Developmental Cognitive Neuroscience 26 (2017) 101–111

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: www.elsevier.com/locate/dcn

Development of selective attention in preschool-age children from lower socioeconomic status backgrounds

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ARTICLE INFO

Keywords:
Selective attention
Development
ERPs
SES
Children

ABSTRACT

Although differences in selective attention skills have been identified in children from lower compared to higher socioeconomic status (SES) backgrounds, little is known about these differences in early childhood, a time of rapid attention development. The current study evaluated the development of neural systems for selective attention in children from lower SES backgrounds. Event-related potentials (ERPs) were acquired from 33 children from lower SES and 14 children from higher SES backgrounds during a dichotic listening task. The lower SES group was followed longitudinally for one year. At age four, the higher SES group exhibited a significant attention effect (larger ERP response to attended compared to unattended condition), an effect not observed in the lower SES group. At age five, the lower SES group exhibited a significant attention effect comparable in overall magnitude to that observed in the 4-year-old higher SES group, but with poorer distractor suppression (larger response to the unattended condition). Together, these findings suggest both a maturational delay and divergent developmental pattern in neural mechanisms for selective attention in young children from lower compared to higher SES backgrounds. Furthermore, these findings highlight the importance of studying neurodevelopment within narrow age ranges and in children from diverse backgrounds.

1. Introduction

Growing up in a lower socioeconomic status (SES) household is associated with a wide range of negative outcomes across the lifespan, including poorer cognition, physical, and mental health, as well as lower levels of academic and occupational attainment (for reviews, see Hackman et al., 2010; McEwen and Gianaros, 2010; Ursache and Noble, 2016). Efforts to ameliorate these disparities can be informed by understanding the mechanisms underlying the relationships between childhood SES and life outcomes, and the development of these mechanisms in contexts of early adversity. While neuroscientific investigations of SES-related disparities are increasing, most focus on a single time point in development or are cross-sectional. Here we examine the developmental trajectory of neural processes for selective attention in children from lower SES backgrounds during early childhood.

We focus on attention as it is one of the neurocognitive mechanisms most vulnerable to early adversity (e.g., Blair and Raver, 2012). Importantly, attention networks have been implicated in a range of cognitive skills foundational for academic success (Checa and Rueda, 2011; McClelland et al., 2013; Posner et al., 2006; Rhoades et al., 2011; Stevens and Bavelier, 2012; Stipek and Valentino, 2015) and, because they also serve important regulatory functions in the stress response, are the focus of theoretical frameworks linking early adversity to adult outcomes (e.g., Blair and Raver, 2012; McEwen and Gianaros, 2010; Pakulak et al., in press). Several studies have documented differences in aspects of attention between children from lower and higher SES backgrounds (e.g., Blair and Raver, 2012; Weinberg et al., 2012; D'Angiulli et al., 2008; Hackman and Farah, 2009; Kishiyama et al., 2009; Mezzacappa, 2004; Stevens et al., 2009). However, relatively little work has focused on the vulnerability of attention to effects of early adversity during early childhood, between the ages of 3 and 5 years, a time when attention systems are rapidly developing (e.g., Davidson et al., 2006; Gomes et al., 2000; Jones et al., 2015; Posner et al., 2014; Rothbart et al., 2011; Rueda et al., 2004). The goal of the present longitudinal study was to evaluate the development of neural

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http://dx.doi.org/10.1016/j.dcn.2017.06.006
Received 17 January 2017; Received in revised form 19 May 2017; Accepted 28 June 2017
Available online 04 July 2017

processes for selective attention, previously shown to be vulnerable in children from lower SES backgrounds (e.g., D'Angiulli et al., 2008; Farah et al., 2006; Kishiyama et al., 2009; Mezzacappa, 2004; Neville et al., 2013; Noble et al., 2007; Stevens et al., 2009), across the critical preschool-age developmental time period.

Selective attention, the ability to focus on a relevant stimulus in the presence of distracting, competing information, has been proposed to be a foundational skill for learning and educational achievement (e.g., Astheimer and Sanders, 2012; Astheimer et al., 2014; Piazza and Dehaene, 2004; Stevens and Bavelier, 2012). Additionally, aspects of selective attention serve as the foundation on which self-regulation and executive control systems develop (e.g., Posner et al., 2014; Rothbart et al., 2011). While fine-tuning of attentional control continues into adolescence (Gomes et al., 2000; Karns et al., 2015; Rueda et al., 2004), the preschool-age period is particularly important developmentally, as skills of self-regulation and language are also undergoing significant growth (e.g., Miller and Chapman, 1981; Rice et al., 2010; Rothbart et al., 2006; Rueda et al., 2005; Zelazo et al., 2013).

To date, only a few studies have evaluated SES-related disparities in neural mechanisms of selective attention in children. All these studies revealed neurophysiological differences in children from lower compared to higher SES backgrounds (D'Angiulli et al., 2008; Kishiyama et al., 2009; Stevens et al., 2009). In one study (D'Angiulli et al., 2008), pre-adolescents (12–13 years) from lower and higher SES backgrounds completed a pure-tone selective attention task while event-related brain potentials (ERPs) were recorded. Although both groups exhibited comparable accuracy and reaction times, the children from lower SES backgrounds did not exhibit the expected attention effect, indexed by larger early ERP responses to the attended compared to the unattended condition.

Another study of slightly younger children (7–12 years) from lower and higher SES backgrounds evaluated neural processes for attention during a visual oddball task with novel stimuli (Kishiyama et al., 2009). Similar to findings by D'Angiulli et al. (2008), behavioral accuracy and reaction times were comparable between the two groups. However, children from lower SES backgrounds exhibited reduced amplitudes for early ERP components (P1, N1, N2) elicited by rare and novel stimuli, which are thought to reflect modulation of attention, compared to peers from higher SES backgrounds (Kishiyama et al., 2009).

A third study (Stevens et al., 2009) evaluated selective attention in younger children, aged 3–8 years (mean age: 6 years), from lower and higher SES backgrounds using the same child-friendly dichotic listening task employed in the current study. Children heard two stories presented simultaneously but from separate speakers located to the left and right of the participant. Children were instructed to attend to one story and ignore the other. ERPs were compared to identical physical stimuli (probes) embedded in stories when attended versus unattended. The difference in neural responses to probes in the attended versus unattended story indexed the effects of selective attention on neural processing. While children from higher SES backgrounds showed robust effects of selective attention on neural processing, these attention effects were markedly smaller in children from lower SES backgrounds. Further, these group differences were specific to distractor suppression, with children from lower SES backgrounds less able to suppress the response to probe sounds in the ignored channel than their higher SES peers.

Although these previous studies suggest that SES-related disparities in neural processes for attention are evident in childhood, several questions remain. First, the previous studies were conducted either with older children/adolescents or children across a relatively broad age range. Given that brain structure, function, and attention skills undergo significant development during the preschool-age years (e.g., Bates et al., 2003; Huttenlocher and Dabholkar, 1997; Posner and Rothbart, 2007; Sanders et al., 2006), it is critical to evaluate neural systems for attention within a narrow age range. This will allow for clearer delineation of neural processes during this critical period of neurodevelopment. Second, although we know that neural systems for attention differ as a function of SES background, it is unclear whether differences reflect a developmental delay or a divergence from developmental patterns observed in children from higher SES backgrounds, which requires a longitudinal design to assess. Elucidating these differences is relevant not only to our basic understanding of disparities related to SES, but may also have relevance for the timing or nature of interventions targeting attention skills.

