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Electrocortical indices of selective attention predict adolescent executive functioning

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ABSTRACT

Executive functioning is considered a powerful predictor of behavioral and mental health outcomes during adolescence. Our question was whether executive functioning skills, normally considered "top-down" processes, are related to automatic aspects of selective attention. Event-related potentials (ERPs) were recorded from typically-developing 12–14-year-old adolescents as they responded to tones presented in attended and unattended channels in an auditory selective attention task. Examining these ERPs in relation to parental reports on the Behavior Rating Inventory of Executive Function (BRIEF) revealed that an early frontal positivity (EFP) elicited by to-be-ignored/unattended tones was larger in those with poorer executive functions, driven by scores on the BRIEF Metacognition Index. As is traditionally found, N1 amplitudes were more negative for the to-be-attended rather than unattended tones. Additionally, N1 latencies to unattended tones correlated with parent-ratings on the BRIEF Behavior Regulation Index, where shorter latencies predicted better executive functions. Results suggest that the ability to disengage attention from distractor information in the early stages of stimulus processing is associated with adolescent executive functioning skills.

Executive functioning (EF) refers to the ability to monitor and exercise control over one's inner state during purposeful, goal-directed and problem-solving behavior. These functions have been variously described to include components of working memory, inhibitory control and cognitive flexibility (e.g., Blair & Ursache, 2011). EF skills increase from infancy to adulthood (Casey et al., 1997; Keating & Bobbitt, 1978; Rothbart & Rueda, 2005) and, of particular importance, poor EF during adolescence has been associated with both externalizing (e.g., risk-taking and substance use; Magar, Phillips, & Hosie, 2008) and internalizing behaviors (e.g., anxiety, depression; Castaneda, Tuulio-Henriksson, Marttunen, Suvisaari, & Lonnqvist, 2008) as well as poor academic achievement (Buckner, Mezzacappa, & Beardslee, 2009). Multiple neuroimaging and electrophysiological studies suggest that EF is dependent on the prefrontal cortex (e.g., Spessot, Plessen, & Peterson, 2004). Critically, this region is relatively late to mature (see Gogtay et al., 2004; Segalowitz, Santesso, & Jetha, 2010; Steinberg, 2007) which might contribute to the poor self-regulatory skills often observed in adolescents.

There has been considerable speculation that attentional control, the ability to attend to relevant information and suppress the continued processing of to-be-ignored information, is developmentally linked to EF but there are theoretical disagreements with respect to how these linkages might occur. According to Stuss (1992), controlled attention is one aspect of EF which develops alongside other executive functions as prefrontal structures becoming increasingly adult-like across development. In his view, the broad supervisory attentional functions of the frontal lobes direct more specific lower level systems (e.g., those involved in selective and sustained attention) toward a selected goal. Thus, attentional control is a core aspect of EF which shares a common neurodevelopmental trajectory with other components of EF, e.g., the ability to monitor and evaluate behavior. Another view is that of MacCoon, Wallace, and Newman (2004) who consider attentional control to be a necessary precursor of regulated behavior. That is, EF is only possible when appropriately directed attention is used to enhance the activation of nondominant networks of cognitions, emotions and behaviors when these represent a more adaptive response than the currently active dominant network. A third view is that EF is a necessary precursor of the development of controlled attention. Ruff and Rothbart (1996) support this position by noting that young infants are unskilled at regulating their own behavior and attention but, as children develop, they are required to shift from other-regulation to self-regulation, forcing them to

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develop attentional control. Despite these different perspectives, most researchers agree that the self-initiated ability to direct attention is key to EF, and this is the focus of the current study.

Selective attention is one aspect of attentional control that involves several stages of information processing, i.e., the differentiation of stimulus streams, the selection of the relevant stimulus stream, the suppression of the irrelevant streams, and the maintenance of attention on the relevant information (Määttä, Pääkkonen, Saavalainen, & Partanen, 2005). We hypothesize that attentional control, particularly selective attention, is a major predictor of the ability to self-regulate. Clarifying these associations may help us to better understand the cortical processes underlying disorders where both selective attention and EF are impaired (e.g., attention-deficit hyperactivity disorder; Mayes & Calhoun, 2007; Qian, Shuai, Cao, Chan, & Wang, 2010; psychopathy; Varlamov, Khalifa, Liddle, Duggan, & Howard, 2010; Wahlstedt, 2009).

In the present study, we examined whether selective attention, as reflected in event-related potentials (ERPs) during a dual-channel auditory selective attention task, relate to EF skill in healthy adolescent's everyday lives (as assessed by the parent-completed Behavior Rating Inventory of Executive Function™ – BRIEF). Participants were asked to pay attention to one auditory stimulus stream while ignoring the other and were required to identify, by pressing a response button, an infrequent "target" stimulus (i.e., high tone) in the specified attended channel. Recording EEG throughout the task allowed us to use differences in the amplitude and/or latencies of ERPs to stimuli in the attended versus unattended ears as indicators of efficient (or inefficient) attentional control. Engagement with the attended stimuli would be reflected in larger neural ERP responses to attended stimuli while disengagement, or suppression, would be reflected in smaller ERP responses to unattended stimuli.

