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Neurophysiological evidence of an association between cognitive control and defensive reactivity processes in young children

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ABSTRACT

Interactions between cognitive control and affective processes, such as defensive reactivity, are intimately involved in healthy and unhealthy human development. However, cognitive control and defensive reactivity processes are often studied in isolation and rarely examined in early childhood. To address these gaps, we examined the relationships between multiple neurophysiological measures of cognitive control and defensive reactivity in young children. Specifically, we assessed two event-related potentials thought to index cognitive control processes – the error-related negativity (ERN) and error positivity (Pe) – measured across two tasks, and two markers of defensive reactivity processes – startle reflex and resting parietal asymmetry – in a sample of 3- to 7-year old children. Results revealed that measures of cognitive control and defensive reactivity were related such that evidence of poor cognitive control (smaller ERN) was associated with high defensive reactivity (larger startle and greater right relative to left parietal activity). The strength of associations between the ERN and measures of defensive reactivity did not vary by age, providing evidence that poor cognitive control relates to greater defensive reactivity across early childhood years.

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1. Introduction

It has been long acknowledged that interactions between emotional and cognitive processes are integral to healthy and unhealthy human development (Gray, 2004). Individual differences in cognitive control are thought to reflect variations in neural systems for regulating behavior and affect whereas variation in defensive reactivity represents differences in responsiveness of the brain's negative-valence system. In particular, researchers have been interested in how top-down cognitive control processes govern bottom-up processes such as defensive reactivity (Moser et al., 2015). Evidence from adults and adolescents indicate that prefrontal cortex regions involved in cognitive control processes are functionally linked to emotion centers of the brain (i.e., the amygdala; Monk, 2008; Siegle et al., 2007) such that prefrontal control regions down-regulate activation of emotion generation regions (Hare et al., 2008; Ochsner and Gross, 2005). Individuals for whom this functional connection is effective tend to engage in adaptive self-regulation skills whereas individuals with poor prefrontal-mediated cognitive control tend to have difficulty regulating affective processes and therefore experience more emotional problems (Casey et al., 2010; Muris et al., 2007; Oldehinkel et al., 2007).

The capacity to engage cognitive control processes begins to emerge in early childhood and continues to develop into late adolescence (Eisenberg et al., 2009; Rothbart et al., 2007). Changes in cognitive control during this developmental period have important implications for understanding how these top-down processes ultimately interact with bottom-up affective processes. As cognitive control and defensive reactivity processes co-develop over time, their interaction contributes to a wide range of functional outcomes. However, measures of cognitive control and defensive reactivity are often studied in isolation. Studies that have explored their interaction (Muris et al., 2007; Oldehinkel et al., 2007) have used parent report questionnaires, which tap behaviors that are considerably down-stream from the neurobiological mechanisms involved in these systems early in development.

Toward this end, the current study had two primary aims. The first was to examine the relationship between cognitive control and defensive reactivity at the neurophysiological level in children. The second was to examine whether age, as a proxy for developmental status, moderated the association between these indices of cognitive control and defensive reactivity.

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1.1. Cognitive control

We selected the error-related negativity (ERN) and error positivity (Pe) as neurophysiological indices of interest because of evidence for their construct validity as measures of cognitive control in adults (e.g., Yeung and Summerfield, 2012) and evidence that both markers can be elicited in children as young as 3 years (Grammer et al., 2014). The ERN appears as a negative deflection at frontocentral electrodes within approximately 100 ms of an error. It has been identified as a robust marker of processes related to error correction or suppression (Gehring et al., 2012; Yeung and Summerfield, 2012). The Pe follows the ERN, is maximal at centroparietal sites between 200 and 400 ms following an error, and is thought to reflect conscious error detection (Hughes and Yeung, 2011; Nieuwenhuis et al., 2001). The morphology and scalp distribution of the ERN and Pe in children appear similar to those of adults (Arbel and Donchin, 2011); however, whereas the ERN is reported to increase with age, the Pe tends to be quite stable over time.

1.2. Defensive reactivity

We selected the startle reflex and resting parietal asymmetry based on evidence these are among the best-replicated physiological correlates of defensive reactivity (e.g., Bradley et al., 2001; Heller and Nitschke, 1998; Sabatinelli et al., 2005). Research in animals (e.g., Davis et al., 2008; LeDoux and Schiller, 2009) and humans (e.g., Sabatinelli et al., 2005) has demonstrated that the startle reflex activates the brain's fear-defense circuit, instantiated by the amygdala, and is enhanced when individuals are exposed to threatening stimuli. Eliciting the startle reflex in young children has been inconsistent due to methodological challenges selecting age-appropriate stimuli. In order to address these challenges, Quevedo et al. (2010) developed a task using age-appropriate film clips that successfully elicited the startle in children aged 3–9 years and adults (*M* age = 22.16 years). It is unclear whether the startle relates to neurophysiological measures of cognitive control.

