Neural Correlates of Emotion Regulation in Preschool Children with and without Disruptive Behavior Disorders

by

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Dedication

To my loving wife, Ali, who has supported me since I was a preschool teacher.

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Chapter I

Cognitive Micro-Processes and Emerging Emotion Regulation: An Expanded Neurobiological Model of Preschool Onset Externalizing Behavior Problems

Approximately 25% of children and adolescents in the United States will meet criteria for clinically significant externalizing behavior problems during their lifetime (Kessler et al., 2005). Externalizing problems encompass a broad range of behaviors including noncompliance, aggression, hyperactivity, and impulsivity (Campbell, Shaw, & Gilliom, 2000). Externalizing behavior problems range in severity from disrupting relationships with peers, caregivers, and authority figures to committing criminal acts and violating the rights of others (American Psychiatric Association, 2013). Serious problems often begin during childhood, where they include the Disruptive Behavior Disorders (DBD) Oppositional Defiance Disorder (ODD) and Conduct Disorder (CD) (American Psychiatric Association, 2013). These disorders are often manifested in early childhood: 4-8% of preschool aged children meet diagnostic criteria for a DBD (Nock, Kazdin, Hiripi, & Kessler, 2006; Egger & Angold, 2006). Thus, clinically significant externalizing behavior problems can be identified early in the lifespan, a fact that has important implications for prevention (Campbell, Shaw, & Gilliom, 2000).

Growing evidence suggests that deficits in self-regulation, specifically, difficulty regulating behavior and emotion, are core etiological causes of DBDs and externalizing behavior in general (Martel, Gremillion, Roberts, von Eye, & Nigg, 2010; Shields & Cicchetti, 1998). The most recent Diagnostic and Statistical Manual (DSM-V) now defines Disruptive Behavior Disorders as resulting from deficits in specific self-control processes, such as emotion dysregulation (ER; American Psychiatric Association, 2013). Clearly, knowledge of how preschool children regulate themselves during emotionally challenging events- what strategies they attempt, what

skills explain their success or failure- will impact our understanding of how to assess and treat early externalizing behavior problems.

Interest in emotion regulation has dramatically increased in recent years (Gross, 2007). There are still major gaps, however, in our understanding of emotion regulation and its role in early disruptive behavior problems. Specifically, the underlying mechanics of early emotion regulation, the neural processes that explain a preschool child's ability to overcome an emotional challenge, have not been well articulated in research (Cole, Martin, & Dennis, 2004). Understanding how the preschool brain reacts to and regulates emotion will elucidate our understanding of normative and non-normative emotion regulation development.

The central goal of this dissertation is to elucidate how cognitive micro-processes, and their neural correlates, underpin emerging emotion regulation and early onset externalizing behavior problems. In this chapter, I begin with a discussion of the societal costs of externalizing behavior problems, and how these problems develop across childhood. Next, I review three topics that provide a foundation for a theoretical model of early emotion regulation development. First, I describe the normative development of emotion regulation in early childhood. Specifically, I explore the hypothesis that executive function (EF) subcomponent skills are mobilized to achieve independent emotion regulation during the preschool years. Moreover, I argue that understanding the precursors of these EF subcomponents, which I label "cognitive micro-processes", are critical to understanding the link between EF and ER. Second, I review evidence that early onset externalizing behavior problems may similarly be driven by the interplay between these EF subcomponents and ER deficits. Third, I discuss methodological challenges in defining the construct Emotion Regulation itself. Specifically, I review evidence

that how children respond to emotional challenges can be framed as comprising separate emotion reactivity and emotion regulation phases.

Next, I use these previous discussions to develop a neurobiological model of emerging emotion regulation: how cognitive micro-processes reflecting prevention, awareness, and processing of errors and conflicts are mobilized during the onset of negative affective events. These cognitive micro-processes underpin emotion and behavior dysregulation in preschool children. Moreover, cognitive micro-processes mobilized during the onset of negative affective events differentially relate to emotion reactivity and emotion regulation phases. Subsequently, I describe how Event Related Potential (ERP) techniques can test this model by measuring the electrophysiological correlates of cognitive micro-processes activated during emotion-inducing events. I then describe three distinct studies presented in subsequent chapters (Chapters II, III, and IV) that investigate the neural correlates of emotion regulation in preschool children clinically referred for externalizing behavior problems and typical peers. These three studies are summarized in an integrated fashion in Chapter V, and implications for understanding early onset externalizing behavior problems, and how to treat them, are discussed.

The Societal Costs of Externalizing Problems

Children and adolescents with externalizing behavior problems exert an enormous cost on their support systems, their communities, and society as a whole. For example, youths with early onset externalizing behavior problems are two to three times more likely to become lifelong criminal offenders than peers (Loeber, van der Laan, Slot, & Hoeve, 2013). A single lifelong offender costs society an estimated 4.4 million U.S. dollars, on average, via criminal damages, health care costs, residential and foster care costs, and educational resources (Cohen, &

Piquero, 2009). Comparatively, these financial costs are 10 times greater than for a non-disordered peer (Scott, Knapp, Henderson, & Maughan, 2001).

Furthermore, youths with externalizing behavior problems place a significant burden on the mental health care system. Overall, the United States health care system spends more on childhood mental health problems, approximately $8.9 billion dollars per year, than any single childhood medical condition (Soni, 2009). Disruptive behavior disorders comprise approximately half of all cases referred to mental health clinics (Loeber, 1990). Moreover, even when children receive evidenced-based treatments for DBDs, a substantial proportion, perhaps as many as one-third, will not see significant improvement in behavior post-treatment (Scott & Dadds, 2009).

Over the past 25 years, diagnoses of disruptive behavior disorders have increased substantially (Collishaw, Maughan, Goodman, & Pickles, 2004). Thus, it is imperative to create better policies, practices, and interventions that will prevent children with early onset externalizing behavior problems from becoming lifelong offenders. As described below, the preschool years may be a sensitive period for the development of these problems.

The Development of Externalizing Behavior Problems

All children have times when they act aggressively, throw tantrums, and become defiant. Thus, it is critical to distinguish age-normative from clinically significant problems. Researchers have examined the development of externalizing behavior through two lines of inquiry: examining normative trajectories of problem behaviors and examining the progression of chronic behavior problems in clinically impaired children.

Data from longitudinal studies of normally developing children suggest that disruptive behaviors begin in late infancy, reach their peak between 2 and 4 years, and then decrease across

the lifespan (Bongers, Koot, van der Ende, & Verhulst, 2004; Tremblay, 2010). For example, Tremblay (2010) noted that the frequency of overt disruptive behaviors such as aggression (e.g. hitting, pushing, biting), temper tantrums, and non-compliance seem to follow a similar course. These behaviors appear to reach peak levels around two and a half years old, decline but remain relatively high during the preschool years, and then continue to decline across the middle childhood. Thus, many externalizing behaviors peak in early childhood and decrease as children age into later childhood.

Among studies of clinically impaired children, however, disruptive behavior disorder symptoms and diagnoses are remarkably stable across early childhood and into later childhood. In young children showing the highest levels of disruptive behavior, symptoms such as aggressive and defiance appear to remain stable from toddlerhood through the end of the preschool period and beyond (Côté et al., 2007; Petitclerc, Boivin, Dionne, Zoccolillo, & Tremblay, 2009). A recent longitudinal study by Keenan and colleagues (2011) followed three to five year old children recruited from pediatric and behavioral clinics annually for three years. Among children diagnosed with ODD at baseline, 72% still met criteria one year later and 66% and 52% continued to meet criteria two and three years later, respectively. 82% of children diagnosed with ODD at baseline later met criteria at least once over the next three years. Among the children diagnosed with CD at baseline, 61% still met criteria one year later and 33% and 26% still met criteria two and three years later, respectively. 61% of children diagnosed with CD at baseline met criteria at least once over the next three years. In addition, even children who "lost" their baseline diagnosis at subsequent evaluation points still exhibited high, sub-clinical levels of these symptoms. These results suggest that young children with severe behavior

problems early in life maintain clinical diagnoses, or hover around the clinical threshold, as they move into the school-age years.

In addition to focusing on phenotypic differences in clinically significant and typical externalizing behavior, researchers must search for core biological markers of dysfunction that may be common to a range of at-risk preschool children (Dahl & Conway, 2009). Recently, Wakschlag, Tolan, and Leventhal (2010) noted some of the challenges in trying to identify at-risk youngsters based on overt behavior alone. Although disordered preschool children differ from their peers in the frequency, quality (e.g. greater use of proactive aggression) and persistence of their behavior problems, these disordered preschool children are also quite heterogeneous. This heterogeneity appears to be linked to long-term trajectories of antisocial behavior. For example, early oppositional problems have been found to predict future covert delinquency while early physical aggression predicts future overt physical violence delinquency (Nagin & Tremblay, 1999). These heterogeneous pathways make discriminating developmentally appropriate and inappropriate patterns of externalizing behavior especially challenging (Wakschlag, Tolan, & Leventhal, 2010).

Thus, during the preschool years normally developing children are at or near their peak of manifesting disruptive behaviors while at-risk peers are beginning a chronic course. Research that leads to better differentiation of disordered and non-disordered children very early in life will improve the identification, diagnosis, and treatment of at-risk children. The neural processes that underpin early dysregulation, and emotion regulation specifically, may shed light on the multifinality of disruptive behavior disorder trajectories. In order to understand how emotion dysregulation contributes to early externalizing behavior problems, however, we must first consider the unfolding of emotion regulation competence in normally developing children.

Interplay of Executive Function and Emotion Regulation in Normative Development

The construct of emotion regulation comprises processes necessary for modulating the intensity, time-course, and valence of emotional experiences (Thompson, 1994). Emotion regulation serves an adaptive purpose and is goal directed (Barrett & Campos, 1987). The development of early emotion regulation is embedded within rapid physiological, psychological, and social maturation from infancy through the preschool years. In many ways, our current understanding of emotion regulation early in life comes from knowledge of how children make gains in cognitive and motoric abilities. Infants who can orient themselves towards and away from emotion-inducing stimuli, and can self-soothe with thumb-sucking, grow into toddlers and preschool children who can walk, run, talk, manipulate objects, use working memory, understand social demands, and delay gratification to achieve emotion-driven goals (Calkins & Hill, 2007; Kopp, 1982; Thompson & Goodman, 2010; Sroufe, 1996). This view of emotion regulation development, however, risks reducing the construct to mere sequelae of increasing physical and cognitive skills rather than qualitative changes in emotion regulation itself.

Kopp (1989) hypothesized that young children's emerging ability to regulate emotion independently results from the mobilization of newly acquired executive function skills (though the idea that emotion and cognition are linked is far older). Executive function (EF) is a set of inter-related skills, including inhibition, attention, and working memory skills used to achieve adaptive goals (Welsh, Pennington, & Groisser, 1991). Kopp postulated that young children achieve independent ER when they learn to apply these EF skills to emotional problems and conflicts. For example, Kopp described a situation in which a pet dog is bothering a boy and preventing him from independent play. The boy tricks his pet into following him outside, and

then runs back inside and closes the door, leaving the dog in the yard. Thus, the boy mobilized planning skills to move out of a negative emotional state (Kopp, 1989).

More recently, Zelazo (2007) expanded on the idea that emotion regulation involves mobilization of EF skills. Specifically, Zelazo's theoretical model delineated a hierarchical structure of executive function. "Computational" processes at lower levels, such as working memory, cascade and organize to form "algorithmic" processes at higher levels, such as representation of rule hierarchies. These lower level processes ultimately reach consciousness and are executed at the "implementation" level (Zelazo, 2007). Moreover, Zelazo argued that emotion regulation should therefore be defined as a *type* of EF. The application of computational and algorithmic processes toward problems with high emotional saliency is categorized as "hot" EF, which Zelazo argued is synonymous with ER.

However, computational processes such as working memory and rule representation are relatively immature in preschool children (Zelazo, 2006). Thus, learning to mobilize EF skills may not begin with higher-order, more complex processes. Furthermore, the computational level is not the lowest level at which cognitive processes of EF can be defined. Models of emotion regulation specific to preschool children must therefore examine smaller-scale cognitive micro-processes that make up higher level computational processes. For example, "computational" EF skill such as error detection and correction (Zelazo, 2007) comprises the cognitive micro-processes error awareness, occurring within 50 milliseconds of an error, and the subsequent evaluation of the error, occurring 200 milliseconds later (e.g. Herrmann, Römmler, Ehlis, Heidrich, & Fallgatter, 2004).

To date, studies examining the link between EF and ER in early childhood have primarily focused on higher-order cognitive processes. For example, Carlson & Wang (2007) found that

preschool children who performed better on inhibitory control (IC) tasks, a subcomponent of EF, and were rated higher on IC, were better able to regulate their behavior during an emotional challenge, and were rated higher on ER by caregivers. American preschoolers who were rated higher on inhibitory control showed less cortisol reactivity and a quicker return to baseline cortisol levels following an emotional challenge (Grabell et al., in press). Thus, these studies examined longer time windows of emotion regulation. As stated previously, executive function is simply an umbrella term describing a collection of inter-related but distinct skills. Many researchers examining EF deficits in children with externalizing behavior problems create global EF composites that obscure which subcomponents are driving effects (Séguin & Zelazo, 2005). Other studies, such as the aforementioned study by Carlson and Wang (2007) examine just one subcomponent of EF, such as inhibitory control, and don't test how other subcomponents might relate to ER. To further know the mechanics of emotion regulation, we must examine the processes that relate to emotional events at smaller time scales.

When a cognitive or emotional challenge occurs, immediate neural processes engage. Precursors of higher-order EF skills include orienting attention, and anticipating, recognizing, and gauging the salience of errors and conflicts (Lamm, Zelazo, Lewis, 2006; Hillman et al., 2012). These cognitive micro-processes occur within milliseconds of the onset of a cognitively or emotionally salient conflict. Thus, examining cognitive micro-processes engaged moments after emotional challenges occur may reveal *how* and *which* EF skills are mobilized for ER. To date, however, this has not been tested in young children.

If typical children develop competent, independent ER by mobilizing EF skills, it logically follows that failure to do so would result in early onset externalizing behavior problems.

As described in the following section, although some evidence suggests this may be the case, process models have not yet been tested in clinically impaired preschoolers.

Deficits in Executive Function and Emotion Regulation in Childhood Externalizing Behavior

Self-regulation deficits that characterize externalizing behavior problems have often been grouped into two categories: deficits in executive function and deficits in emotion regulation.

Children with externalizing behavior problems show deficits in executive function (Raine et al., 2005). Preschool children with high levels of externalizing behavior have poorer effortful control: a temperamental analogue of executive function comprising inhibitory control, attentional focusing, and delay of gratification skills (Olson et al., 2005). Furthermore, children with Disruptive Behavior Disorders perform worse than their peers on a wide range of executive functioning tasks including working memory, sustained attention, and attentional shifting tasks (Barkley, 1997; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002).

Moreover, deficits in emotion regulation underlie childhood disruptive behavior disorders (and childhood psychopathology in general) (Cole, Hall, & Radzioch, 2009; Martel, 2009). A 1996 study by Cole, Zahn-Waxler, Fox, Usher, and Welsh found that preschool children who were better able to modulate their facial expressions while watching emotion inducing video clips had significantly lower maternally rated disruptive behavior problems compared to peers. Furthermore, the preschool children who had the highest levels of physiological reactivity to the emotion inducing videos also had higher levels of disruptive behavior compared to children with moderate physiological responses. When they are frustrated, young children with disruptive behavior problems are more likely to show behaviors reflecting emotion dysregulation such as temper tantrums (Calkins, 2002; Calkins & Dedmon, 2000).