The current study aimed to address these questions by characterizing the development of neural processes for selective attention in young children from lower SES backgrounds. Focused on the narrow range of preschool-age children (3–5 years), neural systems for selective attention were compared between children from lower versus higher SES backgrounds using the same child-friendly dichotic listening task as Stevens et al., (2009. In addition, children from lower SES backgrounds were followed longitudinally for one year in order to trace developmental changes during the critical preschool-age time period. As suggested by previous research with this age group (Karns et al., 2015; Sanders et al., 2006), we expected an attention effect in the 4-year-olds from higher SES backgrounds. Furthermore, based on previous findings in preschool-age children from lower SES backgrounds (Isbell et al., 2016a; Neville et al., 2013), we hypothesized that 4-year-old children from lower SES backgrounds would not show a significant attention effect. We also hypothesized that group differences would be specific to deficits in distractor suppression in the children from lower SES backgrounds, as suggested by previous research (Stevens et al., 2009). For the longitudinal component of the study, in which the children from lower SES backgrounds were followed for one year, we hypothesized that the effects of selective attention on neural processes would either be absent or small but emerging at age five. We based this prediction on prior literature showing protracted development of neural processes for selective attention into adolescence (Karns et al., 2015) as well as research demonstrating that slightly older children from lower SES backgrounds exhibit a significant attention effect, albeit smaller than that observed in their age-matched peers from higher SES backgrounds (Stevens et al., 2009). Importantly, these findings will enhance our understanding of the vulnerability in and development of selective attention in young children from lower SES backgrounds.

2. Materials & method

2.1. Participants

Fifty-eight typically developing preschool-age children, aged 3- to 4-years, were included in the present study. Of these, 44 children were from lower SES (LSES) backgrounds, aged 3;5–4;11 months (Mean: 4;3 months, 9 males). Children in the LSES group were recruited from Head Start preschool sites in Oregon as part of an ongoing longitudinal study assessing the maintenance of gains in selective auditory attention following a two-generation training program (Neville et al., 2013). The current study involves only children who participated in Head Start as usual, with no children who participated in the training program (Neville et al., 2013). The remaining 14 children were from higher SES (HSES) backgrounds, aged 3;6–4;11 months (Mean: 4;3 months, 7 males). Children in the HSES group were recruited from the Developmental Database at the University of Oregon, pre-screened for maternal education of partial college or higher, and invited to participate in a single session experiment (see SES information below). All children were monolingual speakers of English with no history of neurological impairment or disorder, and not taking medications that might alter neurologic function. All children were right-handed, except one child in the HSES group who was left-handed. All children had normal or corrected-to-normal vision and passed a hearing screening at 20 dB at 1000, 2000, and 4000 Hz.

Inclusionary criteria for children from LSES backgrounds included completion of electrophysiological testing in Years 1 and 2. As part of the ongoing longitudinal study, the LSES group completed additional behavioral tasks not reported in this study, requiring two visits. Year 2 longitudinal sessions occurred approximately one year after the child's initial lab visit (Mean (*SE*): 15.18 (*0.11*) months, range: 12.7–17.4 months) and the same ERP testing battery was administered in both Years 1 and 2. The children from HSES backgrounds completed one session of behavioral and electrophysiological testing in Year 1.

From the total of 58 children who met all of the above criteria, one child in the LSES group had data with a high degree of electroencephalographic (EEG) artifact, resulting in too few trials per condition and exclusion from analysis. An additional ten children in the LSES group were excluded for answering fewer than half of the ERP paradigm comprehension questions correctly in Year 1, consistent with the exclusionary criterion used in previous studies using this paradigm (Isbell et al., 2016a; Neville et al., 2013; Stevens et al., 2009). All children in the HSES group had acceptable EEG data and performed with at least 50% accuracy on the comprehension questions.

Following these procedures, the final sample included in the analysis consisted of 33 children from LSES backgrounds and 14 children from HSES backgrounds. The two groups did not differ in age in Year 1 ($t(45) < 1$, $p = 0.700$, $d = 0.13$; Table 1). In the LSES group, parent reports indicated that 24 children were Caucasian, two American Indian/Alaskan Native, one Asian, and five bi/multiracial. One parent chose not to respond. In the HSES group, parent reports indicated 11 children were Caucasian, one not Hispanic/Latino (but without identifying race), and two parents chose not to respond.

Although children were recruited specifically from lower or higher SES environments, parental education and occupation information was also collected. Parental education scaling and SES were calculated using the Hollingshead Four Factor Index of Social Status (Hollingshead, 1975) and means (*SE*) are presented in Table 1. Maternal and paternal education levels were significantly lower for the LSES compared to HSES groups ($t(44) = 5.12$, $p < 0.001$, $d = 1.49$ and $t(40) = 8.51$, $p < 0.001$, $d = 2.58$, respectively; Table 1). Although the Hollingshead has been critiqued for its multi-faceted nature (Duncan and Magnuson, 2012), it is nonetheless recognized as a valuable proxy variable for capturing environmental differences, and SES scores based on the four factor index are included for comparison to previous studies (e.g., D'Angiulli et al., 2008; Isbell et al., 2016a; Neville et al., 2013). All children in the HSES group had composite SES scores of 47 or higher, categorized as the top two (of five) social groups (Hollingshead, 1975). As expected based on recruitment strategies, the LSES group had significantly lower composite SES scores than the HSES group ($t(44) = 8.58$, $p < 0.001$, $d = 2.21$).

All children performed within or above one SD of the norm-based mean on a nonverbal intelligence quotient (IQ) task, the Fluid Reasoning subtest of the Stanford-Binet Intelligence Test (SB-5; Roid, 2003), and a receptive language task, the Sentence Structure subtest of the Clinical Evaluation of Language Fundamentals, Preschool-2 (CELF-P2; Wiig et al., 2004). Four children in the HSES group were recruited as part of a separate study and their behavioral data were not acquired. Thus, behavioral analyses include 10 children in the HSES group. Means (*SE*) for both the nonverbal IQ and the language tasks are presented in Table 1. In Year 1, unpaired *t*-tests revealed that the LSES and HSES groups demonstrated comparable performance on the nonverbal IQ task ($t(41) < 1$, $p = 0.962$, $d = 0.02$). The LSES group exhibited lower standard scores on the CELF-P2 Sentence Structure subtest compared to children in the HSES group ($t(41) = 2.57$, $p = 0.016$, $d = 0.71$).

2.2. ERP stimuli

The current study employed the selective auditory attention paradigm used and described in detail in our previous studies of young children (e.g., Isbell et al., 2016a; Karns et al., 2015; Neville et al., 2013). Briefly, four stories (2.5–3.5 min each) from children's book series were digitally recorded (16 bit, 22 kHz) using an Electro Voice 1750 microphone connected to a Macintosh computer running a sound-editing program. Stereo files were then created containing pairs of stories, with one story in the right audio channel and a second story (read by a narrator of the opposite sex, and about a different story series) in the left audio channel. Children were positioned equidistant between the right and left speakers. Children heard two simultaneously presented stories that differed in location (left/right), voice (male/female), and content and were presented at a normalized average of 60 dB SPL (A-weighted). Children were instructed to selectively attend to one of the two stories. A monitor presenting illustrations that corresponded to the attended story was positioned approximately 150 cm from the participant. Images subtended a visual angle of 5° or less and changed every 5–15 s, at appropriate points in the narrative content.

