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Atypical auditory refractory periods in children from lower socio-economic status backgrounds: ERP evidence for a role of selective attention

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ABSTRACT

Previous neuroimaging studies indicate that lower socio-economic status (SES) is associated with reduced effects of selective attention on auditory processing. Here, we investigated whether lower SES is also associated with differences in a stimulus-driven aspect of auditory processing: the neural refractory period, or reduced amplitude response at faster rates of stimulus presentation. Thirty-two children aged 3 to 8 years participated, and were divided into two SES groups based on maternal education. Event-related brain potentials were recorded to probe stimuli presented at interstimulus intervals (ISIs) of 200, 500, or 1000 ms. These probes were superimposed on story narratives when attended and ignored, permitting a simultaneous experimental manipulation of selective attention. Results indicated that group differences in refractory periods differed as a function of attention condition. Children from higher SES backgrounds showed full neural recovery by 500 ms for attended stimuli, but required at least 1000 ms for unattended stimuli. In contrast, children from lower SES backgrounds showed similar refractory effects to attended and unattended stimuli, with full neural recovery by 500 ms. Thus, in higher SES children only, one functional consequence of selective attention is attenuation of the response to unattended stimuli, particularly at rapid ISIs, altering basic properties of the auditory refractory period. Together, these data indicate that differences in selective attention impact basic aspects of auditory processing in children from lower SES backgrounds.

1. Introduction

A large literature documents the robust relationship between socio-economic status (SES) and academic outcomes (for reviews, see Brooks-Gunn and Duncan, 1997; Duncan et al., 1994). Whether assessed using school grades, standardized test scores, or graduation rates, children from lower SES backgrounds fare worse on average than their higher SES peers (Baydar et al., 1993; Liaw and Brooks-Gunn, 1994; Walker et al., 1994). More recently, research in cognitive science and cognitive neuroscience has focused on identifying particular cognitive skills and neural systems underlying these academic disparities (e.g., Noble et al., 2005, 2007; Stevens et al., 2009). The promise of these more focused investigations is twofold (for discussions, see Hackman and Farah, 2008; Neville et al., 2013a). First, this research can identify foundational systems that, if impaired, might have cascading consequences for performance on broad academic indicators (e.g., Noble et al., 2005; Stevens and Bavelier, 2012). Second, by identifying vulnerable foundational systems, interventions to reduce SES-related academic disparities can be developed that target these foundational systems (e.g., Neville et al., 2013b, targeting selective attention; Noble et al., 2012, targeting preschool preliteracy and math skills).

While previous research identifies aspects of attention and language as particularly vulnerable to SES-related disparities (Hackman and Farah, 2008; Hackman et al., 2010; Mezzacappa, 2004; Noble et al., 2005; Stevens et al., 2009), to date no research has examined SES-differences in more basic aspects of sensory processing. In the present study, we sought to investigate whether lower SES is also associated with differences in a basic aspect of auditory processing: the auditory neural refractory period, or reduced amplitude neural response at more rapid rates of stimulus presentation. We examined the auditory refractory period because it is a sensory-driven neural response that is associated with atypical language development (Neville et al., 1993; Stevens et al., 2012). The present study also sought to investigate whether any observed differences in auditory refractory period effects could be accounted for by manipulations of selective attention. This permitted a simultaneous investigation of both sensory-driven and top-down modulation of auditory processing in children from higher versus lower SES backgrounds.

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1.1. Auditory evoked potentials

Event-related brain potentials (ERPs) provide a unique window into the nature of basic auditory processing. With their exquisite temporal resolution, ERPs are ideal for characterizing the timecourse of processing, as well as the impact of experimental manipulations on different stages of processing. Moreover, as ERPs can be recorded noninvasively in infants and young children, the technique is particularly well suited for characterizing the development of auditory processing. We focus here on aspects of the auditory evoked potential arising from cortical activity during the initial few hundred milliseconds of auditory processing.

Morphologically, the auditory evoked potential shows developmental shifts from childhood to adulthood. In adults, the auditory evoked response is typically characterized by an initial positivity (P1) peaking ~50 ms after stimulus presentation, followed by an early negativity (N1) peaking ~100 ms after stimulus presentation (Ponton et al., 2000). The obligatory P1–N1 complex is sometimes followed by a second positivity and negativity (Ponton et al., 2000), though these later peaks are not observed with all auditory stimuli (Sanders et al., 2006). In contrast to the mature adult response, children's auditory evoked responses are typically dominated by a single broad positivity from ~50 to 200 ms after stimulus presentation, with little or no N1 apparent in this latency range until after age 12 (Albrecht et al., 2000; Ponton et al., 2000). Other studies report a delayed negativity in children as young as six years old, peaking closer to 300 ms post-stimulus onset (Coch et al., 2005b). Together, these studies indicate important development shifts in the morphology of the underlying auditory evoked response during maturation.