Therefore, preschool children with externalizing behavior problems may be unable to adequately mobilize executive function skills for emotion regulation purposes. To my knowledge, however, there have been no studies testing the relation between multiple indicators of EF and ER in preschoolers with externalizing behavior problems. To date, most studies examining the mechanisms that explain the link between emotion regulation and disruptive behavior have looked at broader, more distal factors such as the child-rearing environment (e.g. maltreatment) and genetics (Lahey et al., 2011; Shields & Cicchetti, 1998), with relatively less focus on specific mechanisms such as the cognitive determinants of emotion regulation and their neural correlates.

To summarize, the development of cognitive micro-processes of executive function during the preschool years may uncover how typical children develop competent emotion regulation, and why children with externalizing behavior problems do not. In order to examine the interplay between EF and ER in more detail, however, we need to examine how the preschool brain initially mobilizes cognitive micro-processes during affective challenges. Furthermore, we need to examine and compare these processes in preschool children with and without externalizing behavior problems.

Moreover, as described below, the construct emotion regulation comprises a range of regulatory strategies and behaviors in response to an emotional challenge. The multi-faceted nature of emotion regulation has implications for our models of emerging, independent ER in early childhood.

Methodological Challenges Defining Emotion Regulation

Current definitions of emotion regulation have been criticized as being overly vague and nonspecific (Cole, Martin, & Dennis, 2004; Eisenberg & Spinrad, 2004; Thompson, 1994). The

process of modulating emotions can occur at different timescales and may change depending on context, situation, and available resources (such as a comforting caregiver). There are seemingly endless methods, measures, and instruments used to quantify emotion regulation, each tapping into different aspects of the construct. Scholars have called for emotion regulation research that explores and embraces this complexity (Cole, Martin, & Dennis, 2004). In what follows, I describe two aspects of emotion regulation relevant to the etiology of externalizing behavior problems: emotion regulation at different timescales, and emotion reactivity versus more deliberate emotion regulation (Woltering & Lewis, 2009; Eisenberg & Spinrad, 2004; Cole et al., 2004).

Emotion regulation at different timescales

Psychological processes underlying children's responses to emotional experiences can occur across a wide range of time scales. For example, EEG studies of adults have shown that reactions to emotional stimuli occur within milliseconds (Davidson, Jackson, & Kalin, 2000). Studies of how infants attend to and avert their gaze to emotional stimuli have shown that these processes occur within a few seconds (Rothbart, Ziaie, & O'Boyle, 1992). Finally, studies of how children use emotion regulation when delaying gratification, such as waiting to play with a toy, have highlighted behavioral strategies that unfold over several minutes (Carlson & Wang, 2007; Gilliom, Shaw, Beck, Schonberg, & Lukon, 2002; Grolnick, Bridges, & Connell, 1996). The continuity of emotion regulation at these different levels and their relation to early onset externalizing behavior problems is largely unknown. How do ER deficits at small time scales, and in narrow contexts, predict ER deficits at large time scales and in broad contexts? This question has important implications for etiological models of externalizing behavior.

Emotion reactivity versus deliberate emotion regulation

It has been argued that researchers should distinguish reactive and deliberate processes of emotion regulation, which are typically placed under the same general heading (Eisenberg & Spinrad, 2004; Cole, Martin, & Dennis, 2004). Emotion reactivity involves responses that are pulled from the situation and are governed more so by immediate processes and less so by intentional and conscious processes (Woltering & Lewis, 2009). A child's initial reaction after having a toy yanked out of his hand by a peer is an example of emotion reactivity. Deliberate emotion regulation, in contrast, is a longer unfolding process. Deliberate emotion regulation involves more effortful control, reflection, and reappraising of the situation. A child who wants a cookie from a cookie jar across the room, has been told that having a cookie is forbidden, and takes several minutes to decide what to do is an example of deliberate emotion regulation (Eisenberg & Spinrad, 2004).

Emotion reactivity may appear to be activated emotion without subsequent regulation. However, in adults and rodents, regulatory neural circuitry activates and modulates amygdala functioning immediately following a salient emotional event, such as fear (Phillips, Ladouceur, & Drevets, 2008), suggesting that, as others have hypothesized, emotion and regulation are never independent (Campos, Frankel, Camras, 2004).

The debate over emotion reactivity versus deliberate emotion regulation can also be framed as "negative emotionality" versus "emotion regulation". Young children with disruptive behavior problems display higher levels of negative emotionality, defined as dispositional levels of anger and irritability compared to peers, particularly anger and frustration (Eisenberg et al., 2005). High levels of negative emotionality have been linked to temperament precursors in infancy (Aksan et al., 1999). Although both emotion regulation and negative emotionality play a role in disruptive behavior, negative emotionality represents more dispositional reactivity to

emotional stimuli, hypothesized to influences but be separate from processes designed to modulate emotional experience (Cole, Martin, & Dennis, 2004). Others, however, have challenged this view as ontologically impossible, and argue that negative emotionality is always ingrained with regulation (Campos, Frankel, Camras, 2004). That children with externalizing behavior problems exhibit higher levels of negative emotionality *and* poorer deliberate regulation (Eisenberg et al., 2009) complicates our understanding of the emotion processes that underpin disruptive behavior. Children with externalizing behavior problems may simply get angry and upset more easily and more intensely, and these high levels of negative affect are more difficult to dampen. Alternatively, children with externalizing behavior problems may also have separate, specific deficits in deliberate regulation of emotion. Thus, there have been calls for research that delineates the unique contribution of each of these constructs in disruptive behavior disordered children (Olson, Sameroff, Lunkenheimer, & Kerr, 2009). To my knowledge, studies have yet to examine the specific neural correlates of reactive and deliberate emotion regulation in preschool children, and test how these patterns relate to early onset externalizing behaviors.

Neurobiological Model of Emotion Regulation

Current models of emerging emotion regulation hypothesize that hierarchically structured executive function skills are mobilized during emotional challenges. My dissertation expands on this model in the following ways (see Figure 1): First, a hierarchical model of EF must include its smallest scale subcomponents. Cognitive micro-processes may be mobilized when affective events first occur and cascade into other, higher order regulatory processes. Thus, examining these cognitive micro-processes may elucidate how higher-order EF subcomponents are mobilized for ER, and which processes signal risk for early onset externalizing behavior problems. This builds on other scholarly work hypothesizing that ERPs in response to emotion

inducing stimuli are precursors of higher-order emotion regulation that unfold over longer periods of time (Hajcak, MacNamara, & Olvet, 2010). Second, this expanded theoretical model postulates that the mobilization of cognitive micro-processes relate to different aspects of how preschool children respond to emotional challenges. In my hypothesized neurobiological model I denote these aspects using the following terminology: Emotion reactivity and emotion regulation are distinct but related phases within overarching "response to emotional challenge." I theorize that engagement of cognitive micro-processes at the onset of emotional challenges may underpin the manifestation of both emotion reactivity and more effortful emotion regulation. Finally, I theorize that the link between cognitive micro-processes and different aspects of response to emotional challenge may explain both normative and clinically impaired behavioral regulation. This theoretical model describes how initial neural responses to emotional challenges, at small time scales, might drive regulatory processes that occur over longer windows of time. Of course, responding to different emotional challenges most likely involves multiple complex, recursive, and reciprocal processes involving different time scales. While future research elucidating models of emotion regulation are needed, the neurobiological model presented here describes hypothetical ways these processes could begin to unfold at the neural level.

Parts of this theoretical model are tested in sequence across the three studies presented in this dissertation. These studies are novel in that I attempt to measure small-scale cognitive micro-processes closely tied to real-time neural functioning. In what follows, I review literature on neural networks comprising the Prefrontal Cortex (PFC) and Anterior Cingulate Cortex (ACC). The PFC and ACC are two regions of the brain hypothesized to generate cognitive micro-processes important for emotion regulation at the instance emotion-eliciting events occur. I then describe how Event Related Potential (ERP) technique is capable of measuring these

small-scale cognitive micro-processes. Finally, I review the ERP literature and describe neural components hypothesized to reflect processing of emotional events in children.

Neural Architecture of Response to Emotional Challenge

Research on animals, as well as neuroimaging studies on adult humans, suggest that the PFC and ACC are are two critical pieces of regulatory circuitry that exert a top-down influence on activated negative emotion (Davidson, Putnam, & Larson, 2000; Davidson, Fox, & Kalin, 2007; Ochsner & Gross, 2008; Butter, Snyder, & MacDonald, 1970; Iverson & Mishkin, 1970; Rainville et al., 1997). Furthermore, the PFC and ACC are important for resolving non-emotional, cognitive conflicts, such as maintaining the representation of goals despite distraction, inhibiting a response in the presence of conflicting stimuli (Garavan, Ross, & Stein, 1999), shifting attention from one stimuli to another (Frankenstein, Richter, McIntyre, & Remy, 2001; Valet et al., 2004), and monitoring attention and emotion (Devinsky, Morrell, & Vogt, 1995). Thus, as described below, the PFC and ACC are hypothesized to play an important role in mobilizing cognitive strategies to regulate emotion.

Functional imaging studies of adults have revealed that attempting to decrease negative emotion induced by pictures was associated with increased PFC activation (Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner et al., 2004). In pediatric populations, Perlman and colleagues' (2013) study of older children and adolescents similarly demonstrated a link between PFC regional activity when viewing fearful faces and parent-ratings of emotional reactivity (Perlman, et al., 2013). In a sample of healthy preschool children, Perlman and colleagues (2014), using fNIRS, found that PFC activation during an emotional challenge was associated with parent ratings of frustration tolerance.

The anterior cingulate cortex (ACC) also plays an important role in a range of cognitive and emotional processes (Bush, Luu, & Posner, 2000). For example, individual differences in ACC activation, measured using fMRI technique, relate to adults' performance on conflict tasks using emotional stimuli, such as a Stroop task with emotionally salient words (Bush, Luu, & Posner, 2000). Moreover, ACC activation is positively correlated with adults' appraisal and expression of negative emotion (Rainville et al., 1997), and generating emotional responses (Etkin, Egner, & Kalisch, 2011). Lesions to the ACC are associated with an impaired ability to appraise the salience of affectively distressing events in adult patients (Foltz & White, 1962). Finally, an fMRI study in adults revealed that the ACC signals to both the amygdala and prefrontal cortex during emotionally-valenced conflict trials (Etkin, Egner, Peraza, Kandel, & Hirsch, 2006), suggesting a neural network in which the PFC and ACC modulate amygdala activity.

Thus, tests of how cognitive micro-processes relate to emotion reactivity, emotion regulation and externalizing behavior must be guided by the neural architecture that generates these processes. Moreover, examining these cognitive micro-processes requires techniques capable of measuring their magnitude and timing in very small, precise windows of time. It has been suggested that PFC and ACC activation can be measured as electrophysiological activity recorded across the scalp using Event Related Potential technique (ERP) (Gehring, Liu, Orr, & Carp, 2012). Specific Event Related Potential components hypothesized to reflect ACC and PFC regulatory activity, described in more detail below, include the Error Related Negativity (ERN), Error Positivity (Pe), Feedback Related Negativity (FRN), and Inhibitory-N2. Evidence that these ERP components are generated by specific regions of the brain are based on fMRI and source modeling data (Gehing et al., 2012). For example, the ERN component is a negative

voltage deflection that occurs when an individual makes an error. Early studies on the ERN suggested that the ACC was the likely generator of this component based on source modeling (Gehring et al., 1993), a finding that was replicated in subsequent studies (Matthewson et al., 2005; van Veen & Carter, 2002). Moreover, fMRI studies on healthy adults also found that ACC activation was associated with commission errors (Carter et al., 1998). Finally, a 2005 study by Debner and colleagues simultaneously collected ERP and fMRI data in healthy adults. The authors found links between ACC BOLD activity and the ERN and Pe components.

Other studies using fMRI and source modeling methodology similarly suggest that the ACC and PFC are the generators of the FRN and Inhibitory-N2 components, respectively (Gehring & Willoughby, 2002; Luu, Tucker, Derryberry, Reed, & Poulson, 2003; Rubia, Smith, Brammer, & Taylor, 2003). However, there are limits to the accuracy of source modeling data, even in adult populations. These models don't always fit the raw data well and it is unclear if source modeling can identify generators deeper in the brain, such as the ACC, or discriminate multiple generators (Gehring et al., 2012). Moreover, source modeling and fMRI techniques to determine where these ERP components are generated in the brain have not adequately extended to pediatric populations. Therefore, at best, source modeling and fMRI data in adult populations can theoretically inform how the ERP components described below relate to the neurobiology of emerging emotion regulation. However, more research on early childhood populations is needed before claiming that preschool children's ERPs reflect specific regional activity. Therefore, in the current dissertation, I examined ERP waveforms as biomarkers of specific cognitive processes, without making strong claims as to the areas of the brain that generated them.

As described below, Event Related Potential (ERP) techniques are uniquely suited to explore the cognitive micro-processes engaged during an emotional challenge. Below, I describe

ERP methodology and review studies of ERP components examined in typical and disruptive behavior disordered preschool children.

Event Related Potential Techniques

Event Related Potential techniques record the electrical activity generated by brain and detected across the scalp (raw electroencephalogram data, "EEG"). Event Related Potential components linked to cognitive, emotional, and behavioral processes are derived from time-locking the EEG signal to a specific sensory, cognitive, or motor event, such as a behavioral response to a prompt. The small voltages generated by these events, when averaged over many repeated trials, reveal positive and negative voltage deflections, or waveforms. Individual differences in the timing and magnitude of these waveforms thus reflect underlying sensory, cognitive, and regulatory micro-processes (Luck, 2005).

Therefore, ERP techniques are suited to examine multiple underlying processes that may be important for processing emotional events. An advantage of ERP is its excellent temporal resolution. As described below, some scholars have begun examining ERP components important for processing emotion, with a handful of recent studies focusing on young children.

ERP Components of Emotion Regulation

Over the past decade, ERP studies have revealed components important for reacting to and regulating emotional challenges, either directly or indirectly. For example, several ERP studies have examined how children's brains react when they prevent or commit errors. However, these phenomena are typically studies through a cognitive lens rather than framing errors as negative emotional events. Other ERP studies have more explicitly examined how children's brains react when they receive positive and negative valenced emotional feedback.

Typical Children

Error Related Negativity

The commission of an error, such as responding to a lure stimulus during a go no-go task, results in electrical activity generated by the anterior cingulate cortex. This signal, known as the Error Related Negativity (ERN; Gehring, Goss, Coles, Meyer, & Donchin, 1993), typically occurs -20-100ms after individuals make an incorrect response (Dehaene et al., 1994; Gehring, Goss, Coles, Meyer, & Donchin, 1993). A recent study by Grammer and colleagues (2014) demonstrated that the ERN can be detected in children as young as three years. Children, with higher levels of anxiety show larger ERN amplitudes following flanker task errors (Ladouceur, Dahl, Birmaher, Axelson, & Ryan, 2006). Although this suggests a link between the ERN and general emotional functioning, it is unknown whether individual differences in ERN amplitude relate to superior emotion regulation in typical preschool children.

Error Positivity

The Error Positivity component, or Pe, is a positive voltage deflection typically occurring 200 to 400 milliseconds after the offset of the ERN (Overbeek et al., 2005). In general, the Pe component appears to reflect post-error processing or the conscious awareness of errors (Overbeek, Nieuwenhuis, & Ridderinkkhof, 2005). For example, adults who completed an anti-saccade task showed larger Pe amplitudes at parietal sites for aware compared to unaware errors, whereas error awareness was not related to ERN amplitudes (Endrass, Reuter, & Kathmann, 2007). Wessel, Danielmeier, and Ullsperger (2011) found that Pe amplitudes were positively associated with the perceived emotional salience of events in adults (Wessel, Danielmeier, & Ullsperger, 2011). This suggests that the Pe might reflect post-error processing important for emotion regulation. Recent evidence suggests that children as young as three generate a clear Pe

during a go no-go task (Grammer et al., 2014). Less clear, however, is how the Pe relates to the processing and regulation of emotion in this age range (though see Kim et al., unpublished).