Children attended to two stories presented on the right side and two on the left. Stories were counterbalanced within participants such that the same narrator occurred in the attended and unattended position within a session (narrating different stories) and children attended to the same voices, but different stories, in Years 1 and 2. All test conditions (attend narrator and story) and the order of narratives were counterbalanced between participants and, for the LSES group, across time.

A researcher sat in the booth next to the child to ensure task compliance and that the child remained equidistant between the two speakers. At the end of each story, the researcher asked three basic comprehension questions about the attended story, for a total of twelve questions throughout the experiment. Questions had two alternatives, and a response of "I don't know" was counted as incorrect.

ERPs were recorded to identical physical stimuli, linguistic and nonlinguistic probes, embedded in stories when they were attended and unattended. The linguistic probe was a /ba/ syllable recorded by a female speaker (different than the female storytellers) then digitized and edited to 100 ms. The nonlinguistic probe was created by scrambling 4–6 ms segments of the /ba/ syllable resulting in a 100 ms broad spectrum 'buzz' sound that preserved many of the acoustic properties of the linguistic probe. Probes were presented at 70 dB SPL. Probes were super-imposed on the stories in each channel and an equal number of probes (N ∼ = 400 probes per condition [attend/unattend]) were randomly presented every 200, 500, or 1000 ms in one of the two auditory channels. Identical probe stimuli were used in all sessions.

2.3. Procedure

Upon arrival, children were given time to acclimate to the laboratory, then parents/caregivers signed a consent form prior to children providing verbal assent. Children in the LSES group participated in two days of laboratory testing separated by no more than 30 days in Years 1 and 2. The first day consisted of the battery of behavioral tasks and the second involved ERP testing. The children in the HSES group completed behavioral tasks and electrophysiological testing in one day. For both groups, a single testing session lasted approximately two hours.

Behavioral testing was administered in an individual child-friendly testing room with the child and a trained research assistant and supervised by a certified speech-language pathologist. Parents could monitor all testing via closed circuit cameras in a room adjacent to the testing room.

For ERP testing, once the EEG cap was in place, participants sat in a comfortable chair in a sound-attenuating booth. Children were instructed to sit as still as possible, with reinforcement by the research assistant. Before recording began, a practice session introduced children to the task. Half of the children attended first to the story on the left, and half attended first to the story on the right (RLLR or LRRL). A camera transmitted the session so that other researchers and the caregiver(s) could observe from outside the booth.

Table 1
Descriptive statistics for age, maternal and paternal education, SES, nonverbal IQ, receptive language, comprehension question accuracy on the ERP task, and ERP trial numbers included in analyses for each condition.

	Higher SES Group N = 14	Lower SES Group Year 1 N = 33	Lower SES Group Year 2 N = 33
Age	4.23 (*0.12*)	4.29 (*0.07*)	5.55 (*0.07*)
Maternal Ed	6.07 (*0.16*)	4.94 (*0.15*)	
Paternal Ed	6.43 (*0.17*)	4.39 (*0.17*)	
SES	52.36 (*1.57*)	30.16 (*2.06*)	
SB-FR Subtest	12.80 (*0.88*)	12.85 (*0.48*)	
CELF-SST	13.6 (*0.43*)	12.06 (*0.42*)	
Comprehension Accuracy	9.00 (*0.23*)	8.39 (*0.30*)	9.60 (*0.30*)
ERP Trial Numbers			
Attended	232 (*14.86*)	259 (*9.68*)	289 (*10.19*)
Unattended	237 (*14.27*)	258 (*9.30*)	286 (*9.72*)

Note: Parental Education: 2 = 9th grade completed; 3 = 10-11th grade completed/partial high school; 4 = high school graduate; 5 = partial college; 6 = college graduate; 7 = graduate degree; SES range = 8–66; SB-FR = Stanford Binet Intelligence Test – 5, Fluid Reasoning subtest; CELF-SST = Clinical Evaluation of Language Fundamentals, Sentence Structure subtest.
Means (*SE*) are presented for maternal education, paternal education, and SES,[1] for standard scores from subtests of the Stanford Binet Intelligence Test – 5 (Roid, 2003) and the Clinical Evaluation of Language Fundamentals – Preschool-2 (CELF-P2; Wiig et al., 2004), accuracy on the ERP comprehension task, and number of trials accepted for the two ERP conditions (attended, unattended) are also presented for each group (Higher SES Group, Lower SES Group Year 1, and Lower SES Group Year 2).

2.4. Electroencephalographic recordings & measures

The EEG was recorded using 32 Ag/Ag-Cl electrodes embedded in an elastic cap (Biosemi Active 2, Amsterdam, Netherlands). Online, electrodes were referenced to the Common Mode Sense (CMS) active electrode and then referenced offline to the mean of the left and right mastoids. Horizontal eye movements were monitored by electrodes placed over the left and right outer canthi while electrodes over the inferior and superior orbital ridge monitored vertical eye movements. Eye channels were used to determine EEG artifact and were not included in statistical analyses. Left and right horizontal eye channels were re-referenced to one another offline. Electrical signals were recorded with a digitized sampling rate of 512 Hz and downsampled offline to 256 Hz.

ERP analyses were carried out using EEGLAB (Delorme and Makeig, 2004) and ERPLAB (Lopez-Calderon and Luck, 2014). Raw EEG data were imported into EEGLAB and were high-pass filtered at a 0.1 Hz cutoff and low-pass filtered at a 40 Hz cutoff using a noncausal (infinite impulse response; IIR) Butterworth function with 12 dB/octave roll-off (Luck, 2014) to attenuate activity below and above these frequencies, respectively. For each probe type, epochs were extracted from −100 to 500 ms relative to probe onset. Epochs containing large eye movements, evidenced by changes greater than ± 100 μV in eye channels, or other artifact, evidenced by changes greater than ± 200 μV in all other scalp channels, were removed using the ERPLAB moving window peak-to-peak artifact detection algorithm across a 200 ms window, moving at 50 ms increments. Trained researchers then visually inspected individual retained epochs following this automatic procedure and manually removed epochs containing residual artifact, identified as large voltage changes that were not detected by the automatic program (e.g., changes greater than 100 μV in eye channels across a 350 ms window), to ensure accurate artifact detection and removal. The mean (*SE*) number of trials accepted for the LSES and HSES groups are presented in Table 1. In Year 1, although on average the LSES group had more trials accepted than the HSES group, this difference was not significant (Group: F (1, 45) = 1.90, p = 0.174, n_p^2 = 0.04). There were no effects of or interactions with condition in Year 1 (Cond & Group X Cond: all *F*s < 2.12, all *ps* > 0.153). The LSES group in Year 2 had more trials accepted than the same children in Year 1 (Time: F (1, 32) = 6.40, p = 0.017, n_p^2 = 0.17), with comparable trial numbers accepted between conditions (Cond & Time X Cond: all *F*s < 1, all *ps* > 0.570).

The following analyses were conducted as in previous studies using this paradigm (e.g., Isbell et al., 2016a; Neville et al., 2013). Based on visual inspection of the data, mean amplitudes relative to baseline were measured between 100 and 200 ms post-stimulus onset using ERPLAB. To allow a factor of anterior/posterior to be included, three aggregate electrode values were created as follows: Anterior F7/8, F3/4, FT7/8, FC5/6; Central T7/8, C5/6, CP5/6, C3/4; Posterior P7/8, P3/4, PO3/4, O1/2.

