodes were referenced to nose tip. Impedances were kept below 5 kOhms. Vertical electrooculogram was recorded from a split bipolar electrode on the left supraorbital ridge and the left zygomatic arch. The data from all channels were digitized on-line at a sampling rate of 1000 Hz. Ocular artifact reduction was based on the eye movement reduction algorithm devised by Semlitsch, Anderer, Achuster and Presslich (1986).

**ERP processing.** Each participant's EEG was epoched (100 ms pre-stimulus and 900 ms post-stimulus) and averaged with respect to the onset of each tone. Averages were computed to both relevant and irrelevant tones, separately for 800 Hz and 1200 Hz. Analyses showed no significant differences as a function of type of pure tone, therefore, the ERPs were averaged across the two types of tones to yield relevant and irrelevant pure tone averages for each subject.

The effect of selective attention was operationalized by computing negative difference waveforms as in previous work in children of comparable ages (Berman & Friedman, 1995). Event-related potential (ERP) differences between *attended tones (same frequency but different duration compared to the target tone)* and *unattended tones (different frequency and duration compared to the target tone)* were calculated. That is, we subtracted averaged ERP responses to 800 Hz (1200 Hz) tones when unattended from averaged ERP responses to 800 Hz (1200 Hz) tones when attended. Note that these trials did not require manual responses. Amplitudes of the attention-related *Nd (difference negativity)* wave were calculated as the maximum negative deflection at two intervals: 100-400 ms (classified as the *early Nd*) and 500-800 ms (classified as the *late Nd*) in the ERP difference waveforms between attended and unattended tones. Analyses of variance were used to determine significant differences of the early and late Nd peak amplitudes and latencies between low- and high-SES groups. Additionally, to test for significant response differences between attend and unattend conditions, we

applied the basic bootstrap percentile method (Efron & Tibshirani, 1993) with 1024 bootstrap samples to compute the 99% confidence interval for the latency and amplitude difference between the conditions averaged across the baseline interval. The difference in the post-stimulus waveform was considered significant when the difference waveform exceeded the confidence interval. Tests were therefore assessed at critical significance levels of  $p_{crit} < 0.001$ .

**Cortisol sampling.** Basal cortisol patterns were determined from saliva samples collected over the course of the school day, before (8:20am, 12:10pm, 12:45pm, 1:15pm) and after (1:45pm, 2:45pm) the ERP session and completion of the attention task. The first sample was taken within a few minutes after arrival at school (8:20am). Four samples were taken after lunch (lunch period was from 11:45 am to 12:30 pm) at 30 minute intervals (12:10 pm, 12:45 pm, 1:15 pm; 1:45 pm) in relation to the ERP session. The first two of these post-lunch samples were obtained to evaluate cortisol changes due to putting on the EEG cap and being in an experimental session, as reported in previous neuroimaging studies (e.g., Tessner, Walker, Hochman & Hamann, 2006). The second two of these samples assessed cortisol responses pre- vs. post-ERP testing. These target samples were those collected at 1:15 pm, immediately before starting the attention task, and at 1:45 pm, immediately after completion of the 30 min ERP task. Saliva was also obtained before the children went home (2:45pm) to measure possible differences between low- and high-SES groups in returning to baseline after the ERP session, as well as to assess more fully the expected decrease in cortisol levels over the school day.

To collect saliva, the child was asked to spit into a small plastic test tube. Saliva samples were stored at 4°C until sampling was completed. The samples were then brought to the laboratory, where they were stored at -20 C<sup>0</sup> until assayed by radioimmunoassay using the Salimetrics High Sensitivity Salivary Cortisol Enzyme Immunoassay Kit (Salimetrics LLC, Philadelphia, PA). The interassay and intraassay variation were both below 10%.

**Data analysis.** Cortisol data were examined for outliers, defined as any value more than  $\pm 3$  SD from the mean. Two children had outlier values for cortisol. These values were 'winsorized' (Tukey, 1977). To compare pre- and post-ERP cortisol levels we computed *residualized change scores* (as in Zumbo, 1999) based on standardized residuals.