Inhibitory-N2

Inhibitory control, a subcomponent of EF, is defined as the capacity to suppress a prepotent response under instructions or in novel or uncertain situations (Rothbart, Ahadi, Hershey, & Fisher, 2000). Inhibitory-N2 is the ERP component reflecting neuro-electrical activity associated with inhibiting a response, for example, during a correct no-go trial (Eimer, 1993). This negative deflecting voltage signal is hypothesized to generate from the prefrontal cortex (Sasaki, Gemba, & Tsujimoto, 1989). The Inhibitory-N2 waveform occurs approximately 200-400 milliseconds after the presentation of a stimulus in which the subject correctly inhibits their response (Eimer, 1993; Falkenstein, Hoormann, & Hohnsbein, 1999; Jodo & Kayama, 1992).

Research on adults has shown that the Inhibitory-N2 is influenced by negative emotional information and attributions (Tucker et al., 2003; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; Deldin, Keller, Gergen, & Miller, 2000). In children, scholars have primarily examined the Inhibitory-N2 from a more purely cognitive rather than an emotional perspective. Lewis and colleagues (2006), however, developed a go-no-go (based on Garavan et al., 1999) designed to explicitly induce negative emotion. Participants were 58 children between 5 and 16 years of age. Prior to the task, children were told they would receive a desirable if they had earned enough points, but an undesirable if they did not. The authors' go-no-go task was divided into three blocks. Points were awarded for correct responses, and deducted for errors. Point deductions were manipulated such that children would accrue points in the first block, lose points in the second block, and regain points in the third and final block. Thus, the authors hypothesized that

the second block would induce negative emotion and affect amplitudes of Inhibitory-N2 during correct no-go trials. They also expected that amplitudes for correct no-go trials would be larger for the second and third blocks.

Results revealed that amplitudes of Inhibitory-N2 linked to correct no-go trials for the second and third blocks were significantly larger than for the first block, but only for children ages 13 to 16 years. These data suggested that a link between Inhibitory-N2 and negative emotion is present in older children. Furthermore, when this task was replicated in 85 school-age children, the Inhibitory-N2 amplitudes were larger following negative emotion induction (Lamm & Lewis, 2010), confirming the importance of Inhibitory-N2 in regulating negative affect.

Feedback Related Negativity

Feedback tied to performance outcomes linked with positive and negative emotion (e.g., as in a gambling task) is associated with neuro-electrical activity generated by the anterior cingulate cortex (Gehring & Willoughby, 2002). This negative voltage deflection, known as Feedback Related Negativity, occurs approximately 250ms after the presentation of a positive or negative outcome (Gehring & Willoughby, 2002; Hajcak, Holroyd, Moser, & Simons, 2005). Although the FRN is generated by the same region as the ERN, and similarly linked to an emotional event, it is a distinct component (Gehring & Willoughby, 2002). In addition, the FRN is elicited by feedback in both performance-based tasks (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003) and in gambling tasks where the outcome cannot be anticipated beforehand (Gehring & Willoughby, 2002). Furthermore, the FRN appears to be sensitive to events associated with negative affect, at least in adults. Healthy adults completing a gambling task showed larger FRN amplitudes for negative outcomes than positive outcomes (Gehring & Willoughby, 2002).

To date, there has been little research on the FRN in children. Hammerer, Li, Muller, and Lindenberger (2011) found larger FRN amplitudes in children between 9 to 11 years of age compared to young adults. However, the authors found no difference in FRN amplitude for negative versus positive outcomes in children. To my knowledge, Mai and colleagues (Mai et al., 2011) were the first to look at the FRN in preschool children. Thirteen typically developing 4 to 5 year old children completed a computerized "prize guessing game" by repeatedly guessing which of two boxes presented on a screen would reveal a desired prize instead of an unwanted prize. Each child played the computerized game to win a pre-selected toy, and the game was rigged such that half of the trials would yield positive "correct" feedback and half would yield negative "incorrect" feedback. Results revealed no differences in FRN amplitudes for good versus bad prizes. These data suggested that the FRN in early childhood might be less sensitive to emotional valence than later in life. However, the Mai et al. study was unable to test whether individual differences in the FRN related to other indicators of emotion or to level of externalizing behavior.

To summarize, ERP waveforms time-locked to preventing, perceiving, or processing negative affective events such as mistakes and negative feedback can be detected in preschool age children. Specifically, the ERP components ERN, Pe, FRN, and Inhibitory-N2 reflect cognitive micro-processes related to the onset of negative affective events. To date however, few studies have explicitly studied these components through an emerging emotion regulation framework. Moreover, most ERP studies only examine one or two of these components. In order to examine a more comprehensive model of emerging emotion regulation, we must study multiple ERP components simultaneously. As described below, even fewer studies have examined these components in children with externalizing behavior problems.

Disruptive Children

Most previous studies of specific ERP components underlying early externalizing behavior have focused on children with Attention Deficit Hyperactivity Disorder (ADHD). For example, mixed evidence suggests that children with ADHD show smaller Pe and ERN amplitudes compared to peers (Wiersema, Van der Meere, & Roeyers, 2005; Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005; van Meel, Heslenfeld, Oosterlaan, & Sergeant, 2007). Comparatively, very little research has compared groups of children based on oppositional and conduct behavior problems.

Using the emotion inducing go-no-go task described above, Steinbein, Lewis, and colleagues (Stieben et al., 2007) examined ERN and Inhibitory-N2 in school-age children with Disruptive Behavior Disorders (ODD and CD) and fifteen age-matched controls. Children with Disruptive Behavior Disorders had significantly lower amplitudes of the Inhibitory-N2 and ERN components during the frustration block compared to normally developing controls. These findings suggest deficits in monitoring errors and ability to inhibit negative emotion for children with ODD and CD (Stienben et al., 2007). However, the effect appeared to be due to a group of children who had significant comorbid externalizing *and* internalizing problems, and thus had a more complex diagnostic picture in terms of their emotion regulation problems. Nevertheless, the authors argued Inhibitory-N2 and ERN represent important neural correlates of emotion regulation in childhood psychopathology.

Thus, Inhibitory-N2 and ERN are waveforms reflecting two potentially important cognitive micro-processes of emotion dysregulation in older children. Whether this distinction is present in very early onset externalizing behavior problems has, to my knowledge, never been

tested. Furthermore, to my knowledge, studies have yet to examine whether Pe and FRN differ in preschool children with Disruptive Behavior Disorders.

Current Studies

The three studies presented in this dissertation examined the same sample of typical and clinically referred preschool children. In Chapter II, I present Study 1: an investigation of how typical preschool children respond to two different types of negative events. I examined the cognitive micro-processes associated with making a mistake versus receiving negative feedback. This study involved creating and testing the feasibility of a paradigm capable of simultaneously measuring multiple ERPs in preschool children. Therefore, to my knowledge, Study 1 is the first to measure and compare characteristics of ERN, Pe, and FRN in preschool children. Findings from Study 1 elucidate our understanding of the development of ER by examining the cognitive micro-processes, and corresponding neural correlates, reflecting two different kinds of negative affective events. As a result, data from this first study will advance understand of early normative emotion regulation.

In Chapter III, I present Study 2: A comparison of preschool children referred to outpatient clinics for externalizing behavior problems and typical peers. Both groups completed the same adapted go no-go task described in Study 1. I compared amplitude of ERN, Pe, FRN, and Inhibitory-N2 across the two groups. Thus, I was able to investigate the specific cognitive micro-processes underpinning self-regulation deficits in early externalizing behavior problems.

In Chapter IV, I present Study 3: A test of whether the ERN, Pe, FRN, and Inhibitory-N2 components predict parent-rated emotion reactivity and regulation. Furthermore, in Study 3 I examined how emotion reactivity and regulation uniquely contribute to early externalizing behavior problems. Thus, Study 3 examined a process model testing how cognitive micro-

processes, engaged at the onset of negative affective events, related to externalizing behavior problems via emotion reactivity and more effortful emotion regulation.

Overall, these three studies will contribute substantially to our understanding of both the normative development of emotion regulation, and the etiology of early onset externalizing behavior problems. The current study fills in critical gaps in our understanding of how independent emotion regulation develops in early childhood, and how it relates to externalizing psychopathology.

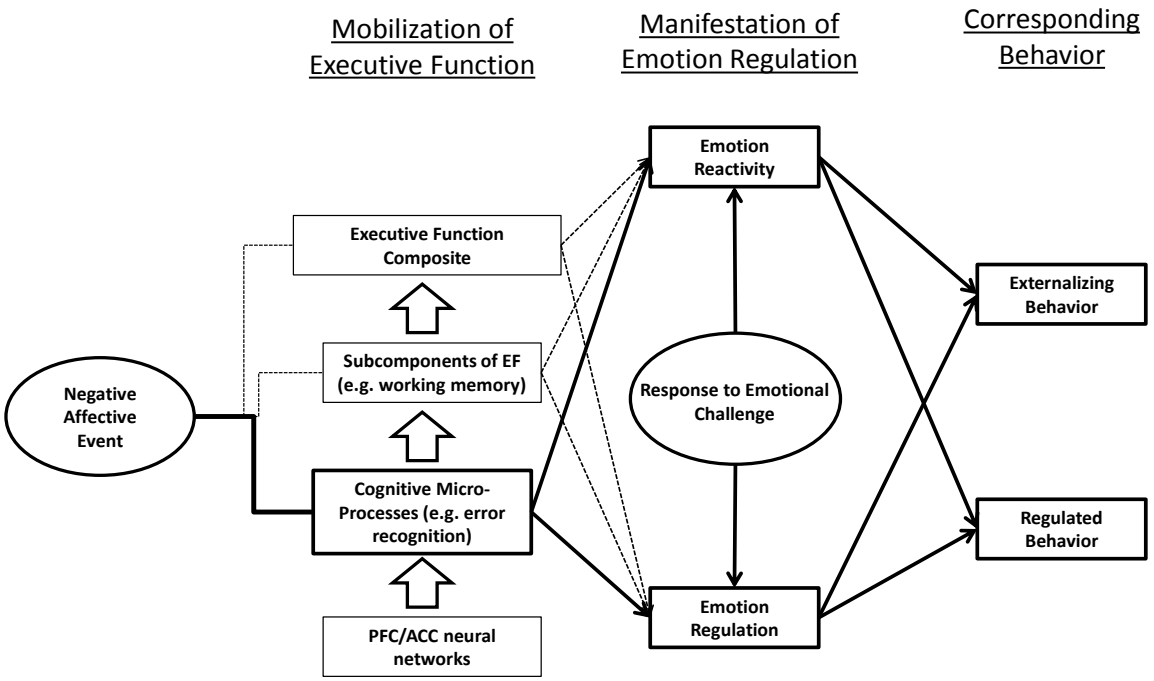

Figure 1. Theoretical model of emerging emotion regulation. Bolded paths indicate paths of interest tested in dissertation studies.

Chapter II
Error and Feedback Processing in Preschool Children

Adequately responding to emotional challenges is a critical developmental milestone in early childhood. Young children who respond maladaptively to everyday stressors such as frustration or disappointment are at risk for concurrent and future negative developmental outcomes including peer, academic, and behavior problems (Olson et al., 2005; Olson et al., 2011). Yet, despite its importance, little is known about the specific neural underpinnings of emotion reactivity and regulation during early, critical periods of development such as the preschool years. This stems in part from an incomplete picture of how the preschool brain processes different types of negative emotion-inducing events at onset. For example, what happens in the preschool brain the instant a child makes a mistake versus the instant they receive a reprimand? The goal of the present study was to examine and compare electrophysiological signals reflecting two different types of negative emotion-inducing events: committing an error and receiving negative feedback.

In recent years, neurophysiological assessment techniques such as Event Related Potential (ERP) have been used to examine how the developing brain responds to negative events. Most studies have focused on the neural correlates of error detection, a component known as Error Related Negativity (ERN). Furthermore, prior studies of ERN have been based on cognitive or executive function perspectives rather than emotion processing perspectives. Few studies have focused on the neural correlates of other types of negative events, such as receiving negative feedback, in preschool children. Specifically, there has been little research on the ERP component underlying the processing of positive and negative feedback: Feedback Related Negativity (FRN), in very young children. In what follows, I review relevant literature on the ERN and FRN components from a developmental perspective, with a focus on early

childhood in particular. Furthermore, I will illustrate gaps in our understanding of the development of the FRN component relative to the ERN.

Error Related Negativity

When humans commit an error, such as shutting a car door while simultaneously realizing their keys are still on the seat, the realization of the error is reflected as an electrical signal generated by the anterior cingulate cortex (ACC; Gehring, Goss, Coles, Meyer, & Donchin, 1993). This signal, known as the Error Related Negativity (ERN; citation), typically occurs -20-100ms after individuals make an incorrect response (Dehaene et al., 1994; Gehring, Goss, Coles, Meyer, & Donchin, 1993). To my knowledge only one study to date has examined the ERN in children younger than 5 years of age. Grammer and colleagues (2014) recently demonstrated that the ERN can be clearly observed in children as young as 3 years. There is some debate as to whether the amplitude of ERN increases as a function of age. For example, some investigators have found that ERN is larger in older children (Davies, Segalowitz, Gavin, 2004) whereas others have found no differences across age (Grammer et al, 2014).

Error Positivity

The offset of the ERN typically precedes a positive voltage deflection known as Error Positivity, or Pe (Overbeek et al., 2005). In adults, the Pe occurs approximately 200-400ms after commission of an error (Overbeek et al., 2005). The aforementioned study by Grammer and colleagues also found that a clear Pe was seen in children as young as three years at parietal-midline locations. Furthermore, the Grammer study found that the amplitude of Pe was larger in older children than preschool age children.

Unlike the ERN, the functional significance of the Pe is still under debate (Overbeek et al., 2005). Broadly, Pe amplitudes appear to be related to post-error processing and the conscious

awareness of errors (Overbeek, Nieuwenhuis, & Ridderinkkhof, 2005). Furthermore, more recently, amplitude of Pe has been shown to relate to the perceived emotional salience of events in adults (Wessel, Danielmeier, & Ullsperger, 2011) and to motivational strategies in preschool children (Kim et al., unpublished).

Feedback Related Negativity

The Feedback Related Negativity component is a negative voltage deflection occurring approximately 250ms after the presentation of a positive or negative outcome (Gehring & Willoughby, 2002; Hajcak, Holroyd, Moser, & Simons, 2005). Like the ERN, it is hypothesized that the FRN is generated by the ACC (Gehring & Willoughby, 2002). In addition, the FRN is elicited by feedback in both performance-based tasks (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003) and in gambling tasks where the outcome cannot be anticipated beforehand (Gehring & Willoughby, 2002). Studies of healthy adults have shown that the amplitude of the FRN is larger following negative outcomes than positive outcomes (Gehring & Willoughby, 2002), suggesting that the FRN is sensitive to events associated with negative affect.

The sensitivity of the FRN to outcomes with different emotional valences suggests its importance in reacting to and regulating negative emotion. To date, however, little research has been conducted on how the FRN changes across development. Hammerer, Li, Muller, and Lindenberger (2011) found children ages 9 to 11 years completing a gambling task had larger FRN amplitudes compared to young adults. Yet, whereas the young adults in the Hammerer study showed expected larger FRN amplitudes following negative outcomes than positive ones, children showed no difference in FRN amplitude between positive and negative trials. Furthermore, there has been little research on the FRN in early childhood. To my knowledge, only one study team has examined the FRN in preschool-age children. Using a prize-guessing

game where children received positive and negative feedback at random after choosing which of two boxes a prize was hidden in, Mai and colleagues (2011) found that 4- and 5-year-old children showed a negative voltage deflection 370ms after the presentation of both positive and negative outcomes. However, unlike adults, these preschool children did not show a difference in response amplitude between positive and negative trials.