2.5. Statistical analyses

Performance on the comprehension questions was compared between groups using an unpaired *t*-test. A paired *t*-test with a within-subjects factor of time (Year 1/Year 2) evaluated change in comprehension question accuracy over time for the LSES group.

The ERP measure of selective attention at Year 1, when the children were 3- to 4-years-old, was compared between the HSES and LSES groups using a mixed-design ANOVA including the between-subjects factor of SES (Group: HSES/LSES) and within-subject factors of condition (Cond: Attend/Unattend) and anterior-posterior distribution (AP: Anterior/Central/Posterior). Changes in the attention effect across time in the LSES group were assessed using a 2 × 2 × 3 repeated-measures ANOVA including within-subject factors of time (Time: Year 1/Year 2), condition (Cond: Attend/Unattend), and anterior-posterior (AP: Anterior/Central/Posterior). Preliminary analyses including probe type (linguistic/nonlinguistic) as a factor indicated that probe type did not interact with group or change over time. Thus, all analyses reported below collapse across this factor, following previous studies (Isbell et al., 2016a,b; Neville et al., 2013; Stevens et al., 2009). Alpha was set at p < 0.05. Following omnibus ANOVAs, further step-down analyses were performed to isolate significant interactions, collapsing across factors for which no interactions were observed. Based on previous findings indicating differences in amplitude for the unattended, but not attended condition between HSES and LSES groups (Stevens et al., 2009), we also tested our a priori hypothesis about reduced distractor suppression skills in children from LSES backgrounds via separate ANOVAs for the attended and unattended conditions, including between-subjects factors of SES and within-subject factors of distribution (AP: Anterior/Central/Posterior). For all repeated measures with greater than one degree of freedom in the numerator, the Greenhouse-Geisser adjusted *p*-values are reported (Hays, 1994). Effect sizes, indexed by Cohen's *d* (*t*-tests) or partial-eta squared (n_p^2) are reported for all effects.

3. Results

3.1. Auditory attention effects: comprehension questions

Mean (*SE*) accuracy for the ERP comprehension questions for each group are presented in Table 1. In Year 1, although the HSES group had slightly higher accuracy on the ERP comprehension questions than the LSES group, this difference was not statistically significant (t (45) = 1.61, p = 0.115, d = 0.41). From Year 1 to Year 2, the LSES group showed a significant improvement in accuracy on the ERP comprehension questions (t (32) = 3.03, p = 0.005, d = 0.73).

[1] The detailed SES questionnaire was not completed by one child recruited from Head Start for the LSES group.

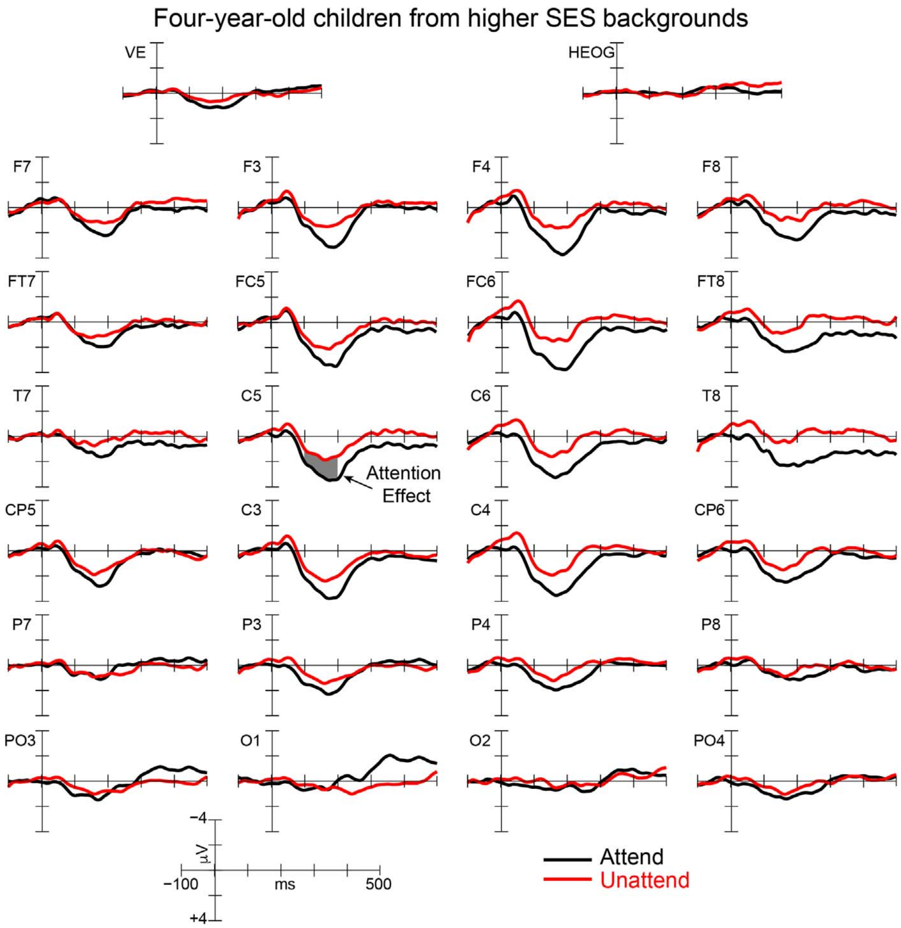

Fig. 1. Grand average ERPs of participants in the HSES group elicited by the attended (black) and the unattended (red) conditions. For illustrative purposes, the attention effect (gray), which was largest over anterior and central electrode sites, is highlighted at C5. For this and all subsequent ERP figures, grand average waveforms were low-pass filtered at 20 Hz for display purposes only and negative is plotted upward.

3.2. Auditory attention effects: electrophysiological responses (ERPs)

Grand average ERPs for the attended and unattended conditions are presented for the HSES group in Fig. 1, for the LSES group in Year 1 in Fig. 2, and for the LSES group in Year 2 in Fig. 3. As illustrated in the figures, all three groups show a robust positivity in response to probe stimuli. However, effects of selective attention (i.e., larger – more positive – mean amplitudes elicited by the attended compared to the unattended condition) were not apparent in all groups. Whereas 4-year-olds from HSES backgrounds appeared to exhibit a larger positivity to the attended condition, the 4-year-olds from LSES backgrounds exhibited similar neural responses to both attended and unattended conditions. In contrast, one year later, the LSES group, now five years old, appeared to exhibit an emerging attention effect. These observations were confirmed in the statistical analyses described below.

3.2.1. 4-year-olds from lower compared to higher SES backgrounds

At age four, children from LSES backgrounds exhibited reduced attention effects compared to children from HSES backgrounds (Cond X Group: $F(1, 45) = 11.04$, $p = 0.002$, $n_p^2 = 0.20$; Fig. 4), which did not differ by scalp distribution (Cond X AP X Group: $F(2, 90) < 1$, $p = 0.606$, $n_p^2 = 0.01$). Follow-up step-down ANOVAs examined each of the SES groups separately. In analyses restricted to the 4-year-olds from HSES backgrounds, a significant attention effect was observed, with the probes in the attended stories eliciting significantly larger ERP amplitudes than the probes in the unattended stories (Cond: $F(1, 13) = 8.13$, $p = 0.004$, $n_p^2 = 0.49$). This effect was largest over anterior and central electrode sites (Cond X AP: $F(2, 26) = 5.48$, $p = 0.011$, $n_p^2 = 0.30$). In contrast, the 4-year-olds from LSES backgrounds did not exhibit a significant amplitude difference between the attended and the unattended conditions (Cond: $F(1, 32) = 1.24$, $p = 0.273$, $n_p^2 = 0.04$). Although there was a trend for the response to the attended condition to be larger over anterior and central electrode sites, this did not reach statistical significance (Cond X AP: $F(2, 64) = 3.01$, $p = 0.080$, $n_p^2 = 0.09$).