## Results

**EEG/ERP and behavioral data.** There were no significant differences between low and high SES children in mean reaction times (579 ms vs. 616 ms) or in mean accuracy (73% vs. 76%). In contrast, the early Nd amplitudes were more negative for high- than low-SES children (based on bootstrap sampling of the baseline difference waveform,  $p < .001$ ). The effects were evident centro-frontally but were best seen at site FC3, with a mean difference at maximum peak of  $\sim 1.1 \mu\text{V}$  ( $t(26) = -2.17, p < .05$ ). No significant effect was found at Pz ( $t < 1$ , for

maximum peak). There were no ERP latency differences between the two groups (*median t* (26) = 1.11, *p* = .28). In sum, children's Nd brain response, which reflects selective attention, varied with SES and seemed associated with a gross location of mid-frontal areas.

The small or absent Nd in the low-SES children means that attentional resources reflected by evoked responses were allocated about equally to both the unattended and the attended channel. However, because these children performed similarly to children with high SES, they must have used neurocognitive processes other than those used by their high-SES counterparts. To investigate this possibility, we conducted a spectral power analysis of the single-trial EEG recordings in the theta band (4-8 Hz). This analysis revealed non-phase-locked activity concurrent with Nd. The results showed that low-SES children had significantly greater event-related theta power to the unattended than attended tones between 200-700 ms, whereas high-SES children showed very small or no differences in theta power between the tones (*p* < .001). Thus, the results from the power analysis confirm that low-SES children probably used neural pathways different from those used by high-SES children to attend and respond selectively.

**Cortisol data.** A 2 x 6 (SES x Cortisol Collection Time) mixed-design ANOVA was computed with repeated measures on the last factor using Greenhouse-Geisser adjustment as required. There was a main effect of Cortisol Collection Time ( $F(3, 62) = 6.57, MSE = .04, p = .001$ ) and a marginal effect of SES ( $F(1, 23) = 3.72, MSE = .01, p = .07$ ), but no interaction effect ( $F > 1$ ). Overall, cortisol levels in low-SES children were marginally higher than levels in high-SES children. Polynomial ANOVA contrasts revealed that cortisol levels over time followed a similar, typical linear pattern in low- and high-SES children, with highest levels in the morning, and levels progressively declining over the day ( $F(1, 23) = 7.86, MSE = .04, p = .01$ ).

To test the hypothesis that low-SES children exerted more effort to inhibit their responses to the unattended tones in order to performance as well as high-SES children, we examined individual differences using a simple hierarchical regression model that emulates ANOVA contrasts, and relative levels of between-subjects and repeated-measure factors, with adjusted degrees of freedom (Sackett & Wu Shortt, 1995). The model regressed positive *increase in selectivity of attention* as reflected by the Nd (the inverse linear transformation of Nd amplitudes) against pre-post ERP cortisol residualized change scores. This analysis revealed the expected difference between the low- and high-SES groups ( $F(2, 25) = 3.69, MSE = 1.60, p < .05, R^2 = .23$ ). Specifically, for low-SES children, an increase in selectivity of attention corresponded to an increase in post-ERP cortisol levels ( $R^2 = .27$ ) whereas no such relationship existed for high-SES children ( $R^2 = .002$ ) as confirmed by a significant slope difference ( $t(1, 25) = -2.43, SE = .49, p < .05$ ). This association between selectivity of attention and cortisol levels appear to support the hypothesis that low-SES children exerted additional executive control to inhibit

their responses to the unattended tones in order to performance as well as high-SES children.

## Discussion

There are three major and novel findings in this study. First, children's Nd brain response, which reflects selective attention, varied with SES. The Nd effect was present in the high-SES children but not in the low-SES children, which suggests that the latter group attended to irrelevant information about as much as they attended to relevant information. These results agree with those of Lauinger, Sanders, Stevens, & Neville (2006) who found that children of various ages in their low-SES group attended equally to distracters as much as to target stimuli. Furthermore, just like these investigators, who found no behavioural/performance differences between their low and high SES participants, the children from both groups in our study did not differ in their performance. Taken together, these findings indicate that there may be attention processing differences as a function of SES level even in the absence of reliable performance differences, which suggests that behavioural measures alone may not be sufficient to uncover the effects of social context on cognition. Second, cortisol levels in low-SES children were marginally higher than levels in high-SES children. Third, for low-SES children, an increase in selectivity of attention corresponded to an increase in post-ERP cortisol levels, whereas no such relationship existed for high-SES children, suggesting that the processing of irrelevant tones caused low-SES children to exert greater executive control to inhibit their responses to the unattended tones in order to performance as well as high-SES children.