Although Mai and colleagues proposed that preschoolers' brains may not show the sensitivity to negative feedback that mature brains do, it is important to note that task characteristics can affect the amplitude of the FRN. In particular, the amplitude of components such as the FRN are affected by the degree to which an outcome is expected or unexpected (Hajcak, Moser, Holroyd, & Simons, 2007) and how frequently an outcome occurs during the task (Folstein & Van Petten, 2008). In the Mai et al. study, unlike a typical go no-go task, children were presented with good and bad outcomes an equal number of times. In the current study, presentation of positive and negative outcomes were linked to performance rather than chance, and occurred infrequently. In the current study, I tested whether FRN amplitudes are more sensitive to negative feedback when outcomes are tied to performance.

Furthermore, an advantage of the current study was the ability to examine FRN and compare it to the parameters of the ERN and Pe. Specifically, I examined these three components simultaneously across a sample of preschool age children. Comparing ERN, Pe, and FRN within subjects allowed me to explore if certain neural processes important for responding to emotional challenges are more developed than others in this age range. Thus, data from the current study have implications for understanding how children manage negative affect.

The current study had two main goals: 1) to determine the feasibility of an adapted go no-go task that also generated response contingent, emotionally-valenced feedback in a population

of preschool-age children; and 2) to test whether typically developing preschool-age children produce a detectable ERN, Pe *and* FRN, and compare the characteristics of these components. A relative lack of data on the FRN in early childhood prevented me from generating strong hypotheses about the appearance of this component in a preschool sample. Thus, the aim of this study was to generate new, unique data that would help fill in a critical gap in our understanding of how preschool children react to different types of negative affective events. Thus, my exploratory goals were as follows:

1. To determine whether adapting a go no-go task to provide performance based, emotionally-valenced feedback would yield a separate ERN and FRN in preschool aged children.
2. To determine whether preschool-age children generate an FRN that is larger for negative outcomes than positive outcomes when feedback is tied to performance.
3. To compare the amplitude of FRN to ERN and Pe as a means of inferring the relative development of different neural processes underlying the immediate processing of negative affective events.

Methods

Participants

Thirty-seven typically developing preschool-age children (M = 57.9 months, SD = 7.8 months; 50% female) were recruited from area preschools via community flyers and web advertisements. Based on maternal report, 75% of the sample identified as Caucasian, 13.8% as mixed-race, 5.6% as African American, and 5.6% as Asian. All were right handed or identified as ambidextrous. Children were excluded from the study if they met any of the following criteria: diagnosis or concerns consistent with any DSM-IV disorder of mood or behavior, diagnosis of

mental retardation or developmental delay, autism spectrum disorder, or psychosis; medical condition; or use of medication affecting mood or attention. Of 37 children enrolled in the study, 18 failed to yield usable ERP data due to the following reasons: did not generate enough artifact free trials (16) and equipment failure (2).

Procedure

Adapted go no-go task

Participants performed a child-friendly go no-go task originally developed by McDermott and colleagues (McDermott et al., 2014) and substantially expanded by Grammer and colleagues (Grammer et al., 2014). In the present study, I further adapted the task to provide performance-based emotionally-valenced feedback. Children were told that were going to play a computer game called "Zookeepers" to win a toy. The task had 8 trial blocks; each block consisted of 40 trials. Children were instructed to click a button each time they saw an animal picture (go stimuli), with the exception of an orangutan picture (lure stimuli) (See Figure 1.1). Children completed two practice blocks, the first without lure stimuli and the second with lure stimuli, to ensure they understood the task. Children were awarded special animal stickers after each trial block, regardless of performance, to increase motivation. Research assistants were trained to praise children on their speed, regardless of their performance, rather than their accuracy to ensure children made enough errors for analyses.

Stimuli were weighted such that the lure stimuli were randomly selected 25% of the time. As shown in Figure 1, for every correct no-go trial (child correctly abstained from hitting the button), the child was presented with a happy face after 500ms of black screen. For every incorrect no-go trial (child accidentally hits the button), the child was presented with an unhappy face after 500ms of black screen. This 500ms gap was designed to separate ERN and FRN

waveforms. Happy and unhappy faces were designed to be as similar as possible in terms of their size, percentage of yellow to black pixels, and position on the screen to ensure these stimuli characteristics did not influence waveforms.

Furthermore, beginning with the practice block, and continuing through all trial blocks, a dynamic algorithm was used to ensure participants had a sufficient number of correct and incorrect no-go trials by adjusting the stimulus duration. The purpose of the dynamic timing algorithm was to ensure that all children, regardless of their inhibitory ability, would make approximately the same number of errors, and thus encounter the same number of emotion eliciting events across the task. The duration of go and no-go stimuli decreased by 100ms increments each time children completed a successful no-go trial. Similarly, go and no-go stimuli duration increased by 100ms increments each time children made an error on a no-go trial. Adjustments in duration were capped such that go and no go stimuli could be no faster than 800 milliseconds and no slower than 1800 milliseconds. Speed adjustments did not affect the duration of black screen, fixation cross, or feedback presentation.

Prior to EEG recording, children were seated in a comfortable chair and engaged in rapport building with research assistants. This included reading a picture book together about animals in a zoo, and administrating an assent script in child friendly language. Parents were allowed to remain in the room with their child during both the assent and EEG recording.

EEG data was recorded using a 128 channel child-friendly Geodesic Sensor Net (Tucker, 1993). Impedance for all electrodes was kept below 50 KΩ, and all recordings were referenced to the vertex, Cz. The EEG signal was amplified using a 0.01-100 Hz bandpass and digitized at 500 Hz. The electro-oculogram (EOG) was monitored with 6 electrodes placed bilaterally in the external canthi (Ch 128 and 125), supraorbital (Ch 25 and 8) and infraorbital (Ch 127 and 126)

regions. Recording in every channel was vertex-referenced. Data was recorded and processed using Net Station 4.1 (EGI software).

Once acquired, the data were lowpass filtered below 20 Hz. The continuous EEG was segmented into epochs for ERN/Pe and FRN. ERN/Pe segments began 400 milliseconds before the onset of the response to 800 milliseconds after the response. FRN segments began 200 milliseconds before the onset of feedback presentation to 1200 milliseconds after. Segmented files were scanned for artifacts with the Artifact Detection NS tool for excessive muscle activities, eye blinks and eye movements

Segments were marked for artifact if the running average of activity exceeded pre-defined thresholds for eye movement (55 μV), blinks (100 μV), and bad channels (200μV). Following this automated process, segments were manually inspected. Segments with more than 10 bad channels were excluded from analyses. In segments with less than 10 bad channels, and no movement artifacts, spherical spline interpolation was used to replace bad channels using values from neighboring channels (Gratton, Coles, and Donchin, 1983). Children with at least 6 good segments in each trial were included in analyses.

Artifact-free ERN and FRN segments were averaged separately and then re-referenced against the average of all channels. A baseline correction was performed for -200 to -100ms for ERN/Pe segments and -100 to 0ms for FRN segments. Based on visual inspection of the grand averaged ERPs, and in accordance with previously published reports, I defined ERN as the largest negative deflection between -25 and 50ms after the response onset, Pe as the largest positive deflection between 200 and 500ms after the response onset, and FRN as the largest negative deflection between 350 and 450ms after the feedback onset. Furthermore, I made

manual adjustments for a small number of children who showed peak amplitude of these components outside, but within 50ms of, these predefined windows of interest.

Results

Behavioral Results

Consistent with other studies (e.g. Grammer et al., 2014) children had faster reaction times for incorrect no-go trials than for correct go trials. Mean reaction times were 599ms (*SD* = 62ms) for go trials and 482ms (*SD* = 64ms) for no-go trials. The mean accuracy was 81% for go trials and 74% for no-go trials. As stated previously, the pre-set duration of go and no-go stimuli was dynamically adjusted throughout the task based on the child's performance on no-go trials. The average pre-set duration for go and no trials was 887ms (*SD* = 66ms).

On average, children had 78 artifact-free CRN trials (*SD* = 26 trials), 13 artifact-free ERN/Pe trials (*SD* = 7 trials), 29 artifact-free FRN trials for positive outcomes (*SD* = 8 trials) and 9 artifact-free FRN trials for negative outcomes (*SD* = 5 trials).

ERP Results

ERN

Response-locked waveforms showing the ERN and Pe components at midline electrode sites can be seen in Figure 1.2. Consistent with previous studies, ERN and Pe were examined at frontal-midline sites Fz, FCz, Cz, and Pz.

Consistent with Grammer and colleagues' findings, visualization of grand averaged data showed a clear ERN component at midline sites (see also Figure 1.4). A 2 (ERN, CRN) by 4 (Fz, FCz, Cz, Pz) repeated measures ANOVA revealed a main effect of condition, such that ERN amplitudes were significantly larger than CRN amplitudes ($F(1) = 63.83$, $p < .001$). There was no significant main effect of site or a trial by site interaction.

Pe

Also consistent with Grammer et al.'s study, the ERN preceded a positive deflection consistent with Pe. A repeated measures ANOVA revealed no significant main effect of trial, but a main effect of site ($F(3) = 20.33$, $p < .001$), and a significant trial*site interaction ($F(3) = 14.02$, $p < .001$). Post-hoc paired sample t-tests revealed that Pe amplitude was significantly larger for incorrect trials than correct trials at Pz only ($t(16) = 3.7$, $p < .01$), and significantly smaller than correct trials at Fz ($t(16) = -3.83$, $p < .01$) (see also Figure 1.5).

FRN

As shown in Figure 1.3, visualization of the waveforms showed a clear negative deflection around 375ms post feedback. Peak to peak values were analyzed rather than the amplitude of the FRN peaks themselves due to differences in the height of the waveforms as early as the N1 component.

Furthermore, there appeared to be a larger deflection linked to negative feedback than positive feedback. A 2 (negative, positive feedback) by 4 (site) repeated measures ANOVA revealed a main effect of trial ($F(1) = 9.63$, $p < .05$), such that negative feedback peak to peak amplitude was significantly larger than positive feedback amplitude, and a main effect of site ($F(3) = 29.46$, $p < .001$). Post-hoc paired sample t-tests revealed that FRN peak to peak amplitudes following negative feedback were significantly larger at Fz ($t(16) = -3.83$, $p < .01$) and significantly smaller at Pz ($t(16) = 3.77$, $p < .01$). As shown in Figure 1.6, the largest negative voltages for negative feedback were seen around central midline sites.

Association between Components

As shown in Table 1.1, bivariate correlations revealed that ERN amplitudes at Cz were significantly positively correlated with error-trial Pe amplitudes at FCz such that children with larger magnitude ERN amplitudes at Cz had larger magnitude Pe amplitudes at FCz. FRN

amplitudes following negative trials were uncorrelated with ERN amplitudes. FRN amplitudes following positive trials at Fz, however, were significantly positively related to ERN amplitude at Cz, such that children with larger magnitude FRN amplitudes associated with positive feedback at Fz had larger magnitude ERN amplitudes at Cz. Furthermore, FRN amplitudes following negative feedback at Pz were significantly correlated with error-trial Pe at Pz. This relation was such that children with larger magnitude FRN amplitudes following negative feedback had smaller error-trial Pe amplitudes. Finally, error-trial Pe amplitudes at Cz were negatively correlated with FRN amplitudes following negative feedback at Cz such that children with smaller Pe amplitudes following errors had larger FRN amplitudes following negative feedback. These two components were also marginally correlated at FCz and Fz.

Discussion

The main goal of the present study was to examine, in typical preschool children, the neural processes that underlie initial responses to two types of negative events: making an error and receiving negative feedback. To accomplish this, I developed, to my knowledge, the first task designed to extract the ERN, Pe, and FRN in children this young. The current study used a child-friendly go no-go task developed by Grammer and colleagues, and adapted it such that children received positive and negative emotionally-valenced feedback. By separating the onset of the commission error and the onset of feedback presentation by 500ms, I was able to detect waveforms consistent with ERN, Pe, and FRN in children ages 3.5 to 5 years.

In the present study, preschool children's ERN and Pe components replicated what Grammer and colleagues found in their study of 96 preschoolers, kindergarteners, and first-graders. Like the Grammer study, I found ERN amplitudes that were of similar size and latency, were significantly larger than corresponding CRN waveforms, and were most robustly seen at

frontal-midline sites. Also like the Grammer study, I found a Pe component with significantly larger amplitude for negative than positive trials at Pz. However, in the Grammer et al. study, children did not receive any feedback on their performance. That the current study and the Grammer et al. study showed similar appearing ERN and Pe waveforms suggests that these components may be unaffected by the emotional saliency of the task. However, while I can perhaps be confident that ERN and Pe in our study are in fact ERN and Pe, perceived emotional saliency of errors has been shown to affect ERN amplitude (Pailing & Segalowitz, 2004). The degree to which the emotional saliency of a task might affect the amplitude of error-related components in early childhood is an unexplored area of research.

The go no-go task used in the current study was unique in that children received performance-contingent feedback that could be anticipated, rather than random feedback such as in a gambling task. Nonetheless, I found that the characteristics of the FRN waveform were consistent with previous studies in adults and children. First, in the current study I found FRN waveforms peaks at 365 milliseconds post-feedback. Although adults who completed a gambling task showed FRN waveform peaks between 200 and 300 milliseconds (Gehring & Willoughby, 2002; Hajcak, Moser, et al., 2005), Mai et al.'s 2011 study of preschool children found FRN peaks amplitudes at 370 milliseconds post-feedback. Thus, later occurring FRN waveforms found in the current study are consistent with limited literature suggesting a delayed onset of this component in early childhood.

Moreover, in the current study I found that peak to peak differences for positive and negative outcomes were largest at frontal midline sites, specifically Fz, and smallest at parietal sites, specifically Pz. Similarly, adults who completed gambling tasks showed FRN waveforms largest at Fz (Gehring & Willoughby, 2002; Hajcak, Moser, et al., 2005). In addition, the

aforementioned 2011 study by Mai and colleagues also found larger FRN amplitudes at more frontal than posterior sites (FCs and Cz) in typical preschool children.

Furthermore, not only did I find a clear FRN component following feedback, but I also found the amplitude of FRN was significantly larger for negative feedback than positive feedback outcomes. This is in contrast to Mai and colleagues' 2011 study on typical preschool children who completed a prize-guessing task, which showed no difference in FRN for negative versus positive trials. In fact, the difference in FRN waveforms for negative and positive outcomes in the present study is consistent with FRN waveforms seen in adults (Gehring & Willoughby, 2002). The Mai et al study, as well as other studies in young children failing to find a difference in FRN by valence (Hammerer, Li, Muller, and Lindenberger, 2011), used a prize-guessing task analogous to a gambling task, where feedback was randomly linked to the child's choice.

