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Toddlers' dysregulated fear predicts delta–beta coupling during preschool

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ABSTRACT

Dysregulated fear, or the persistence of high levels of fear in low-threat contexts, is an early risk factor for the development of anxiety symptoms. Previous work has suggested both propensities for over-control and under-control of fearfulness as risk factors for anxiety problems, each of which may be relevant to observations of dysregulated fear. Given difficulty disentangling over-control and under-control through traditional behavioral measures, we used delta–beta coupling to begin to understand the degree to which dysregulated fear may reflect propensities for over- or under-control. We found that toddlers who showed high levels of dysregulated fear evidenced greater delta–beta coupling at frontal and central electrode sites as preschoolers relative to children who were low in dysregulated fear. Importantly, these differences were not observed when comparisons were made based on fear levels in high threat contexts. Results suggest dysregulated fear may involve tendencies toward over-control at the neural level.

1. Introduction

Extreme fearfulness in childhood is associated with a sevenfold increase in risk for being diagnosed with an anxiety disorder (Clauss and Blackford, 2012). Despite this large effect, rates of stability in fearfulness (Kagan et al., 1988; Pfeifer et al., 2002) and its associations with subsequent disorder (Biederman et al., 2001; Hirshfeld et al., 1992) are highly variable, making it difficult to understand how and for whom early fear leads to disorder. Recent work suggests that risk may be greatest for children who are highly fearful in low-threat contexts (Buss, 2011; Buss et al., 2013). This work describes *dysregulated* patterns of fear (Cole et al., 1994) in which observed fear is unmatched to contextual incentives (Buss, 2011). It remains unclear, however, whether dysregulated fear is associated with the under-engagement or over-engagement of regulatory resources expected to mitigate fearful behaviors. In fact, both tendencies for under-control (Murray and Kochanska, 2002) and over-control (Eisenberg et al., 2001) have been suggested as factors of risk for anxiety problems. This has resulted in ambiguity about the processes that should be targeted for programs of intervention and treatment. In the current study, we explore a behavioral neuroscience approach to understand whether dysregulated fear is associated with trait-level propensities for the over- or under-engagement of regulatory processing at the neural level.

Dysregulated fear reflects a lack of modulation of fear across contexts (Buss, 2011). Greater dysregulated fear is associated with longer, more intense expressions of fear in both high-threat and low-threat contexts. High levels of fearfulness in low threat contexts, in particular, distinguish dysregulated fear from traditional fear-based risk. Importantly, dysregulated fear predicts anxiety risk even when traditionally-assessed fear is statistically controlled (Buss, 2011; Buss et al., 2013), suggesting that a focus on high levels of fear in low-threat contexts may be critical for identifying early risk for disorder.

Still, the processes that underlie dysregulated fear are unclear. Consistent with differing theoretical perspectives on emotion regulation, greater dysregulated fear may reflect two types of disruptions in emotion processing. From a functionalist perspective, dysregulated fear may reflect a lack of coordination of response systems (Campos et al., 1994; Levenson, 1999) such that fear functions to mount behavioral responses (e.g., autonomic arousal, withdrawal) to one's environment even if such a response is unnecessary. From this orientation, it is sensible that dysregulated fear is linked to a propensity for over-control or an underlying readiness to respond to threat even when threat is not apparent. This is consistent with previous behavioral and neuroscience reports linking propensities for over-control to greater fear-based risk for anxiety problems (Brooker et al., 2011; Brooker and Buss, 2014).

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Alternatively, dysregulated fear may reflect a disruption in the down-regulation of negative emotion, or an inability to alter the time course and/or intensity of the fear response (Thompson, 1990). From this orientation, dysregulated fear might reflect under-control, or a lack of availability of regulatory resources and ultimately an inability to abate the fear response. This perspective is also consistent with past work showing that lower levels of self-control predict greater risk for behavior problems (Eisenberg et al., 2001). At first glance, these two perspectives may appear to be separated only by nuance. However, their distinction is critical at the intervention and treatment levels. If dysregulated fear is associated with propensities for under-control, then interventions focused on enhancing processes of self-control and regulation may be most effective for preventing disorder. If, however, dysregulated fear is associated with over-control, then these same interventions risk affirming, or even enhancing, the very tendencies that put children at risk. Thus, the aim of the current work was to examine the association of dysregulated fear with trait-level propensities for under- or over-control in children.

The majority of work characterizing dysregulated fear has been done via investigations of observed behavior. However, trait-level propensities for regulation, including under- versus over-control, are notoriously difficult to disentangle at the behavioral level (Cole et al., 2004; Gross and Thompson, 2007). This difficulty has led to an increased focus on physiological measures in studies of emotion and development. At least one study has shown positive associations between dysregulated fear and physiological measures in infants, including baseline autonomic activity and diurnal cortisol levels (Buss et al., 2004). Baseline measures provide unique information about the dispositional regulatory style of the individual, including a dispositional readiness to respond to challenges in one's environment (Coan et al., 2006; Davidson, 2002; Gunnar, 1992). In this way, baseline measures may be most appropriate for questions about trait-level tendencies for over- or under-control.