If our interpretation of the Nd differences between low- and high-SES children is correct, it would appear that low-SES children did not use the selective attention mechanisms that are customarily associated with the evoked Nd waveform in the same way that high-SES children did. This conclusion is further supported by the finding of a different pattern of theta activity in the two groups of children. Low-SES children had significantly greater event-related theta power to the unattended than the attended tones, whereas high-SES children showed very small or no differences in theta power between the two types of information. Consistent with previous data on theta activity (Ishii et al., 1999), these findings suggest that low-SES children used additional frontal executive resources to control for the greater processing of irrelevant information compared to the high-SES children.

Although, the electrophysiological method in our study had limited spatial resolution, based on the results of other studies that used more complex integrative ERP-fMRI to make inferences about localisation (Opitz, Mecklinger, Friederici, & von Cramon, 1999) with similar auditory selective attention tasks, suggests that the observed differences between low- and high-SES children involve frontal lobe structures, which continue to undergo extensive development well into childhood. Thus, our findings support the hypothesis that the influences of SES on

selective attention may be associated with the way experience-dependent neural connectivity shapes the course of postnatal development of frontal brain regions (Noble, Norman & Farah, 2005).

The frontal areas of concern are likely part of the extensive network known as the anterior attentional system which includes areas of the midprefrontal cortex. The chief function of this system is to integrate processes of perception and selection of environmental information with the processes that regulate effortful control and execution of actions (Posner & Rothbart, 1998). Accordingly, in conjunction with the results from the power analysis, the finding of differential patterns of relationship between selective attention and cortisol in our two groups suggests that low-SES children used more executive resources to control for the processing of irrelevant information than did the high-SES children.

Also, the components of the anterior attentional system are believed to be involved in the regulation of reactive, emotion-related system, such as the HPA axis. Of interest here is a study by Davis, Bruce & Gunnar (2002) that assessed the performance of six-year-old children on neuropsychological tasks known to involve the brain regions that comprise the anterior attentional system. Surprisingly, they found that greater accuracy on the neuropsychological tasks was associated with higher, not lower, cortisol levels. However, cortisol levels were well within the normal baseline range, and thus did not reflect a stress response. Thus, they suggested that associations between higher cortisol and better performance may be in accord with the well-documented inverted U-shaped relationship between cortisol and many cognitive functions (Lupien & McEwen, 1997). More recently, Blair, Granger, & Razza (2005) found better self-regulation was associated with greater cortisol responses in preschool children. If so, this could mean that low SES children may filter out less information but at the same time, their ability to compensate for this additional processing is at the cost of higher cognitive effort as indexed by greater cortisol secretion.

Why would low-SES children, but not their high-SES counterparts, attend to and process irrelevant information? One possible explanation is that this may be the manifestation of learned sustained vigilance or general 'alarm' associated with the particular living conditions and experiences which characterize low SES (Ursin & Eriksen, 2004). As noted, low-SES children generally live in environments that are more crowded, chaotic, noisy and dangerous (e.g., Evans, 2004) than those of high-SES children, and thereby experience more stressful, unpredictable life events and less sense of control (McLoyd, 1998). Hence, these low-SES children may learn to constantly keep "an ear to the ground" attempting to process a broad set of information, relevant or irrelevant to current goals, and anticipate potentially challenging, negative or threatening situations. Transposing the real life situation to our study situation, we can speculate that the low-SES children divided their attention between task-relevant and irrelevant information and then engaged additional

executive control to perform as well as the high-SES children.

Differences between low- and high-SES children in our study may also have been due to differences in IQ, nutrition and/or exposure to dangerous chemicals. Although it is unclear what the exact causal relationship may be between various intrinsic and extrinsic factors associated with the results in the present study, it does not detract from them the fact that they are reflective of real effects of SES on cognition.

From the point of view of developmental psychobiology, the present findings challenge the view that low SES should necessarily have a negative influence on children's performance. We have provided evidence that differences in neural processes in low- and high-SES do not necessarily imply a performance gap, but may instead be interpreted as part of different regulatory systemic responses enabling children to adapt to environments that present different types of information-processing challenges. Given that low and high SES children live in very different environments, from a neural selectionist-constructivist perspective (Quartz & Sejnowski, 1997) it makes sense that these two groups would develop experience-dependent patterns of neural activity and self-regulation that would be differentially and preferentially associated with selective variations in attention and executive cognitive processes. Accordingly, the hypothesis that low-SES children may have an attentional style characterized by learned sustained vigilance or general "alarm" suggests that these children may be better than high-SES children at performing tasks that require sustained attention. We are currently working on testing this possibility in our laboratory.

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