Thus, task characteristics may be critical as to whether the FRN is found to be more sensitive to negative events in this age range. For example, the parameters of the task used in the current study differed in several key ways compared to the Mai et al. study. First, the frequency of feedback was very different in the two studies, with children receiving feedback on every trial in the Mai study compared to just 25% of trials in the current study. This is consistent with research showing that amplitude of the FRN is typically larger when feedback is infrequent (Folstein & Van Petten, 2008). Moreover, children in the current study always received negative feedback after committing an error, suggesting that the ERN might somehow "prime" the brain to be more sensitive to subsequent negative feedback. Second, preschoolers completing the prize-guessing task in the Mai study could not anticipate negative versus positive outcomes, whereas children in the current study, because feedback was linked to performance, could. While

research on adults has shown that the degree to which an outcome violates expectations moderates amplitude of the FRN (Hajcak, Moser, Holroyd, & Simons, 2007), these findings suggest that outcomes in line with expectations should have smaller FRN amplitudes. Thus, the relationship between expectation and FRN amplitude may be different at earlier developmental stages. Finally, the stimuli used as emotionally-valenced feedback were very different in the current study compared to the Mai study. In the Mai study, children saw abstract symbols, black and red stars, indicating their progress toward winning a pre-determine prize. In the current study, children saw happy and angry cartoon faces that weren't explicitly linked to a long-term reward. Thus, the meaning children attribute to stimuli, and how viscerally salient they are perceived, may affect the FRN's sensitivity to negative outcomes. To summarize, these results indicate that, compared to adults, the FRN's sensitivity to negative events may be more dependent on task characteristics in early childhood.

Finally, examining the association between these components revealed that amplitude of FRN following negative outcomes was significantly correlated with amplitude of Pe, but not ERN. This suggests, firstly, that FRN in the current study was a distinct component and not just a subsequent ERN. Furthermore, a strong association between the FRN and Pe makes sense given that both components occur 200 to 500ms after an event, and are hypothesized to relate to the evaluation of an experience, whereas ERN is more often framed as a person's initial awareness of an error (Gehring, Goss, Coles, Meyer, & Donchin, 1993). Specifically, children with larger magnitude FRN amplitudes following negative outcomes tended to have smaller Pe amplitudes. This suggests, perhaps, that children with less awareness of their errors showed stronger reactivity to subsequent negative feedback. Because children in the current study knew they would receive negative feedback after making an error, Pe amplitude in this instance may reflect

not just the child's awareness of the error, but their initial attempt to regulate their emotions and perhaps prepare themselves for an imminent, subsequent, negative event.

Alternatively, larger peak to peak differences following negative outcomes, and an association between Pe and FRN, could be due to the FRN immediately following the Pe. Other studies examining performance-based FRN waveforms used paradigms that deliberately staggered errors and feedback (for example, subjects received error-based feedback several trials later) to avoid expectancy effects (Luu, Tucker, Derryberry, Reed, & Poulson, 2003). In the current study, limitations in preschool children working memory did not allow for staggered feedback. Thus, future research needed to clarify if the relation between Pe and FRN in preschool children when errors and feedback occur sequentially.

Future directions

The current study demonstrated the feasibility of a child-friendly task capable of simultaneously extracting the ERN, Pe, and FRN components. I recommend that future research examining the neural correlates of emotion reactivity and regulation in early childhood use tasks capable of measuring multiple components that reflect different aspects of these complex processes. In the current study, the ability to extract ERN, Pe, and FRN in the same task allowed me to test the relative development and interrelatedness of different neural mechanisms underlying the response to an emotional challenge. Tasks that are both capable of measuring multiple ERP components and are tolerable by young children are ideally suited to elucidate complex patterns of emotion dysregulation in at-risk youngsters, such as preschool children with severe aggression. This is an important direction for future research.

Table 1.1. Intercorrelations of FRN, ERN, and Pe amplitudes at sites Fz, FCz, Cz, and Pz

Waveform	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
1. Inc. FRN (Fz)	-															
2. Inc. FRN (FCz)	**.793****	-														
3. Inc. FRN (Cz)	**.677***	**.914****	-													
4. Inc. FRN (Pz)	.528†	.484	.458	-												
5. Cor. FRN (Fz)	.410	.230	.046	.483	-											
6. Cor. FRN (FCz)	.287	.375	.142	.545†	**.707***	-										
7. Cor. FRN (Cz)	.066	.320	.154	.371	.320	**.838****	-									
8. Cor. FRN (Pz)	.451	**.700***	.532†	**.601***	.299	**.803****	**.818****	-								
9. ERN (Fz)	.385	.058	.153	.421	.426	.113	.001	-.073	-							
10. ERN (FCz)	.026	-.175	-.126	.122	.532†	.096	-.146	-.284	**.612****	-						
11. ERN (Cz)	-.046	.061	-.049	.236	**.586***	.452	.244	.167	-.234	.273	-					
12. ERN (Pz)	-.264	-.223	-.436	-.276	-.327	.099	.144	.195	**-.598***	**-.692****	.061	-				
13. Pe (Fz)	-.314	-.201	-.260	.048	-.147	.038	.20	.143	-.316	-.193	.334	.387	-			
14. Pe (FCz)	-.410	-.374	-.423	-.115	-.040	.002	-.070	-.092	-.382	.044	**.593***	.335	**.737****	-		
15. Pe (Cz)	-.552†	-.565†	**-.594***	-.142	-.151	.107	.116	-.006	-.133	.033	.389	.118	**.486***	**.766*****	-	
16. Pe (Pz)	-.461	-.423	-.338	**-.950*****	**-.640***	**-.632***	-.396	-.588*	-.277	-.255	.134	.147	.051	.232	.436	-

Note. †$p < .10$, *$p < .05$, **$p<.01$, ***$p <.001$

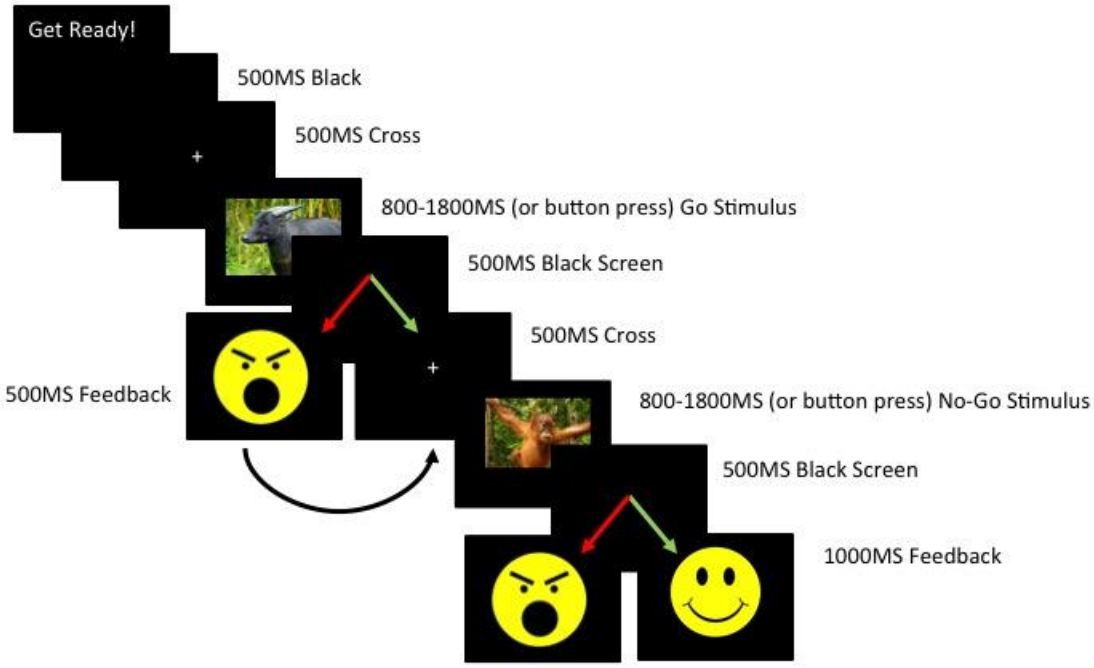

Figure 1.1. Flow chart of the emotion inducing go/no-go task. Response contingencies represented with arrows. Red arrows denote incorrect responses and green arrows denote correct responses.

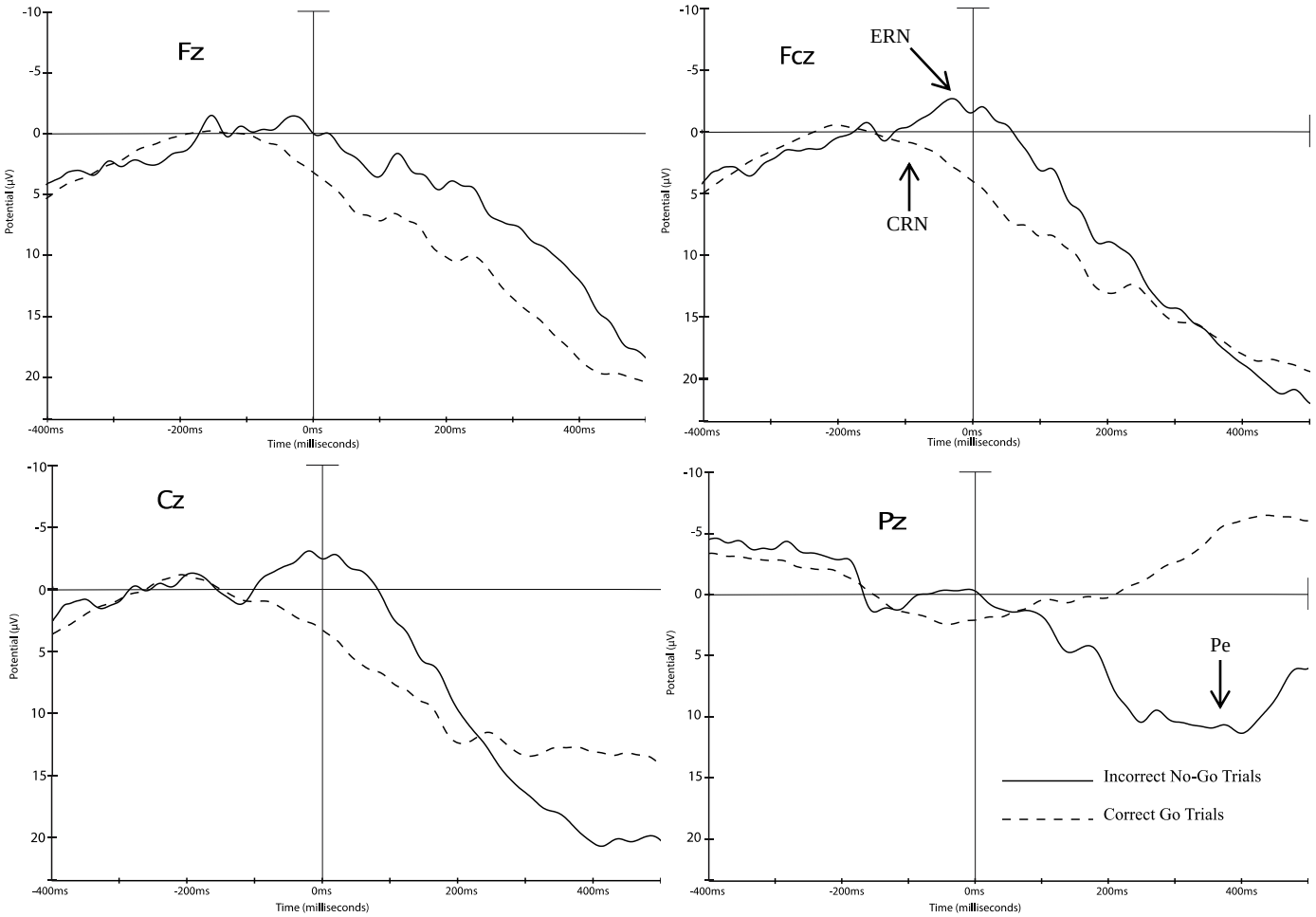

Figure 1.2. Response locked error and correct waveforms at sites Fz, FCz, Cz, and Pz (*N* = 18).

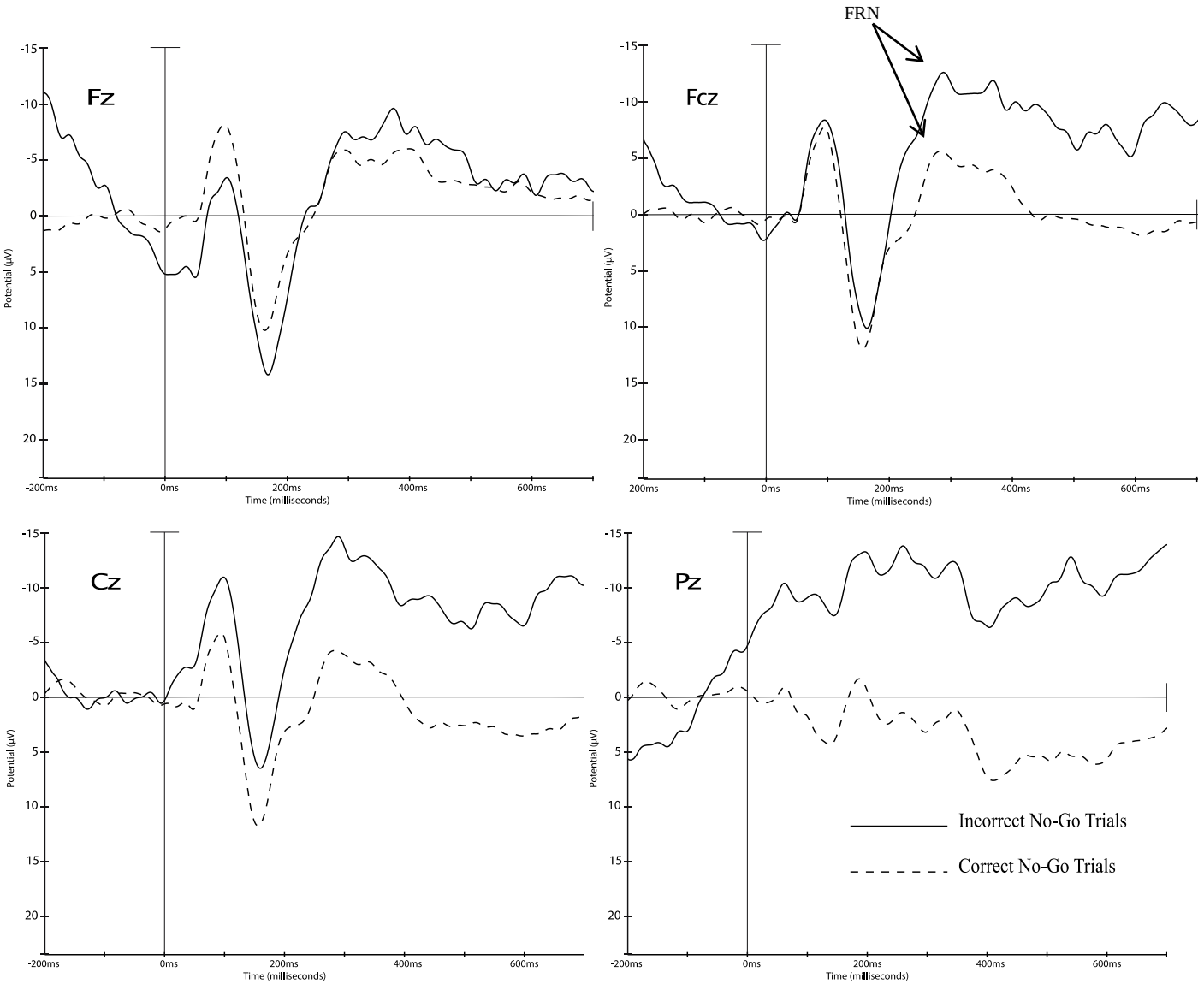

Figure 1.3. Response locked negative and positive feedback waveforms for correct and incorrect no-go trials at sites Fz, FCz, Cz, and Pz (N = 18).