Despite this utility of baseline assessments, autonomic arousal and diurnal cortisol reflect fairly ubiquitous processes through which it would be difficult to separate individual tendencies for under- or over-control. A more optimal measure would allow for some degree of distinction between emotion-based behavioral responses that are often linked to subcortical neural activity, and more cognitive processes of regulation, often linked to cortical neural activity. From this approach, relative increases in subcortical activity without parallel increases in cortical activity would reflect under-control, as motivational and emotion processes become heightened in absence of downregulation. Similarly, simultaneous increases in cortical and subcortical activity would reflect increasing propensities for over-control, as both excitatory and regulatory mechanisms become active. Clearly, the invasiveness of recording neural activity from deep-brain structures associated with emotional arousal makes such procedures inappropriate for research with children. Similarly, the sensitivity of Functional Magnetic Resonance Imaging (*f*MRI) to movement artifact, coupled with its temporal imprecision, make it suboptimal for examinations of real-time emotion processing in very young children (Byars et al., 2002). However, parallel changes in cortical and subcortical activity have been linked to oscillations within specific frequency bands of the electroencephalogram (EEG) in both children and adults.

Power in the delta frequency band of the EEG is the predominant frequency in early life as neural activity develops into its adult-like form (Bell, 1998; Stern et al., 2001). Delta oscillations are visible in primitive animal brains (González et al., 1999) and, in humans, have been linked to generators in subcortical areas and linked to motivational, reward, and emotional processes (Knyazev, 2007; Uhlhaas and Singer, 2006). In contrast, power in the beta frequency band of the EEG is associated with alertness, with greater beta power visible during periods of cognitive processing (Ray and Cole, 1985). Although their neural bases are not entirely clear, fast-wave oscillations such as beta are believed to reflect intracortical connections that are important for attention and higher cognitive functions (Engel et al., 2001; Ray and Cole, 1985) which exert an inhibitory influence on subcortical systems (Robinson, 1999).

While the spatial resolution of EEG limits the degree to which real-time oscillations can be linked to specific neural structures, relations between slow (e.g., delta) and fast (e.g., beta) wave activity are believed to reflect functional interactions between cortical and subcortical circuitry (Knyazev and Slobodskaya, 2003; Knyazev, 2007). Indeed, physiological studies have suggested that the stimulation of brainstem and limbic areas of the brain result in increased slow-wave activity (Gray, 1982; Guyton, 1976) while fast-wave beta oscillations are associated with increased activity in cortico-cortical circuits (Knyazev and Slobodskaya, 2003). Greater positive associations between delta and beta power are believed reflect functional coherence between cortical (i.e., cerebral cortex) and subcortical (i.e., limbic) structures. Thus, it has been proposed that delta–beta coupling may reflect, in real time, efforts by cognitively-oriented, cortical systems to regulate reactivity in emotionally-oriented, subcortical systems (Knyazev, 2007; Knyazev et al., 2006), providing a proxy for emotion-regulation processes. Although these types of interpretations remain tentative, this theory is consistent with evidence that greater delta–beta coupling has been associated with greater anxiety in adults (Knyazev, 2011; Miskovic et al., 2010), greater trait-level inhibition (Putman, 2011; Van Peer et al., 2008), and heritable levels of risk for anxiety problems in children (Miskovic et al., 2011a). Furthermore, delta–beta coupling is reduced in concert with the remediation of symptoms following treatment for Social Anxiety Disorder (Miskovic et al., 2011b).

Cumulatively, this body of work suggests that delta–beta coupling provides an avenue by which questions about links between under-vs. over-control and dysregulated fear during childhood may be explored. Specifically, propensities for over-control, which would increasingly engage cortical regulatory networks as subcortical reactivity increases, should be visible as greater baseline delta–beta coupling. In contrast, propensities for under-control, which would engage cognitive resources for regulation to a lesser degree as subcortical activity increases, would result in smaller associations between cortical and subcortical function.

Thus, two competing hypotheses may be derived. If dysregulated fear is linked to trait-level propensities for over-control, then differences in baseline delta–beta coupling should be visible in children who tend to show high versus low levels of fear in low-threat contexts. Specifically, high levels of fear in a low-threat context should be associated with greater baseline coupling relative to low levels of fear in a high-threat context. In contrast, if dysregulated fear is linked to trait-level propensities for under-control, then differences in baseline coupling should be visible in children who show high versus low levels of fear in high-threat contexts. Specifically, high levels of fear in a high-threat context should be associated with greater delta–beta coupling relative to low levels of fear in a high-threat context. Moreover, if delta–beta coupling is simply reflective of general tendencies to respond with fear, then baseline delta–beta coupling should be associated with high levels of fear, relative to low levels of fear, in both high- and low-threat contexts. We tested each of these possibilities in the current study. Critically, because we view both dysregulated fear and delta–beta coupling as trait-level qualities, we tested their association using a longitudinal study design, eliminating state-level confounds that might artificially increase the degree to which the two measures appear to be related.