Separate step-down ANOVAs for the attended and unattended conditions revealed a significant difference between groups in mean amplitudes elicited by the attended condition (Group: $F(1, 45) = 7.98$, $p = 0.007$, $n_p^2 = 0.15$; Group X AP: $F(2, 90) < 1$, $p = 0.998$, $n_p^2 < 0.01$), with 4-year-old children in the HSES group showing larger amplitude responses to the attended condition compared to 4-year-olds in the LSES group. However, no differences were observed between groups for the ERP responses elicited by the unattended condition (Group: $F(1, 45) < 1$, $p = 0.519$, $n_p^2 = 0.01$; Group X AP: $F(2, 90) < 1$, $p = 0.479$, $n_p^2 = 0.01$), indicating, contrary to predictions, that group differences at age four were specific to differences in signal enhancement, with no differences in distractor suppression.

3.2.2. Development within children from lower SES backgrounds

Consistent with visual observation, analyses indicated a significant increase in the attention effect in the LSES group from Year 1 to Year 2 (Time x Cond: $F(1, 32) = 5.62$, $p = 0.024$, $n_p^2 = 0.15$; Figs. 4 and 5) that was broadly distributed across the scalp (Time X Cond X AP: $F(2, 64) < 1$, $p = 0.884$, $n_p^2 < 0.01$). Step-down ANOVAs were conducted to assess whether changes over time were specific to improvements in signal enhancement (indexed by increases in the response to probes in the attended stories) versus distractor suppression (indexed by reductions in the response to probes in the unattended stories). From Year 1 to Year 2, significant amplitude increases were observed for the attended condition (Time: $F(1, 32) = 13.04$, $p = 0.001$, $n_p^2 = 0.29$).

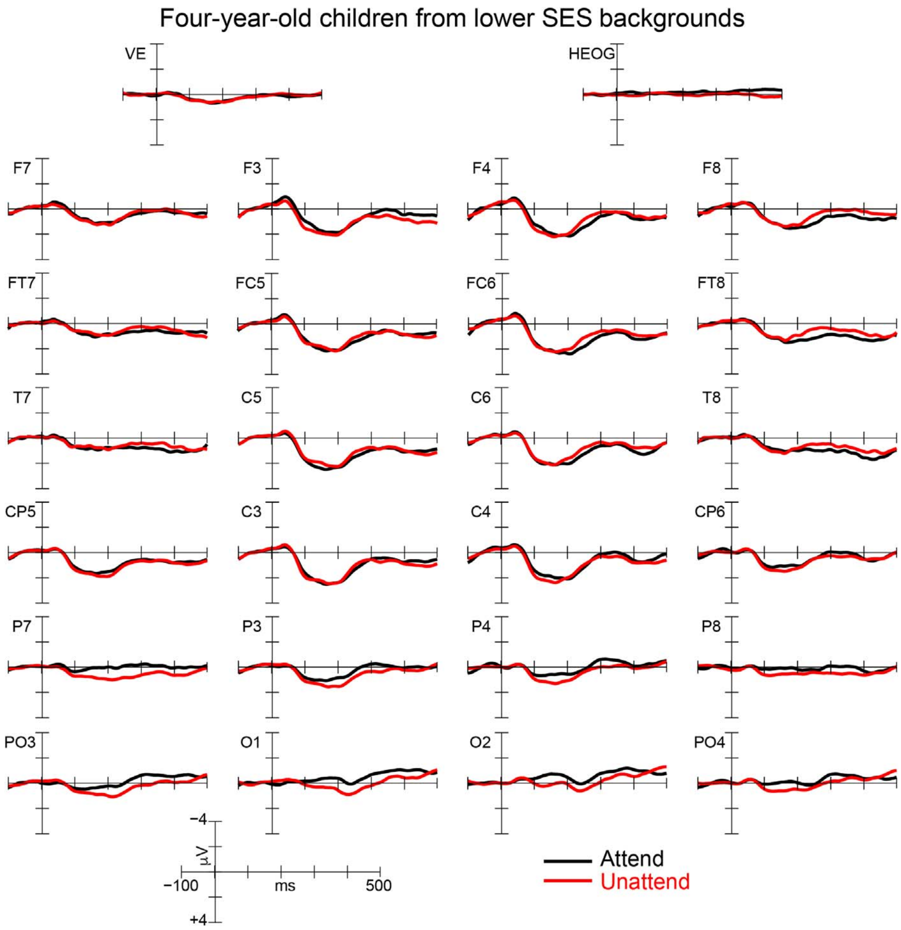

Fig. 2. Grand average ERPs of all participants in the LSES group for Year 1 elicited by the attended (black) and the unattended (red) conditions. Note that no attention effect is present for the LSES group at age four.

This change did not vary across the scalp (Time X AP: F (2, 64) $<$ 1, p = 0.419, n_p^2 = 0.03). In contrast, no significant changes in amplitudes were elicited by the unattended condition (Time: F (1, 32) $<$ 1, p = 0.694, n_p^2 $<$ 0.01), nor were differences observed over time in scalp distribution (Time X AP: F (2, 64) = 1.01, p = 0.352, n_p^2 = 0.03). The change over time in the LSES group for each condition is illustrated in Fig. 5. These findings indicate that the changes in attention effects from Year 1 to Year 2 in the LSES group were driven by increases in the neural responses to the attended condition, which suggest improvements in signal enhancement, with no evidence for improvements in distractor suppression.

To examine whether children from LSES backgrounds demonstrated a significant attention effect at age five, separate ANOVAs were conducted for Year 2. In contrast to findings from the LSES group at age four (Year 1, reported above), the same children at age five (Year 2) demonstrated a significant attention effect, illustrated in Fig. 3 (Cond: F (1, 32) = 8.43, p = 0.007, n_p^2 = 0.21), with a trend for the attention effect to be largest over anterior and central electrode locations (Cond x AP: F (2, 64) = 3.07, p = 0.067, n_p^2 = 0.09).

3.2.3. 5-year-olds from lower SES backgrounds compared to 4-year-olds from higher SES backgrounds

Given the significant increase in the attention effect from age four to five in the LSES group, post-hoc analyses were conducted to evaluate whether the attention effect in 5-year-olds from LSES backgrounds was comparable to, or differed from, the attention effect in 4-year-olds from HSES backgrounds. Although the 5-year-old LSES group had slightly higher accuracy than the 4-year-old HSES group on the ERP comprehension questions, an unpaired t-test revealed that this difference did not reach statistical significance (t (45) = 1.61, p = 0.115, d = 0.41). ERP responses from the 4-year-old HSES group (Year 1) were compared to the LSES group at age 5 (Year 2) using the same mixed-design ANOVA described above. In contrast to differences observed between children from LSES and HSES backgrounds at age 4, no group effects or interactions were observed between the 4-year-old HSES group and the 5-year-old LSES group (Cond X Group: F (1, 45) = 1.75, p = 0.193, n_p^2 = 0.04; Cond X AP X Group: F (2, 90) $<$ 1, p = 0.453, n_p^2 = 0.02). These results can be seen in Fig. 4. These findings suggest that overall attention effects on neural processing in children from LSES backgrounds at age five are similar in magnitude to effects in children from HSES backgrounds at age four.