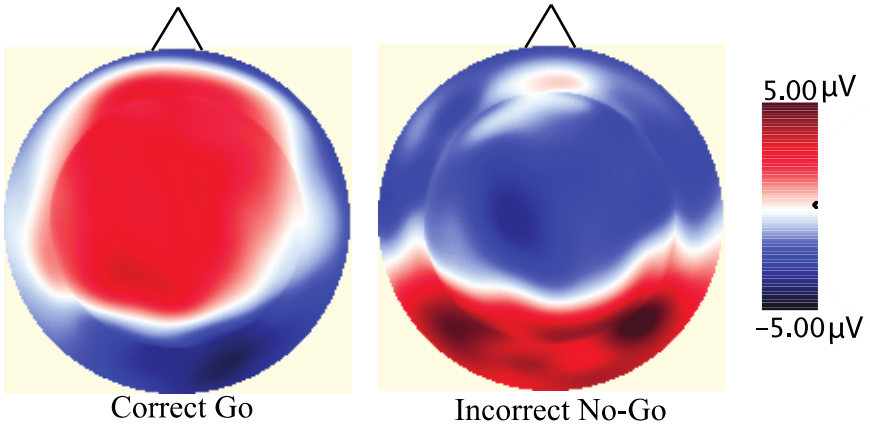

Figure 1.4 Scalp distribution for incorrect no-go and correct go trials. Scalp distribution shows average voltage at -25 milliseconds post-response. Amplitude scale represents 95% of the data.

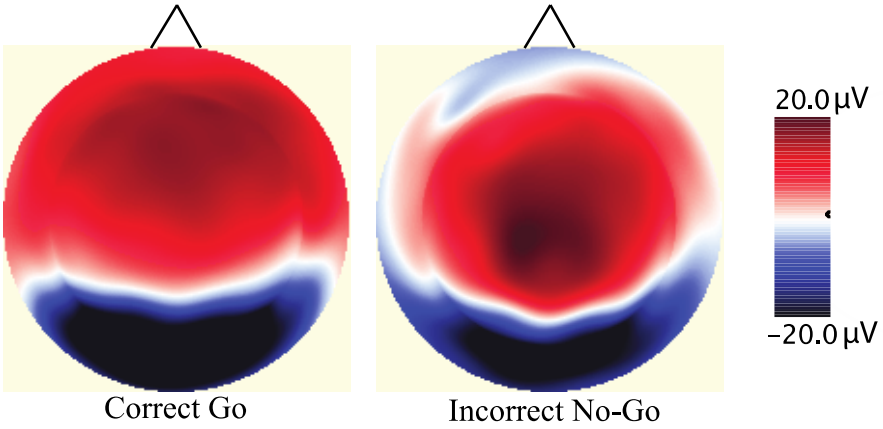

Figure 1.5. Scalp distribution for incorrect no go and correct go trials. Scalp distribution represents average voltage at 350 milliseconds post-response. Amplitude scale represents 95% of the data.

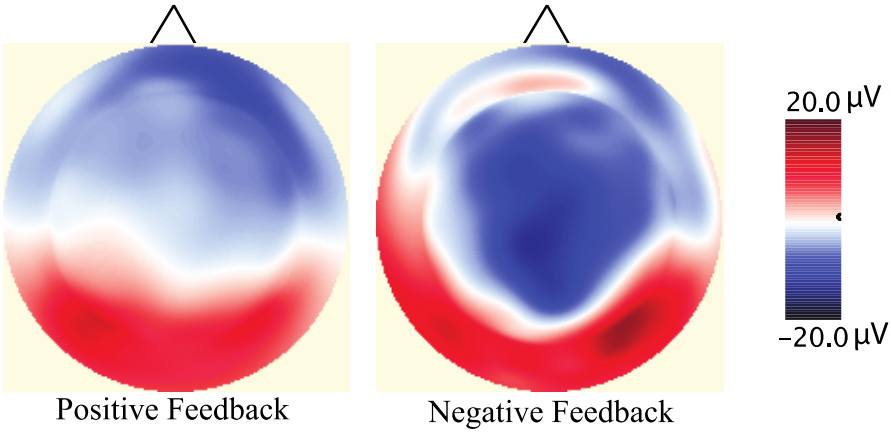

Figure 1.6. Scalp distribution for positive and negative feedback. Scalp distribution represents average voltage at 365 milliseconds post-feedback. Amplitude scale represents 95% of the data.

Chapter III

Neural Mechanisms of Emotion Dysregulation in Preschool Children with Disruptive Behavior Disorders

Approximately 4-8% of children between the ages of 3 and 5 years show severe and impairing levels of disruptive behavior, including aggression, hostility, defiance, non-compliance, and violating the rights of others (Nock, Kazdin, Hiripi, & Kessler, 2006; Egger & Angold, 2006). This spectrum of behaviors comprises the Disruptive Behavior Disorders (DBDs) (American Psychiatric Association, 2013; Wakschlag, Tolan, & Leventhal, 2010), including Oppositional Defiant Disorder and Conduct Disorder. Even at an age where tantrums and defiance are considered developmentally normative, young children with DBDs already show deficits in forming healthy relationships with caregivers, peers, and siblings (Campbell, Shaw, Gilliom, 2000). Even more concerning, these preschoolers often remain severely antisocial as they move into later developmental stages (Keenan et al., 2011), and thus are at risk for a myriad of future, even lifelong problems negatively impacting themselves, their support systems, and society as a whole. For example, children with early-onset, chronic, disruptive behaviors are more likely to be rejected by peers, do poorly in school, have substance abuse problems, and engage in juvenile delinquency (Lahey, Goodman et al., 1999; Shaw, Gilliom, Ingoldsby, & Nagin, 2003; Olson et al., 2005; Olson et al., 2011). Thus, understanding the earliest manifestations of disruptive behavior disorders should be a priority. Specifically, studies are needed that establish the neural correlates that indicate risk for a severe and chronic developmental course.

The goal of the current study was to determine whether preschool children referred to outpatient psychotherapy clinics for disruptive behavior showed abnormal neuro-electrical patterns related to processing and preventing negative affective events. In what follows, I

discuss the importance of emotion regulation in early onset Disruptive Behavior Disorders and the neuro-electrophysiological components that may reflect maladaptive responses to emotional challenges. Finally, I hypothesize how the parameters of these components may discriminate severely disruptive from typical preschool children.

Emotion Regulation and Early Disruptive Behavior

Compared to normally developing peers, children with Disruptive Behavior Disorders have deficits in multiple systems of emotion reactivity and regulation (Beauchaine, 2012; Mullin & Hinshaw, 2007). Emotion reactivity and regulation refer to component processes for reacting to and voluntarily modulating of emotional experiences to achieve adaptive goals (Thompson, 1994; Izard, 2009).

I propose that early emotion dysregulation is more than just a co-occurring symptom of Disruptive Behavior Disorders; it is a core etiological deficit that drives these behaviors and places children at risk (Mullin & Hinshaw, 2007). Longitudinal data have shown that poor emotion reactivity and regulation precede the onset of preschool-age disruptive behavior and uniquely predict changes in disruptive behavior over time (Halligan et al., 2013). Furthermore, the severity of preschool disruptive behavior is associated with physiological reactions, such as changes in heart rate, to negative emotional events (Cole, Zahn-Waxler, Fox, Usher, & Welsh, 1996). Thus, emotion reactivity and regulation problems are ingrained in the psychobiology of early disruptive behavior and robustly predict current and future impairment.

When children with DBDs struggle unsuccessfully to respond to emotional challenges, what are the neural mechanisms that underpin their behaviors? There has been a paucity of research on brain functioning in children with early onset disruptive behavior disorders. To my knowledge, this is the first study to identify neural correlates of emotion dysregulation in

preschool-age children with disruptive behavior disorders. In what follows, I describe studies of emotion reactivity and regulation on older children, adults, and non-human animals, and identify key brain regions involved in responses to emotional challenges: the prefrontal cortex (PFC) and anterior cingulate cortex (ACC). I then describe how PFC and ACC activity map onto the Event Related Potential components examined in the current study. In the present study, I compared electrical signals generated by these regions in preschool children with and without Disruptive Behavior Disorders who completed a computer task designed to elicit emotion reactivity and regulation.

Emotion Regulation and the Developing Brain

Neuroimaging studies in adult humans and lesion studies in animals have identified the prefrontal cortex and the anterior cingulate cortex as two critical pieces of emotion regulation circuitry that exert a top-down influence on the voluntary dampening of negative emotion (Ochsner & Gross, 2008; Butter, Snyder, & MacDonald, 1970; Iverson & Mishkin, 1970; Rainville et al., 1997). The prefrontal cortex has been extensively studied as a region of the brain important for inhibition and executive function tasks (Fuster, 1989), and also plays critical roles in responding to emotional challenges. For example, healthy adults who engaged in strategies to suppress or reappraise a negative emotional experience showed increased PFC activation (Ochsner & Gross, 2002). Similarly, functional imaging research in older children and adolescents has found a link between PFC regional activity when viewing fearful faces and parent-ratings of emotional reactivity (Perlman, et al., 2013). In a sample of healthy preschool children, Perlman and colleagues (2014), using fNIRS, found that PFC activation during an emotional challenge was associated with parent ratings of frustration tolerance.

Like the PFC, the anterior cingulate cortex plays an important role in a range of cognitive and emotional processes (Bush, Luu, & Posner, 2000). Specifically, both the dorsal-caudal and rostral-ventral regions of the ACC are involved in emotional conflict regulation (such as a Stroop task with emotionally salient words; Bush, Luu, & Posner, 2000), appraisal and expression of negative emotion (Rainville et al., 1997), and generating emotional responses (Etkin, Egner, & Kalisch, 2011). Furthermore, the ACC signals to both the amygdala and prefrontal cortex during emotionally-valenced conflict trials (Etkin, Egner, Peraza, Kandel, & Hirsch, 2006), suggesting a neural network in which the PFC and ACC modulate amygdala activity. Not surprisingly then, patients with lesions to the ACC have shown less emotional reactivity to psychological stress (such as pain onset) than others (Foltz & White, 1962), underscoring the importance of the ACC in appraisals of the emotional salience of events Moreover, electrophysiological activity hypothesized to reflect ACC functioning was positively associated with ratings of negative emotionality in healthy adults (Luu, Collin, and Tucker, 2000).

Despite evidence supporting the role of the PFC and ACC in emotion regulation, substantial gaps remain in our understanding of how the brains of preschool children with Disruptive Behavior Disorders might respond to emotional challenges compared to healthy peers. These gaps primarily reflect a lack of empirical research on neural correlates of emotion reactivity and regulation in preschool-age children with Disruptive Behavior Disorders. Thus, in the current study, I used a novel ERP paradigm capable of simultaneously examining four components important for emotion regulation: Inhibitory-N2, Error-Related Negativity (ERN), Error Positivity (Pe), and Feedback Related Negativity (FRN).

Inhibitory-N2, ERN, Pe, and FRN

Inhibitory-N2.

Inhibitory control is defined as the capacity to suppress inappropriate approach responses under instructions or in novel or uncertain situations (Rothbart, Ahadi, Hershey, & Fisher, 2000). Adults and children performing an act of inhibitory control, such as inhibiting a response to a lure stimulus during a go no-go task, generate an electrical signal reflecting this process called inhibitory-N2. The inhibitory-N2 signal is a negative voltage deflection generated by the prefrontal cortex (Sasaki, Gemba, & Tsujimoto, 1989) occurring approximately 200-400ms after the presentation of a stimulus in which the subject correctly inhibits their response (Eimer, 1993; Falkenstein, Hoormann, & Hohnsbein, 1999; Jodo & Kayama, 1992).

Inhibitory-N2 may be impaired in children with Disruptive Behavior Disorders, although to my knowledge only a single study to date has investigated this. In a study comparing late school age children with disruptive behavior problems to typical peers, Steiben and colleagues (2007) found that the inhibitory-N2 signal generated during successful no-go trials was significantly smaller for the clinical sample. However, these findings are more difficult to interpret because the effect appeared to be driven by children who had significant comorbid externalizing and internalizing problems, and thus had a more complex diagnostic picture in terms of their emotion regulation problems. Nevertheless, the authors argued that the findings suggest inhibitory-N2 represents an important neural correlate of emotion regulation in childhood psychopathology. In the current study, I was able to recruit a sample of preschool children who encompassed more single-type disruptive behavior disorders rather DBDs comorbid with internalizing problems, allowing us to better examine the role of inhibitory-N2 specifically in early childhood DBDs.

Error Related Negativity.

When children and adults commit an error during a go- no-go task, the ACC generates a negative voltage deflection -20-100ms around the time of the error (Dehaene et al., 1994; Gehring, Goss, Coles, Meyer, & Donchin, 1993). Studies have established that the ERN can be detected in children as young as preschoolers (Grammer et al., 2014).

The majority of research looking at ERN in psychopathology has focused on internalizing disorders such as anxiety, were there is robust evidence that anxious children have larger error-related negativity than controls (Ladouceur, Dahl, Birmaher, Axelson, & Ryan, 2006). However, the aforementioned study by Stieben and colleagues also found that children with disruptive behavior problems had significantly smaller ERN amplitudes compared to typical peers. However, this finding has yet to be replicated in other samples of children with DBDs, such as younger children.

Error Positivity

When errors are committed, the offset of the ERN typically precedes a positive voltage deflection known as Error Positivity or Pe (Tamnes et al., 2013). In adults, Pe occurs approximately 200-400ms after commission of an error (Overbeek et al., 2005). Pe has been detected in children as young as three years and appears to increase in amplitude across development (Grabell, Study 1 of dissertation; Grammer et al., 2014).

Unlike ERN, the functional significance of the Pe is still under debate (Overbeek et al., 2005). Broadly, Pe amplitude appears to be related to post-error processing or the conscious awareness of errors (Overbeek, Nieuwenhuis, & Ridderinkkhof, 2005).

Less clear, however, is whether Pe reflects *affective* processing of errors. Previously, scholars have argued that evidence that the Pe reflects affective processing of errors is weak (Overbeek et al., 2005). A more recent study, however, found that perceived errors not only

generated a larger Pe amplitude, but were also more strongly related to autonomic nervous response such as heart rate and pupillary dilation compared to trials where errors were not perceived by adult subjects (Wessel, Danielmeier, & Ullsperger, 2011). This finding suggests a link between Pe and the "visceral" response to perceived errors.

Feedback Related Negativity

The Feedback Related Negativity component is a negative voltage deflection, generated by the ACC, occurring approximately 250ms after the presentation of a positive or negative outcome (Gehring & Willoughby, 2002; Hajcak, Holroyd, Moser, & Simons, 2005). Studies in typical adults have found that the amplitude of the FRN is larger following negative outcomes than positive outcomes (Gehring & Willoughby, 2002), suggesting that the FRN is sensitive to events associated with negative affect. However, replication of this finding with young children has been mixed. Hammerer, Li, Muller, and Lindenberger (2011) found that children ages 9 to 11 years completing a gambling task showed no difference in the amplitude of the FRN following negative outcomes versus positive ones. In addition, Mai and colleagues (2011), using a sample of 4- and 5-year old children who completed a prize-guessing game, similarly found no difference in the FRN amplitude for positive and negative trials. However, in a sample of 3 to 5-year old children who completed a go no-go task with emotionally valenced, performance-contingent feedback, I found a significantly larger FRN amplitudes linked to negative outcomes than positive outcomes (Grabell, Study 1 of dissertation). These findings suggest that, perhaps more so than adults, FRN sensitivity to negative events is more task-specific in young children than adults. In the current study, I employed the same adapted go-no-go task in a sample of preschool children referred to outpatient psychotherapy clinics for disruptive behavior.

The Present Study and Hypotheses

My main goal was to determine whether preschool children with early-onset externalizing behavior problems show different PFC and ACC functioning than typical peers during an ERP task designed to engage emotion reactivity and regulation. Specifically, I examined four ERP components reflecting responses to emotional challenges: Inhibitory-N2, ERN, Pe, and FRN, in preschoolers with clinically significant behavior problems and normally developing controls. My primary hypothesis was that the amplitude of each component would appear smaller in preschoolers with Disruptive Behavior Disorders compared to typical peers, consistent with poorer emotion reactivity and regulation.