In such dual-channel auditory selective-attention paradigms, target stimuli elicit the ERP components N1, P2, N2 and P3. Of particular interest, the N1 reflects the activity of the auditory cortex, with later components reflecting further stages of stimulus processing. Nontarget tones normally elicit only the early occurring N1 and P2 (Hillyard, Hink, Schwent, & Picton, 1973; Nager, Estorf, & Munte, 2006; Woods, 1990), suggesting that attentional resources are quickly withdrawn for the non-response-relevant stimuli. In healthy young adults, the N1 component, as observed over midline fronto-central scalp sites, is typically larger for stimuli in the attended stream (Hillyard et al., 1973; Woods, 1990). Thus, the N1 difference between attended and unattended tones (the N1d effect) is thought to reflect differences in low-level sensory activity (Johnstone, Barry, Anderson, & Coyle, 1996) and this difference in activity is thought to result in the suppression of an attentional response to unattended tones (i.e., an automatic gating mechanism to reduce further processing of irrelevant stimuli; Singhal, Doerfling, & Fowler, 2002).

In young children ages 3–8, a similar but non-identical attention effect has been observed. In a series of studies, Stevens and colleagues (Stevens, Sanders, & Neville, 2006; Stevens, Fanning, Coch, Sanders, & Neville, 2008; Stevens, Lauinger, & Neville, 2009) examined attentional processes in young children. Using a dichotic listening task, different stories were presented to each ear with probes embedded in each story. The children were asked to listen to the story in one ear and ignore the other. In the typically developing children, the probes in the attended stream elicited a larger positive going electrocortical response than those in the unattended stream. This difference occurred between 100 and 200 ms post stimulus onset. The authors speculate that this positive going attention effect is not simply a reversal of polarity of the N1 effect in children, but rather it is the absence of an N1 which sometimes occurs due to the complexity and demands of the task (Coch, Sanders, & Neville, 2005). One other paper has also reported an attention-sensitive positive going waveform in 5-year olds, and although it is presented graphically, it is not otherwise analyzed or discussed (Bartgis, Lilly, & Thomas, 2003, see Fig. 2, panel 1). Stevens and colleagues do not suggest a name for this component, and so here in order to distinguish it from the traditional N1, we refer to it as an early frontal positivity (EFP) based on an examination of its polarity and topography. Critically, these selective attention effects were reduced in children from lower SES backgrounds, a circumstance often associated with poorer attentional control (Stevens et al., 2009).

Such auditory evoked potentials, at least those elicited by brief click trains, do not become adult-like until age 12 (Ponton, Eggermont, Kwong, & Don, 2000), and the N1 to standard and target tones, although present by age 12, continues to develop until at least the age of 17 (Johnstone et al., 1996). The attention-sensitive EFP has been reported in children as young as 3 and as old as 9 (Bartgis et al., 2003; Coch et al., 2005; Sanders, Stevens, Coch, & Neville, 2006; Stevens et al., 2006, 2008, 2009) but is not observed in adults (Coch et al., 2005; Sanders et al., 2006), although the upper age limit on the presence of the EFP is currently unknown. We were interested in whether the EFP would also be evident in our adolescent sample in addition to the more traditional N1 thereby allowing us to better understand maturational effects in these components and the processes they reflect. Given that our participants were 12–14 years of age, we expected that we might observe both the EFP and the N1 in response to auditory stimuli.

Most importantly for the present study, we wanted to see whether these indices of early selective attention would relate to parental reports of their adolescent's ability to engage in self-regulatory behavior (e.g., their ability to control their emotions under stress, to stay on task in the service of achieving some goal). We hypothesized that adolescents showing a pronounced neural differentiation in ERP amplitudes to attended relative to unattended tones along with rapid processing of behaviorally relevant stimuli in the selective auditory attention task would be the same individuals with the highest levels of EF as evidenced in parent reports on the BRIEF. We chose to employ the BRIEF measure rather than administering lab-based tests of executive function as we were interested in adolescent's self-regulatory abilities in their day-to-day lives. Previous work has related lab-based measures of EF with lab-based measures of attention control (see e.g., Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001) and with parent-report assessments of regulatory skill (Gerardi-Caulton, 2000; Rothbart, Ellis, Rueda, & Posner, 2003). Our goal was to explore the potential link between attention control as reflected in ERPs with the naturalistic manifestations of EF. Because of the variety of interrelated constructs tapped in any assessment of EF, we wanted to explore which of these might be most strongly related to our neural measures of selective attention, but given the uncertainty of what the EFP versus N1 represents, we did not formulate specific hypotheses beyond this. Moreover, because of the narrow age-range (2 years) used in the present study we did not expect to see evidence of developmental change within our particular sample.

1. Method

1.1. Participants

Participants consisted of 48 adolescents 12–14 years of age (21 female, mean age = 13.1 years), after excluding one who had a substantial hearing loss, one with ERP amplitudes more than 2.5 standard deviations above the mean, one with a large number of false positive responses on the behavioral task. One other participant was excluded from analyses involving the Initiate and Working Memory subscales of the BRIEF due to incomplete responses.

1.2. Materials and procedure

Behavior Rating Inventory of Executive Function (BRIEF; Psychological Assessment Resources, Inc): The BRIEF parent report form is an 86-item measure that asks parents to evaluate their child's daily behavior with respect to eight domains of EF.