Although interactions with condition were not significant, based on previous findings (Stevens et al., 2009) and our a priori hypothesis of reduced distractor suppression in the LSES group, we evaluated potential differences between LSES and HSES groups specific to signal enhancement versus distractor suppression using separate step-down ANOVAs for the attended and unattended conditions. There were no significant differences in ERPs elicited by the attended condition between the 5-year-old LSES group and the 4-year-old HSES group (Group: F (1, 45) $<$ 1, p = 0.728, n_p^2 $<$ 0.01; Group X AP: F (2, 90) $<$ 1, p = 0.690, n_p^2 $<$ 0.01). However, at age five, the LSES group tended to exhibit a larger, more positive response elicited by the unattended condition compared to the HSES group at age four (Group: F (1, 45) = 3.24, p = 0.079, n_p^2 = 0.07; Group X AP: F (2, 90) = 2.91, p = 0.079, n_p^2 = 0.06), suggesting poorer distractor suppression. To better understand this trend, step-down ANOVAs were conducted over anterior and central electrode locations only, where the attention effect is most prominent in both groups. 5-year-olds from LSES backgrounds exhibited significantly larger responses to the unattended condition over anterior and central sites compared to the 4-year-olds from HSES backgrounds (Group: F (1, 45) = 5.32, p = 0.026, n_p^2 = 0.11; Group X AP: F (1, 45) $<$ 1, p = 0.844, n_p^2 $<$ 0.01), suggesting poorer

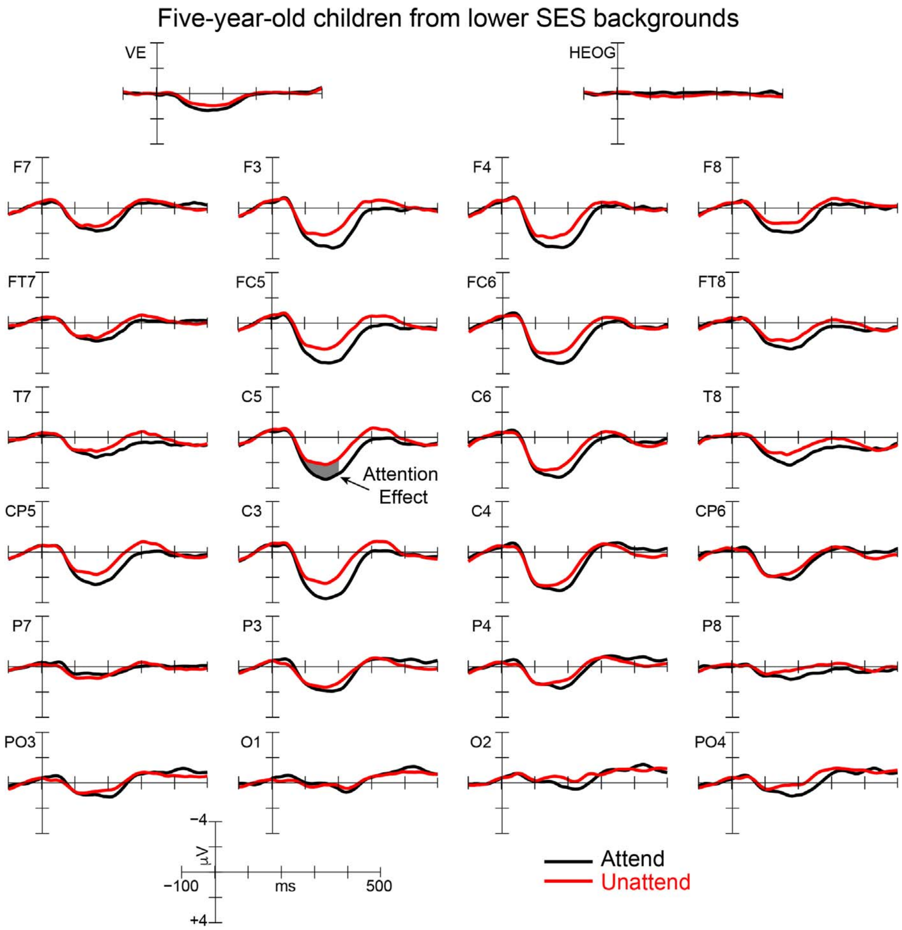

Fig. 3. Grand average ERPs of all participants in the LSES group for Year 2 elicited by the attended (black) and the unattended (red) conditions. For illustrative purposes, the attention effect (gray), which was significant across the scalp in the LSES group at age five, is highlighted at C5.

distractor suppression. Responses over posterior sites did not differ between groups (Group: F (1, 45) < 1, p = 0.671). These results revealed reduced distractor suppression skills in 5-year-olds from LSES backgrounds compared to 4-year-olds from HSES backgrounds (Fig. 5), especially over anterior-central electrodes where the attention effect is most prominent. Together, these findings suggest, despite increased signal enhancement and the development of an attention effect, children from LSES backgrounds at age 5 exhibit a different attention profile compared to 4-year-olds from HSES backgrounds.

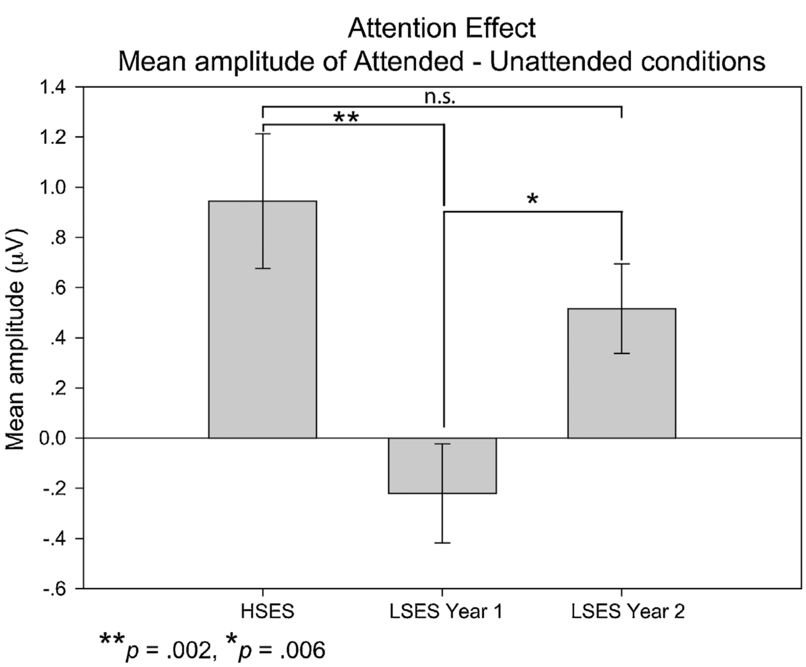

Fig. 4. Plots of the mean (*SE*) amplitudes of the attention effect (difference between the mean amplitudes elicited by the attended and unattended conditions) for children from higher SES backgrounds (HSES, age four) and lower SES backgrounds in Year 1 (LSES Year 1, age four) and Year 2 (LSES Year 2, age five). At age four, the HSES group exhibited a significant attention effect that was not present in the LSES group in Year 1 (group interaction indicated by **). A significant attention effect developed in the LSES group from Year 1 to Year 2 (*) such that there was no difference in the attention effect between the LSES group in Year 2 and the HSES group in Year 1 (non-significant [n.s.]).