Methods

Participants

Twenty-four children ages 3 to 5 years (*M* = 59 months, *SD* = 8.76 months; 41% female) were recruited from three outpatient mental health clinics affiliated with a large local university due to concerns with disruptive behavior. All were right handed or identified as ambidextrous. Based on maternal report, 52.9% of the children identified as Caucasian, 23.5% identified as African American, and 23.5% identified as mixed-race. Families seeking treatment at these clinics due to primary concerns about their child's disruptive or defiant behavior were recruited via flyers or contacted directly by study team members around the time of their initial intake. Parents completed a phone screen with a study team member to verify that their concerns about their child were consistent with an early onset Disruptive Behavior Disorder. Furthermore, children were screened for, and excluded, if they endorsed any of the following criteria: diagnosis of mental retardation, autism spectrum disorder, psychosis, significant medical condition, epilepsy, or history of head injury resulting in loss of consciousness. Children whose parents endorsed disruptive behavior comorbid with other behavior problems, such as mood or anxiety problems, were included in the study if they otherwise met diagnostic criteria for a DBD.

As shown in Figure 2.1, clinically referred preschool children had caregiver-rated CBCL Oppositional Defiant t-scores close to the borderline range (M = 64.10, SD = 8.0). In addition caregiver rated CBCL ADHD (M = 58.52, SD = 7.0), Affective (M = 56.05, SD = 5.7), and Anxiety (M = 56.62, SD = 10.0) t-scores were in the average range. Paired-sample t-tests revealed that CBCL Oppositional Defiant scores were significantly higher than CBCL ADHD, Affective, or Anxiety scores (e.g., ODD-ADHD $t(20) = 4.69$, $p < .001$), whereas CBCL ADHD, Affective, and Anxiety t-scores did not differ significantly from each other. Of the 24 children who enrolled in the study, 9 failed to yield usable ERP data due to not providing sufficient artifact-free trials. In addition, one child was later revealed to have a mild form of epilepsy and was excluded. Furthermore, of the 14 children included in the present analyses, some provided enough artifact-free trials to examine certain ERP components but not others. Therefore, 13 children yielded enough artifact-free trials to examine Inhibitory-N2, 10 children had enough good trials to examine ERN and Pe, and seven children had enough good trials to examine FRN. Clinically referred preschool that provided usable ERP data did not differ from clinically referred peers who did not provide ERP data in terms of age, gender, ethnicity breakdown, or household income. In addition, clinically referred preschoolers who provided usable ERP data did not differ from clinically referred peers in terms of CBCL Oppositional Defiant, ADHD, or Anxiety scale scores. However, clinically referred preschool children who did not provide usable ERP data were rated as having significantly higher levels of CBCL Affective Problems than clinically referred peers ($t(19) = -2.1$, $p < .05$).

Thirty-seven typically developing preschool-age children (M = 57.9 months, SD = 7.8 months; 50% female) were recruited from area preschools via community flyers and web advertisements. Based on maternal report, 75% of the sample identified as Caucasian, 13.8% as

mixed-race, 5.6% as African American, and 5.6% as Asian. All were right handed or identified as ambidextrous. Children were excluded from the study if they met any of the following criteria: diagnosis or concerns consistent with any DSM-IV disorder of mood or behavior, diagnosis of mental retardation or developmental delay, autism spectrum disorder, or psychosis; medical condition; or use of medication affecting mood or attention. Of 36 children enrolled in the study, 18 failed to yield usable ERP data due to the following reasons: did not generate enough artifact free trials (16) and equipment failure (2). Typical preschool children who did not provide usable ERP data did not differ from typical peers in terms of their age, gender, ethnicity breakdown, household income, or caregiver ratings of mood or behavior problems.

Socio-demographic characteristics of both samples are shown in Table 2.1. The clinical and non-clinical samples did not differ in terms of age, gender, income, or ethnicity. Children in the healthy control group had mothers who went significantly farther in school compared to children in the clinically referred group.

Procedure

Adapted go no-go task

Participants performed a child-friendly go no-go task developed by Grammer, McDermott and colleagues (Grammer et al., 2014, McDermott et al., 2014). In the present study, I adapted the task to provide performance-based emotionally-valenced feedback. Children were told that were going to play a computer game called "Zookeepers" to win a toy. The task had 8 trial blocks; each block consisted of 40 trials. Children were instructed to click a button each time they saw an animal picture (go stimuli), with the exception of an orangutan picture (lure stimuli). Children completed two practice blocks, the first without lure stimuli and the second with lure stimuli, to ensure they understood the task. Children were awarded special animal

stickers after each trial block, regardless of performance, to increase motivation. Research assistants were trained to praise children on their speed, regardless of their performance, rather than their accuracy to ensure children made enough errors for analyses.

Stimuli were weighted such that the lure stimuli were randomly selected 25% of the time. As shown in Figure 1.1, for every correct no-go trial (child correctly abstained from hitting the button), the child was presented with a happy face after 500ms of black screen. For every incorrect no-go trial (child accidentally hits the button), the child was presented with an unhappy face after 500ms of black screen. This 500ms gap was designed to separate ERN and FRN waveforms. Happy and unhappy faces were designed to be as similar as possible in terms of their size, percentage of yellow to black pixels, and position on the screen to ensure these stimuli characteristics did not influence waveforms.

Furthermore, beginning with the practice block, and continuing through all trial blocks, a dynamic algorithm was used to ensure participants had a sufficient number of correct and incorrect no-go trials by adjusting the stimulus duration. The purpose of the dynamic timing algorithm was to ensure that all children, regardless of their inhibitory skills, would make approximately the same number of errors, and thus encounter the same number of emotion eliciting events across the task. The duration of go and no-go stimuli decreased by 100ms increments each time children completed a successful no-go trial. Similarly, go and no-go stimuli duration increased by 100ms increments each time children made an error on a no-go trial. Adjustments in duration were capped such that go and no go stimuli could be no faster than 800 milliseconds and no slower than 1800 milliseconds. Speed adjustments did not affect the duration of black screen, fixation cross, or feedback presentation.

Prior to EEG recording, children were seated in a comfortable chair and engaged in rapport building with the research assistants. This included reading a picture book together about animals in a zoo, and administrating an assent script in child friendly language. Parents were allowed to remain in the room with their child during both the assent and EEG recording.

EEG data was recorded using a 128 channel child-friendly Geodesic Sensor Net (Tucker, 1993). Impedance for all electrodes was kept below 50 KΩ, and all recordings were referenced to the vertex, Cz. The EEG signal was amplified using a 0.01-100 Hz bandpass and digitized at 500 Hz. The electro-oculogram (EOG) was monitored with 6 electrodes placed bilaterally in the external canthi (Ch 128 and 125), supraorbital (Ch 25 and 8) and infraorbital (Ch 127 and 126) regions. Recording in every channel was vertex-referenced. Data was recorded and processed using Net Station 4.1 (EGI software).

Once acquired, the data was lowpass filtered below 20 Hz. The continuous EEG was segmented into epochs starting at 200ms before the onset of either the stimulus or response and lasting until 1000ms after the stimulus/response onset. Segmented files were scanned for artifacts with the Artifact Detection NS tool for excessive muscle activities, eye blinks and eye movements.

Segments were marked for artifact if the running average of activity exceeded pre-defined thresholds for eye movement (55 μV), blinks (100 μV), and bad channels (200μV). Following this automated process, segments were manually inspected. Segments with more than 10 bad channels were excluded from analyses. In segments with less than 10 bad channels, and no movement artifacts, spherical spline interpolation was used to replace bad channels using values from neighboring channels (Gratton, Coles, and Donchin, 1983). Children with at least 6 good segments in each trial were included in analyses.

Artifact-free ERN, FRN, and Inhibitory-N2 segments were averaged separately and then re-referenced against the average of all channels. A baseline correction was performed for -200 to -100ms for ERN segments, -100 to 0ms for FRN segments, and -100ms to 0ms for Inhibitory N2 segments. Based on visual inspection of the grand averaged ERPs, and in accordance with previously published reports, I defined ERN as the largest negative deflection between -25 and 50ms after the response onset, Pe as the largest positive deflection between 200 and 500ms after the response onset, FRN as the largest negative deflection between 350 and 450ms after the feedback onset, and Inhibitory-N2 as the largest negative deflection between 200 and 450ms after presentation of no-go stimuli on correct trials. Furthermore, I made manual adjustments for a small number of children who showed peak amplitude of these components outside, but within 50ms of, these predefined windows of interest. Group differences in the peak amplitude of ERP components were tested using t-tests.

Results

Parent Ratings of Externalizing Behavior

All parents rated their children's externalizing behavior using the Child Behavior Checklist For Ages 1 ½ - 5 (Achenbach & Rescorla, 2000). As expected, clinically referred children had significantly higher ratings of externalizing behavior compared to controls ($F(1) = 30.6$, $p < .001$). Children in the clinical group had an average externalizing t-score of 61, consistent with the 87th percentile in terms of severity. Further examination found that 40% of the clinical sample had an externalizing t-score higher than the typical clinical cut-off of 65. Although a significant percentage of the clinical sample had t-scores below the borderline range, it is important to note that all of children in this group were referred to outpatient psychotherapy clinics due to concerns about disruptive behavior at home or at school. Therefore, although the

clinical sample showed a wide range of CBCL externalizing scores, they are representative of preschool children with disruptive behavior clinicians commonly see in outpatient settings. Furthermore, these data are consistent with findings that parent CBCL ratings of externalizing behavior may not agree with other raters, such as teachers, or predict externalizing behavior observed in other settings, such as preschools (e.g., Hinshaw, Han, Erhardt, & Huber, 1992).

Behavioral Measures

Accuracy and reaction time data for each group can be seen in Table 2.2. Clinically referred and control did not differ in accuracy or reaction time for go or no-go trials. The average pre-set duration for go and no-go trials was significantly different between groups such that the task slowed down significantly for clinically referred preschool children in response to their no-go performance. Therefore, differences found in the ERP waveforms between groups were not due to clinically referred children finding the game more frustrating as a result of making significantly more errors than typical peers.

Clinically referred preschool children had fewer usable, artifact free FRN trials for positive outcomes than control preschoolers. There were no significant differences between groups in the number of artifact-free trials for all other conditions.

ERP Waveforms

For each ERP component of interest (ERN, Pe, FRN, and Inhibitory N2), I first tested differences in waveform amplitudes by trial type (e.g. correct versus incorrect trials), and whether these patterns between groups. Next, I tested whether ERP average amplitudes differed between typical and clinically referred children. A Bonferroni adjustment was used to control for alpha inflation for all analyses. Because 40% of the clinically referred sample showed parent-

rated CBCL externalizing scale scores in the high to severe range, I also tested if the waveform amplitudes of this most-impaired subgroup were different from those of other children.

ERN and Pe

Response-locked waveforms showing the ERN and Pe components at midline electrode sites can be seen in Figure 2.1. Both clinical and control preschoolers showed a negative deflection around the time of error commission that larger than for corresponding correct trials (CRN). Paired-sample t-tests, run separately by group, confirmed that ERN amplitudes were significantly larger than CRN amplitude at sites FCz (control group: $t(17) = -5.07$, $p < .001$; clinical group: $t(10) = -.301$, $p < .05$) and Cz (control group: $t(17) = -5.25$, $p < .001$; clinical group: $t(10) = -3.88$, $p < .01$)(see also figure 2.5). In addition, the clinically referred preschoolers had significantly larger ERN amplitudes than CRN amplitudes at Pz ($t(10) = -3.16$, $p < .05$), which was not seen in the control children. For both groups, the magnitude of the ERN/CRN difference was largest at Cz compared to other midline electrode sites.

Paired t-tests were also used to determine whether amplitude of the Pe component was larger for incorrect trials than correct trials for clinical versus control preschoolers. For controls, the amplitude of Pe was significantly larger for incorrect trials than correct trials at Pz only ($t(17) = 5.43$, $p < .001$). For clinically referred preschool children, the amplitude of Pe for incorrect trials wasn't significantly larger than correct trials at any site (see Figure 2.6).

A One-way ANOVA was run to test whether control and clinically referred preschool children differed in the amplitude the ERN and Pe components at midline sites. Because the Pe component occurs over a much longer window of time, and young children's waveforms appeared more turbulent compared to adults, I examined the maximum amplitude rather than the average amplitude. No group differences were found for the amplitude of the ERN component.

The maximum amplitude of Pe was marginally smaller for clinically referred children at Fz ($F(1) = 3.95$, $p = .057$), and not significantly different at other midline sites. Next, children with CBCL Externalizing Scale t-scores above 60 were compared with all other children. Results showed that children with CBCL externalizing t-scores over 60 had significantly smaller Pe amplitudes at electrode Fz ($F(1) = 4.2$, $p < .05$). However, the Pe amplitude following incorrect no-go trials at site Fz was not significantly different than the amplitude for corresponding correct go trials.

FRN

Visualization of the FRN waveform (see Figure 2.2) revealed that children in control and clinical groups showed a negative deflection following positive and negative feedback consistent with the FRN. Furthermore, both groups appeared to show a larger deflection for negative feedback than positive feedback. Paired-sample t-tests, run separately by group, compared the peak-to-peak difference between the preceding P2 peak and the FRN peak for both positive and negative feedback waveforms. Peak to peak values were analyzed rather than the amplitude of the FRN peaks themselves due to differences in the height of the waveforms as early as the N1 component.

For healthy control children, the peak-to-peak difference for negative feedback was significantly larger than for positive feedback at Fz ($t(12) = -2.52$, $p < .05$) FCz ($t(12) = -2.82$, $p < .05$), and Cz ($t(12) = -2.42$, $p < .05$). In contrast, clinically referred preschool children showed a somewhat more robust difference between the negative and positive peak-to-peak values, but only at FCz ($t(10) = -3.95$, $p < .01$) and Cz ($t(10) = -4.1$, $p < .01$) (see Figure 2.7). A Oneway ANOVA comparing healthy control to clinically referred children revealed no differences in FRN peak-to-peak values for correct or incorrect trials. A second Oneway ANOVA, comparing the most impaired children to all other children, revealed that children with CBCL Externalizing

t-scores higher than 60 showed marginally larger peak-to-peak values for correct feedback ($F(1) = 3.45$, $p = .07$).

Inhibitory-N2

Visualization of inhibitory-N2 waveforms (see Figure 2.3) revealed that both groups showed a negative deflection between 200 and 500ms for correct go and no-go trials at all three frontal-midline sites. Furthermore, each of these waveforms showed two distinct peaks in the window of interest. I therefore investigated each of these peaks as separate components and labeled then N2a and N2b respectively.

Paired-sample t-tests revealed that for children in the control group, amplitude of N2a was significantly smaller for no-go trials than for go trials at sites Fz ($t(14) = -8.07$, $p < .001$), and FCz ($t(14) = -5.93$, $p < .001$), and marginally smaller at Cz ($t(14) = -1.89$, $p = .08$). In clinically referred preschool children, amplitude of N2a was significantly smaller for no-go trials than go trials at sites FCz ($t(12) = -2.35$, $p < .05$) and Cz ($t(12) = -2.77$, $p < .05$) (see Figure 2.8). For both control and clinically referred preschool children, amplitude of N2b did not differ significantly between go and no-go trials at any site.

Using a Oneway ANOVA I compared whether the amplitude of N2a and N2b associated with no-go trials differed between control and clinically referred preschool children. Results showed that amplitude of no-go N2a and N2b were significantly smaller for clinically referred preschool children at Cz (N2a: $F(1) = 4.98$, $p < .05$; N2b: $F(1) = 4.93$, $p < .05$). Interestingly, no group differences were apparent when comparing preschool children with high CBCL externalizing scale scores to all other children. Furthermore, I found no significant difference between groups for go-trial Inhibitory-N2 amplitudes.