Further research has examined the effects of different experimental manipulations on early cortical evoked responses, and whether these effects are similar across development. In one experimental manipulation, the effect of rate of presentation is examined by varying the inter-stimulus interval (ISI) between successive stimuli. Among adults, N1 amplitude to auditory stimuli becomes smaller as rate of presentation increases (Budd et al., 1998; Coch et al., 2005b; Wang et al., 2004). The reduced amplitude is believed to reflect the reduced excitability of cortical neurons immediately following an action potential, or the effective processing rate of neurons (Budd et al., 1998; Gastaut et al., 1951). We will use the term ‘auditory refractory period’ to describe the amplitude reduction apparent at more rapid rates of stimulus presentation. While it is statistically impossible to demonstrate full neural recovery, studies of auditory refractory periods typically infer full neural recovery when no significant differences remain in the amplitude of the neural response to stimuli presented at increasing ISIs.

Interestingly, children show similar attenuation of the neural response with increasing rates of presentation, though these effects can be overlaid on a morphologically immature cortical response (Coch et al., 2005b; Rojas et al., 1998; Stevens et al., 2012). For example, when children show a broad positivity in response to auditory stimuli, this broad positivity is smaller in amplitude as rate of presentation increases (Stevens et al., 2012). Moreover, younger children also often exhibit larger refractory effects than adults, or refractory effects that persist at longer ISIs than in adults (Coch et al., 2005b; Rojas et al., 1998). In other words, with increasing age, the neural response appears to recover more quickly, whereas during development, children may require longer intervals between stimuli for the neural response to show full recovery. The reason for this longer recovery time in children remains unclear, however one contributing factor may involve longer neural recovery time when the neural response to stimuli is larger overall and/or longer in duration, as occurs in children's auditory evoked responses.

Cortical auditory evoked responses also vary with experimental manipulations of selective attention (for reviews, see Hillyard et al., 1987; Hopfinger et al., 2004). In a typical selective auditory attention paradigm, two streams of competing auditory input are presented simultaneously to separate ears, with participants monitoring one of the two streams for rare deviant stimuli. In adults, stimuli presented to the attended channel elicit larger N1s than the same stimuli when presented in the unattended channel (Hillyard et al., 1973). Further, as some portion of the cortical distribution of the attention effect mirrors the distribution of the underlying ERP components, attentional modulation appears to act at least in part as a gain control mechanism on input-driven neural activity.

To examine whether children show similar effects of selective attention on auditory processing, we have developed a child-friendly selective auditory attention ERP paradigm (Coch et al., 2005a; Sanders et al., 2006). In this paradigm, two stories are played simultaneously from speakers located to the left and right of the participant, who attends selectively to one of the two stories. ERPs are recorded to probe stimuli superimposed on both attended and unattended narratives. In this paradigm, both children and adults show clear effects of selective attention within 100 ms of processing: in adults, the N1 to probe stimuli in the attended channel is increased in amplitude, and in children as young as three years old, the broad positivity to probe stimuli in the attended channel is increased in amplitude (Coch et al., 2005a; Sanders et al., 2006).

Together, these studies paint a complex picture of the maturation of the neural circuitry supporting basic auditory processing. On the one hand, the basic morphology of the auditory evoked response shows a protracted time course of development. However, despite an immature morphology, the auditory system of children exhibits adult-like functional responses to some experimental manipulations. For example, as described above, with increasing rates of stimulus presentation, both children and adults show an attenuation of early neural responses. Similarly, with selective attention, both children and adults show an increase in the underlying neural response within 100 ms. Indeed, it is interesting to note that in both adults and children, the effects of selective attention and rate of stimulus presentation have complementary effects: whereas rapid rates of presentation effectively *dampen* the neural response, selective attention serves to *increase* the neural response. These findings indicate that basic auditory processing is influenced not only by developmental shifts in neural systems, but also by bottom-up stimulus attributes and top-down attentional control. However, as these studies were generally conducted with typically developing, higher SES samples, they do not elucidate whether or how these aspects of auditory processing are altered in special populations, including those from different SES backgrounds.

1.2. Auditory processing and language development

It has been proposed that higher-level functions including language comprehension depend critically on the integrity of basic auditory processing (Tallal, 1980, 2004; Tallal and Piercy, 1973). The relationship between basic auditory processing and language development has been illustrated most strongly in the case of Specific Language Impairment (SLI), a developmental disorder characterized by poor receptive language skills in the face of typical nonverbal intelligence (Leonard, 1998). For example, several studies have reported that at least some children with SLI have particular difficulty processing auditory information that is presented at rapid rates and/or that is distinguished on the basis of brief auditory cues (Tallal, 1980, 2004; Tallal and Piercy, 1973) (but see also Neville et al., 1993 showing deficits in a sub-sample of children with SLI, but no correlation between rapid auditory processing and receptive language scores). These perceptual deficits have been proposed to impair speech perception by disrupting the ability to form stable representations of some phonemes, such as /ba/ and /da/, which are differentiated only by cues occurring in the first 40 ms of stimulus onset. Indeed, it has been observed that some of the morphemes that are most problematic for children with SLI are also the least perceptually salient (Leonard, 1998), suggesting that subtle