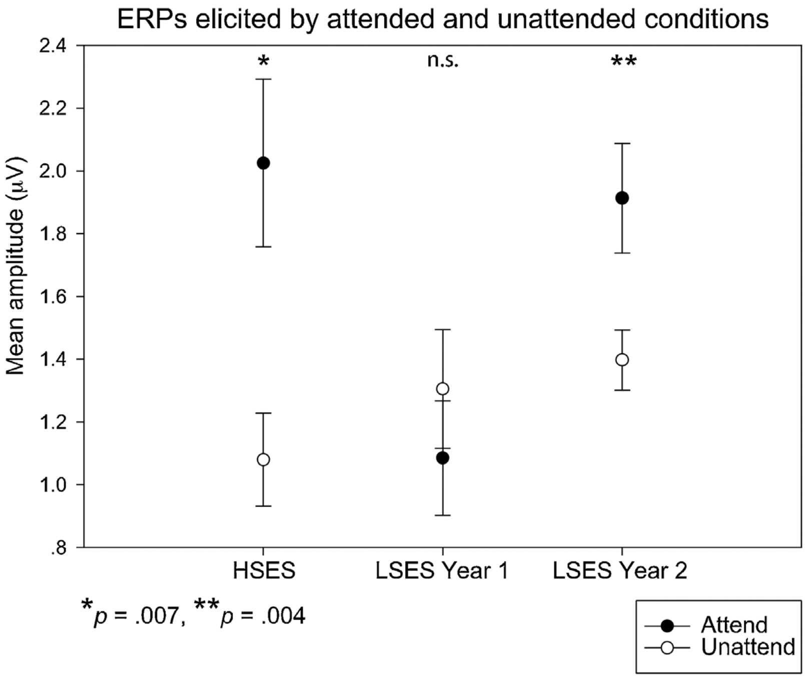

Fig. 5. Mean (*SE*) amplitudes elicited by the attended and unattended conditions for children from higher SES backgrounds in Year 1 (HSES, age four) and children from lower SES backgrounds in Year 1 (LSES Year 1, age four) and Year 2 (LSES Year 2, age five). The ERPs elicited by the attended condition were larger than those elicited by the unattended condition for the 4-year-olds from higher SES backgrounds (*) and the 5-year-olds from lower SES backgrounds (Year 2; **). No differences between attended and unattended conditions were observed for the 4-year-olds from lower SES backgrounds (Year 1; non-significant [n.s.]).

4. Discussion

The current study aimed to characterize the development of neural systems for auditory selective attention in children from lower SES backgrounds across the preschool-age period. Specifically, we evaluated differences between typically developing 4-year-olds from lower and higher SES backgrounds, then followed the children from LSES backgrounds for one year to evaluate the trajectory of development across this time period. In Year 1, children from higher SES backgrounds exhibited a significant attention effect that was not observed in the children from lower SES backgrounds. This group difference was driven by reduced signal enhancement, indicated by smaller responses elicited by the attended condition in Year 1. However, one year later, the same children from lower SES backgrounds displayed a significant attention effect, characterized by growth in the neural responses to the attended condition. Moreover, after one year, the magnitude of the attention effect in 5-year-olds from lower SES backgrounds was comparable to the attention effect in 4-year-olds from higher SES backgrounds, though the older children from lower SES backgrounds showed evidence of poorer distractor suppression. Taken together, these findings are the first to provide prospective, longitudinal evidence on the development of neural systems for selective attention in preschool-age children from disadvantaged backgrounds.

4.1. Selective auditory attention: 4-year-olds

Whereas previous work using the same paradigm in older children suggested *reduced* effects of attention in children from LSES backgrounds (Stevens et al., 2009), the present findings indicate *no* effects of attention on neural processes at age four in children from LSES backgrounds. This difference may be attributable to the younger, more narrow age range in the current study (mean age: 4 years, range: 3–4 years) compared to previous work (mean age: 6 years, range: 3–8 years; Stevens et al., 2009). It is possible that, in Stevens et al., 2009, the younger children in the LSES group did not have an attention effect, but the sample size in the previous study did not allow for an evaluation of age effects. Thus, rather than characterizing group differences as a simple attenuation of the effects of neural processing, the current findings suggest a delayed and potentially divergent developmental trajectory in children from LSES backgrounds compared to peers from HSES backgrounds. These findings, together with previous results (D'Angiulli et al., 2008; Kishiyama et al., 2009; Stevens et al., 2009), indicate both a delay in the emergence of an attention effect and a reduced magnitude of this effect, marked by attenuated distractor suppression skills, that persists into adolescence in children from lower SES backgrounds.

4.2. Selective auditory attention: age four to five years

From age four to five, a significant attention effect emerged in the LSES group, driven by an increase in amplitude of the neural responses to the attended condition. This finding suggests improved signal enhancement skills (increased neural response to the attended condition) across one year in preschool-age children from LSES backgrounds. The magnitude of neural responses to the attended condition in the LSES group in Year 2 was comparable to that of the HSES group in Year 1, and the frontocentral distribution of the attention effect that emerged at age five was consistent with previous studies employing the same paradigm (e.g., Isbell et al., 2016a; Sanders et al., 2006; Stevens et al., 2009). In our previous intervention work (Neville et al., 2013), we documented the emergence of a significant attention effect in preschool children from lower SES backgrounds following an 8-week, two-generation intervention. Interestingly, the improvements observed in this prior study were specific to improved signal enhancement, suggesting that signal enhancement may be a more malleable process during this age range. In this previous study, we also found that the change over time during this brief period was largest over posterior electrode sites, suggesting that growth in attention skills may initially be more broadly distributed, including a posterior scalp distribution, then shift to a more anterior/central distribution. Together these findings suggest that signal enhancement is highly malleable, by intervention or by development, and plays a significant role in the developing mechanisms for attention in preschool-age children from lower SES backgrounds.

Growth observed in the attention effect in the current study may be, at least in part, attributed to participation in Head Start preschools by the children in the LSES group. Many studies have identified the importance of strong early education environments, such as Head Start, for language and cognitive development (e.g., Arnold and Doctoroff, 2003; Barnett, 2011; Blair and Raver, 2012; Gormley et al., 2008; Heckman, 2011a,b; Wong et al., 2008). While the current study was not designed to directly evaluate the efficacy of Head Start, future studies including other comparison groups may confirm this hypothesis.

An alternative hypothesis might be that the change in attention effect over time was simply due to repeated exposure to the laboratory experiences and tasks for the children from lower SES backgrounds, as these children returned to the lab for several visits. However, we believe this explanation is unlikely based on prior research (Neville et al., 2013; Stevens et al., 2008). These previous studies utilized the same auditory ERP attention paradigm as the current study, with both training and control groups completing the paradigm at pre- and post-test periods separated by approximately two months. In both of these studies, children randomly assigned to the control or comparison groups showed no significant change in the attention effect from pre- to post-testing, whereas differences were observed in the training groups. This suggests that mere repeated exposure and familiarity with the laboratory and the task is unlikely to result in larger attention effects.

Although this study was not designed to compare development of children from LSES and HSES backgrounds, the significant development of neural systems across one year in the LSES group motivated a comparison between the 5-year-olds from LSES backgrounds and the 4-year-olds from HSES backgrounds. This comparison revealed a similar attention effect between the two groups, indicating significant growth in neural mechanisms for attention in the LSES group. These findings highlight the rapid neurophysiological development that occurs in attention systems across a one-year period and underscore the importance of evaluating cognitive processes within narrow age ranges, especially in studies of development.