Greater right relative to left parietal activity in adults has also been identified as a reliable indicator of defensive reactivity given its associations with vigilance and anxious arousal (Bruder et al., 1997; Compton et al., 2003; Heller et al., 1997; Heller and Nitschke, 1998; Metzger et al., 2004). Similar correlates of parietal asymmetry have been observed in childhood such as enhanced right-lateralizated parietal activity in children who exhibit high fear-proneness (e.g., McManis et al., 2002; Shankman et al., 2005, 2011). There is also evidence that right frontal asymmetry is associated with negative affect and withdrawal-related behaviors (e.g., Davidson, 1992; Davidson and Tomarken, 1989), constructs that overlap with defensive reactivity. However, more recent evidence suggests that increased emotional arousal may be specific to parietal asymmetry rather than frontal asymmetry in early childhood (Shankman et al., 2005, 2011). Therefore, parietal asymmetry may be a clearer marker of defensive reactivity during this developmental period, and thus we focus on parietal asymmetry in this report.

1.3. Associations between measures of cognitive control and defensive reactivity

Understanding the development of cognitive control and defensive reactivity will require studying the relationship between these processes rather than each in isolation. Few studies have explicitly tested the relationship between markers of cognitive control and defensive reactivity, and all have been conducted in adults. For example, Hajcak and Foti (2008) reported that enlarged ERN was associated with increased startle, but others have failed to replicate this result (Lewis and Pitts, 2015), and re-analysis of the original findings indicated they were driven by a single outlier (Moser et al., 2014).

There is much debate regarding the relationship between the ERN and measures of defensive reactivity, as some propose that enlarged ERN in anxiety reflects cognitive inefficiency (Moser et al., 2013) whereas others suggest enlarged ERN *is* an index of defensive reactivity (Proudfit et al., 2013). Recent findings have indicated that the ERN is actually smaller in young anxious children (Meyer et al., 2012; Torpey et al., 2013). Meyer and colleagues (2012) found that a smaller ERN was related to higher levels of parent-reported anxiety, but only in the younger children of the sample. Similarly, Torpey et al. (2013) found that a smaller ERN characterized young children who displayed fearful behaviors. Others have reported that an enlarged ERN at age 6 predicts onset of an anxiety disorder 3 years later (Meyer et al., 2015). Thus, how the ERN – conceptualized as a marker of cognitive control – relates to defensive reactivity measures in youngsters is currently unclear.

There are no investigations of associations between cognitive control markers and parietal resting asymmetry, and none on the association between the Pe and physiological markers of defensive reactivity. In terms of the association between Pe and self-reported correlates of defensive processes, some have shown a smaller Pe (Hajcak et al., 2004; Moser et al., 2012) and others a larger Pe (Weinberg et al., 2010) correlated with greater negative emotion. In older children, a larger Pe is related to higher obsessive – compulsive symptoms (Santesso et al., 2006). Findings are therefore likewise equivocal as to how the Pe relates to markers of defensive reactivity.

1.4. The current study and hypotheses

In the current study we measured the ERN, Pe, startle response, and right parietal asymmetry to advance our understanding of the relationship between cognitive control and defensive reactivity in young children. We expected that a smaller ERN would be related to a larger startle response to negative-valenced stimuli given findings in young children that a smaller ERN is associated with higher levels of fear and anxiety (e.g., Meyer et al., 2012; Torpey et al., 2013). Similarly, we expected that a smaller ERN would be associated with greater right parietal activity. We anticipated that a larger Pe would be associated with a larger startle reflex and greater right parietal activity given previous findings that larger Pe is related to greater anxiety symptoms in older children (Santesso et al., 2006).

With regards to the second aim, we expected age to moderate the relationship between cognitive control and defensive reactivity measures. Specifically, we hypothesized that the association between poor cognitive control and high defensive reactivity would be stronger in younger children as compared to older children in the sample based on previously reviewed studies that observed a smaller ERN in fearful youth, but only in very young children (Meyer et al., 2012; Torpey et al., 2013).

2. Method

2.1. Participants

Subjects between the ages of 3 and 7 years were drawn from a larger investigation of child temperament among community children (*N* = 277), the aim of which was to examine change in temperament traits across early to middle childhood, and associations between traits and familial risk for psychopathology. A subset of 96 participants (*M* age = 6.00 years, *SD* = 1.21; 46 females and 50 males) was selected to complete the neurophysiological portion of the study that is the focus of this report. We have previously reported

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