The paradigm used in the current study allows us to separately examine group differences and change over time in signal enhancement (ERP response to probes in the attended channel) versus distractor suppression (ERP response to probes in the unattended channel). On the basis of prior research (Stevens et al., 2009), we had hypothesized that group differences would be specific to distractor suppression. We found mixed support for this hypothesis. At age four, the differences in the attention effect between the LSES and HSES groups were specific to the attended condition, with no differences for the unattended condition, suggesting a lag in the development of signal enhancement skills in the younger children from LSES backgrounds. Signal enhancement was also the aspect of neural processing for attention that changed from age four to five, with a larger ERP response to the attended condition present at age five compared to age four in the LSES group. Although no condition by group interaction was observed between the HSES group (age four) and the LSES group at age five, a priori hypotheses motivated assessment of each condition separately. Analyses revealed comparable ERP responses elicited by the attended condition between groups. However, larger ERPs were elicited by the unattended condition over anterior and central electrode sites for the 5-year-olds from LSES backgrounds compared to the 4-year-olds from HSES backgrounds. These findings provide some evidence of reduced distractor suppression in older children from LSES backgrounds compared to younger children from HSES backgrounds. Thus, the current results indicate a delay in the emergence of clear signal enhancement; however, as that skill comes online, and even though a significant attention effect emerges, there is evidence for poorer distractor suppression. This is consistent with other findings using the same paradigm. In a previous study of older children, differences between lower and higher SES groups were also specific to distractor suppression (Stevens et al., 2009). Additionally, a recent study from our lab found that greater adversity in 3- to 5-year-olds was associated with larger ERPs elicited by the unattended condition, even within a sample of children from lower SES backgrounds (Giuliano et al., revision under review). By characterizing change over time, the present findings further suggest a trajectory of reduced distractor suppression in children from LSES backgrounds. Together, these results suggest that one of the key long-term differences in selective attention between children from lower and higher SES backgrounds may be the ability to inhibit distracting stimuli.

One possible explanation for reduced inhibition of distracting stimuli in children from lower SES backgrounds is that it may be advantageous to have increased vigilance to non-target stimuli in more chaotic environments often associated with lower SES. Reduced inhibition of environmental stimuli may be adaptive in such environments, but maladaptive in a classroom (Blair and Raver, 2012), which in turn can lead to long-term costs, including negative impacts on academic performance (Stevens and Bavelier, 2012). Future studies evaluating longer developmental trajectories and relationships between attention, other cognitive skills, and academic outcomes in children from both LSES and HSES backgrounds are needed to determine the impact of reduced distractor suppression skills in children from LSES backgrounds.

In considering these SES-based differences in the developmental trajectory for neural processes of selective attention, we wish to highlight the language used to describe the patterns observed. Rather than capturing "deviant development" in children from LSES backgrounds, the patterns observed may be best understood as differences along a continuum of developmental patterns for selective attention. That is, while in research studies it is common to describe any differences identified relative to typical participant groups (e.g., individuals from higher SES backgrounds) as "deviant", all of the participants in the present study were typically developing. Moreover, especially given the importance of context discussed above, different patterns of development may be adaptive in certain contexts. As such, differences observed relative to higher SES comparison groups may reflect development that is adaptive, and therefore normal, for the environment encountered during development. Thus, the current findings regarding differences in distractor suppression mechanisms are best characterized as a divergence in developmental trajectory of selective attention in children from lower compared to higher SES backgrounds.

Taken together, these findings indicate a delayed emergence of the effects of attention on neural processes in preschool-age children from lower SES backgrounds by at least one year. Previous cross-sectional studies have identified developmental patterns in children from HSES backgrounds (Karns et al., 2015; Sanders et al., 2006). However, it is currently unclear whether children from LSES backgrounds will follow these same developmental trajectories with a maturational lag. It is possible that the current study captured a transitional state in the development of distractor suppression; alternatively, the delayed onset of an attention effect might subsequently be followed by slower, or otherwise altered, growth trajectories than those observed in children from higher SES backgrounds. Identifying this delayed and potentially divergent developmental pattern in selective attention skills is the first step in understanding the trajectory of development of selective attention in children from lower SES backgrounds. Future studies evaluating neural processes for selective attention in younger and older children from lower and higher SES backgrounds, and following the same children for longer periods of time, are needed to answer this question.

4.3. Limitations and future directions

While our findings provide evidence of both maturational delay and a divergent developmental pattern in neural processes for selective attention in young children from LSES compared to HSES backgrounds, as well as significant growth in attention effects in the LSES group, there are several limitations to the current study. First, this study was not designed to elucidate the nature of developmental differences between groups and did not include longitudinal assessment of children from HSES backgrounds. Future studies are needed to evaluate the developmental trajectory of selective attention in younger and older children from HSES backgrounds in order to understand when and how selective attention skills emerge, increasing our understanding of the development of selective attention and informing our hypothesis of maturational delay and divergent developmental trajectory for attention processing in children from LSES backgrounds. Additionally, studies further evaluating the nature of observed differences in distractor suppression, given that behavioral performance is comparable between groups (D'Angiulli et al., 2012a,b), would enhance our understanding of SES-related differences in selective attention.

Second, the current study included only typically-developing, monolingual, English-speaking children. These inclusionary criteria were designed to reduce potentially confounding variables but also limit the degree to which the findings generalize to broader populations of children. Furthermore, the children from both LSES and HSES backgrounds exhibited nonverbal IQ performance above the expected mean (subtest standard score of 10). Therefore, it will be important for future studies to recruit more diverse samples, including children who are bi/multilingual, children with a broader range of nonverbal IQ abilities, and children with atypical development, such as language impairment or attention-deficit disorders, in order to understand how these findings may generalize to the broader population.

4.4. Conclusions

The current study revealed that 4-year-old children from lower SES backgrounds did not exhibit significant effects of selective attention on neural processing, whereas robust attention effects were observed in same-age peers from higher SES backgrounds. Differences between children from lower and higher SES backgrounds at age four were specific to signal enhancement. However, an attention effect emerged in these same children from lower SES backgrounds across one year of development. Whereas this change over time was driven by growth in signal enhancement, after the attention effect emerged, children from lower SES backgrounds continued to display reduced distractor suppression skills compared to their younger peers from higher SES backgrounds. These findings suggest both a maturational delay in selective attention in young children from lower SES backgrounds as well as a potentially divergent pattern of development when the attention effect emerges compared to children from higher SES backgrounds, marked by a lag in signal enhancement and divergent developmental trajectory in distractor suppression. Importantly, by providing evidence for a consistent and seemingly persistent difference in neural processes for distractor suppression, these results increase our understanding of the effects of early adversity at a mechanistic level. This understanding can contribute to ongoing efforts to ameliorate SES-related disparities via evidence-based intervention approaches. Future research that explores the longer developmental trajectory of attention as a function of SES, the relationships between neural systems for selective attention and the development of other cognitive skills, and the impact of targeted intervention on these neural mechanisms will help elucidate the role of delayed maturation of attentional systems on child development.

Acknowledgements

This work was made possible by the National Institute of Health (NICHD R01 DC000481) and the Department of Education/Institute of Education Sciences (IES R305B070018) to H.J.N. We thank members of the Brain Development Lab at the University of Oregon and the Brain Systems for Language Lab at Michigan State University for their support in data acquisition and processing and Linda Heidenreich for her support of this project. This work would not be possible without the support of Head Start of Lane County and the children and families committed to helping advance our understanding of child development.

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