Discussion

The goal of the present study was to identify neural correlates of poor emotion regulation in preschool children with disruptive behavior problems. Using an adapted go- no-go task designed to engage inhibition, error recognition and error processing, as well as performance-based emotional feedback processing, I tested the hypothesis that waveforms reflecting these neural processes would appear different in preschool children with early externalizing behavior problems compared to controls. Specifically, I hypothesized that the amplitude of ERP components ERN, Pe, FRN, and Inhibitory-N2 would appear blunted in preschool children clinically referred for Disruptive Behavior Disorders.

The characteristics of these waveforms revealed similarities and differences between typical and clinically referred preschool children. In what follows, I review and synthesize these findings and discuss how they might contribute to our understanding of early onset conduct problems.

Consistent with other studies of typically developing preschool children (Grammer et al., 2014) both healthy control and clinically referred preschool showed a clear ERN component, and both groups had ERN amplitudes larger than corresponding correct trials. In typical controls, the ERN was most clearly visible at frontal-midline sites, underscoring its importance in appraising the emotional salience of events.

In clinically referred children, the ERN was most clearly seen at frontal and parietal-midline sites. Furthermore, both groups showed a positive deflection following the ERN and CRN consistent with Pe. However, whereas normal preschool children had a significantly larger Pe following ERN than CRN trials at site Pz, this was not seen in clinically referred preschool children.

My examination of the FRN component revealed that both typical and clinically referred preschool children showed a negative deflection following emotional feedback consistent with the FRN. In addition, both groups showed larger FRN amplitudes for negative feedback trials than positive feedback trials. However, I did find some evidence that the scalp distribution of this component differed between groups. The difference in amplitude of FRN associated with incorrect versus correct trials was seen most robustly over a larger portion of the midline for control preschool children. Although I found that children with very high CBCL externalizing scale scores had marginally larger peak-to-peak values for positive feedback than other children, this finding may not have any clinical significance given that, visually, the FRN appeared highly similar between groups. Furthermore, no other group differences for FRN waveform amplitudes were found.

Finally, I examined the characteristics of the Inhibitory-N2 waveform in both groups. Both control and clinically referred preschool children showed Inhibitory-N2 amplitudes that were smaller for correct no-go trials than for correct go trials. This contrasts with studies of older children and adults, which have consistently shown significantly larger N2 amplitudes for no-go trials (Kiefer, Marzinzik, Weisbrod, Scherg, & Spitzer, 1998). Furthermore, children in both groups showed a negative deflection in the window of interest that consisted of two separate peaks, as opposed to one clear peak. Nevertheless, I found that clinically referred children showed significantly smaller amplitudes of both N2 peaks at site Cz compared to healthy peers.

This collection of findings provides insight into which cognitive micro-processes, occurring around the onset of a negative emotional challenge, may be impaired in preschool children with high levels of externalizing behavior, and which may be intact. My findings suggest that the neural correlates of immediate *recognition* and *awareness* of negative affective

events, such as committing an error or receiving negative feedback, appear intact in preschoolers with early onset Disruptive Behavior Disorders. Rather, it is the *subsequent* neural processing of the negative event, and signaling inhibition to *prevent* a negative event from occurring where we see deficits in preschool children with DBDs.

Specifically, while typical control preschool children, similar to adults, showed a larger Pe following commission errors than correct trials (Grabell, Study 1 of dissertation; Grammer et al., 2014), clinically referred preschoolers did not show this important distinction. In fact, the amplitude of the Pe following commission errors was significantly smaller for preschool children with the most severe ratings of externalizing problems. Although less is known about the Pe component, and its links to emotion regulation debatable, it is believed to reflect post-error processing (Overbeek, Nieuwenhuis, & Ridderinkkhof, 2005). Therefore, in the current study, a smaller Pe in children with high CBCL externalizing scores might indicate deficits in awareness, interest, or insight into the errors they commit. Alternatively, a recent study with adults found antisaccade commission errors that participants were subjectively aware of (as opposed to unaware of) were associated with both larger Pe amplitudes and changes in heart rate and pupil dilation. These findings, although in adults, suggests that a blunted Pe might reflect low awareness of errors as well as a smaller biological reaction to committing the error. Although I didn't collect autonomic nervous system data in the current study, this hypothesis is consistent with literature on biological "under-reactivity" in conduct-disordered youth (Raine, Venables, & Mednick, 1997).

It was not surprising that clinically referred preschool children had significantly smaller Inhibitory-N2 amplitudes than others. Studies of children, adolescents, and adults with disruptive or antisocial behavior have consistently shown that poor impulse control is a core

feature in these clinical populations (Tremblay, Pihl, Vitaro, & Dobkin, 1994). What was surprising, however, is that I found robust differences in the Inhibitory-N2 component but no differences in the ERN or FRN components. This suggests that, while young children with disruptive behavior are more likely have deficient emotion regulation, their failure to cope with negative events does not necessarily begin at the instance those events occur. Rather, engaging in *inhibition* of impulses and actions associated with a potential negative event, in this case preventing an error, as well as *secondary* processing of negative events moments after they occur may be the critical neural processes that "trigger" disruptive behavior, and ultimately, impaired functioning.

For example, suppose a child with a disruptive behavior disorder has a toy taken away from him by a peer and responds by shoving. If we think of this situation as a chain of micro-events: recognizing a negative event has occurred, creating an initial interpretation of and reaction to the event, and failing to inhibit subsequent anger and aggressive impulses, these ERP data suggest that it is the latter links that trigger disruptive behavior and impair the functioning.

It is important to note that group differences in the amplitude of Pe and Inhibitory-N2 were dependent on whether we compared all clinically referred preschool children to healthy controls, or compared preschool children with the highest CBCL scores to everyone else. This suggests, firstly, that preschool children referred to outpatient clinical for concerns with their disruptive behavior are quite heterogeneous. Although many children in our clinical sample had CBCL scores exceeding the conventional clinical cutoff, many others had scores well within the normal rage despite the fact their caregivers were seeking treatment for them. This may reflect several phenomena, such as differences in how parents interpret their child's level of disruptive behavior and decide when to seek help, differences in how disruptive behavior is manifested in

this age range, or the sensitivity of the CBCL to detect clinically significant disruptive behavior in our preschool sample. One could also argue, however, that abnormal patterns of neuro-electrical functioning may be present in a subset of preschool children with disruptive behavior but not others, and that some paths to early onset early antisocial behavior are more strongly linked to specific biomarkers of emotion reactivity and regulation than others.

Strengths and Weaknesses

To my knowledge, this is the first research study of ERP components underlying emotion reactivity and regulation in a clinical sample of preschool children referred for disruptive behavior. A strength of the current study was my ability to examine multiple ERP components related to onset of an emotional challenge as opposed to just a single component. This allowed me to frame emotion reactivity and regulation as a series of interrelated processes, and test whether some of these processes are more impaired than others in early onset Disruptive Behavior Disorders.

Although the sample size for each group was typical for an ERP study, especially one examining young children with behavior problems, a larger sample may have yielded more robust differences between groups. In particular, I found evidence of interesting subgroups within our sample of clinically referred preschool children. A larger sample would have allowed me to test whether preschool children with different manifestations of disruptive behavior, such as the presence of absence of hyperactivity, differ in the characteristics of these ERP components.

Implications and Future Directions

These findings showed that preschool children clinically referred for disruptive behavior, compared to typical peers, showed different patterns of neuro-electrical activity related to preventing and processing negative events, but not recognizing them. Future research should

consider how specific interventions might "repair" these neural processes. Current evidence-based interventions for preschool children with disruptive behavior consist primarily of parent management training, in which parents learn new parenting skills, as opposed to direct skill-building with preschool children themselves. The continuity of these ERP differences across development is unclear. Stieben and colleagues (2007), in their sample of older children with Disruptive Behavior Disorders, found smaller ERN amplitudes compared to peers, yet I did not replicate this finding in my preschool sample. Neuro-electrical patterns signaling poor emotion regulation and/or clinically significant disruptive behavior may evolve across developmental stages. This is an important direction for future research.

Table 2.1. Socio-demographic Characteristics in Clinically Referred and Control Preschool Children

Characteristic	Clinically Referred (n = 14) *M* (*SD*)	Control (n = 18) *M* (*SD*)	t/χ^2(df)
Age (months)	59.68(8.5)	59.86(6.4)	ns
Gender (% male)	64%	33%	ns
Ethnicity (% Caucasian)	64%	77%	ns
Income	9.61(3.8)	7.93(3.3)	ns
Mother Age (years)	34.57(5.8)	35.24(4.7)	ns
Mother Education	4.86(1.4)	6.00(1.4)	2.24(29)*
Father Age (years)	36.79(7.6)	39.88(8.9)	ns
Father Education	5.00(2.0)	5.75(1.4)	ns
Marital Status (% married)	83%	81%	ns
CBCL ODD t-score	63.15(7.5)	53	-4.5(27)***
CBCL ADHD t-score	57.00(6.2)	51.31(2.1)	-3.4(27)**
CBCL Affective t-score	53.92(3.9)	54.00(5.3)	ns
CBCL Anxiety t-score	53.54(4.7)	51.50(3.2)	ns

Note. *p<.05, **p<.01, ***p<.001

Table 2.2. Go No-Go Task Behavioral Data for Clinically Referred and Control Preschool Children

	Clinically Referred (n = 14)	Control (n = 18)	
	M (*SD*)	*M* (*SD*)	*t(df)*
Go Trial Reaction Time (ms)	599(61)	589(40)	Ns
No Go Trial Reaction Time (ms)	482(64)	469(62)	Ns
Go Accuracy (% Correct)	81% (12)	82%(8)	Ns
No-Go Accuracy (% Correct)	73%(14)	69%(8)	Ns
Stimuli Duration (ms)	887(65)	951(111)	2.26(36)*
Number of usable, artifact-free trials			
CRN	71(33)	79(26)	Ns
ERN/Pe	12(6)	13(7)	Ns
FRN, positive outcome	20(6)	29(8)	2.61(22)*
FRN, negative outcome	9(5)	10(4)	Ns
Inhibitory-N2	15(8)	20(9)	Ns
N2, go trials	69(39)	88(36)	Ns

Note. *$p<.05$

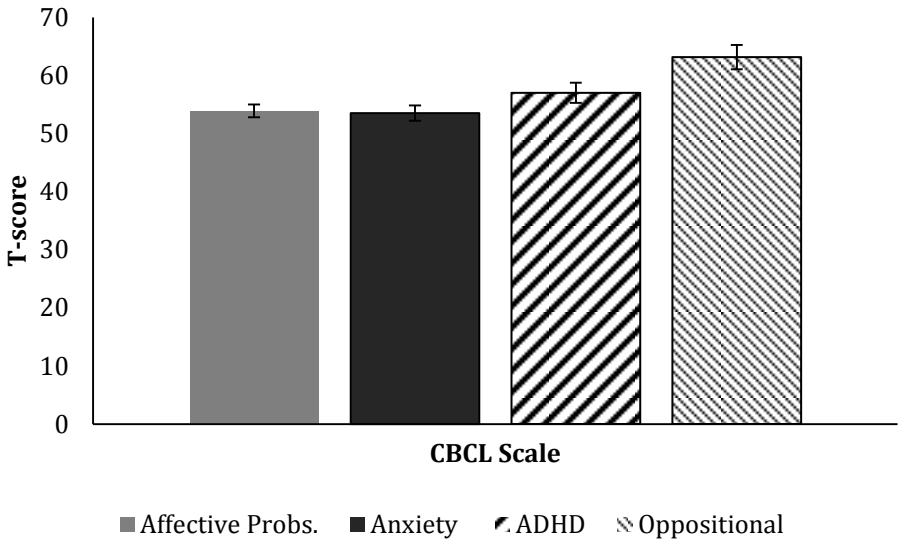

Figure 2.1. CBCL DSM scale t-scores for clinically referred preschool children with error bars.

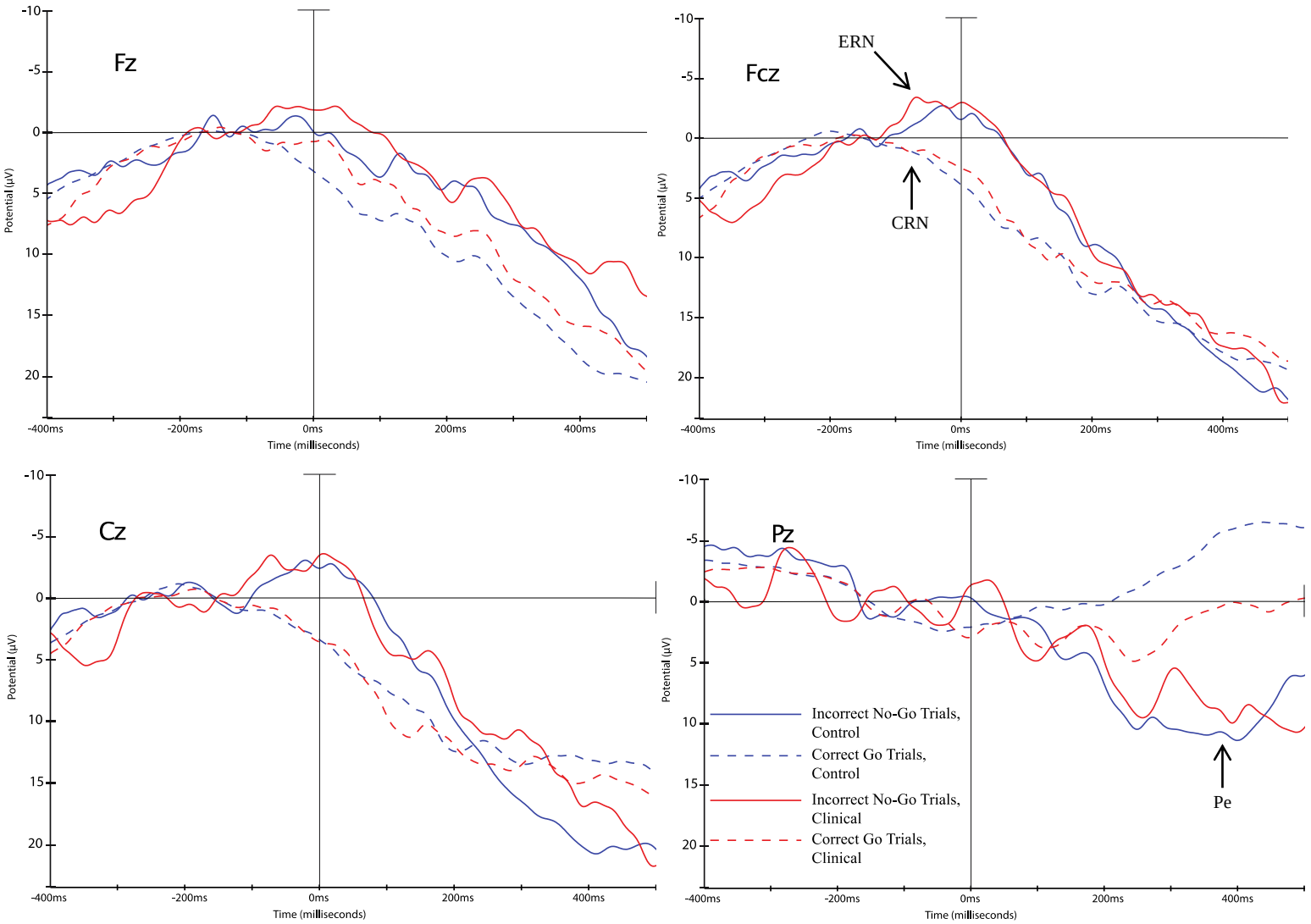

Figure 2.2. Response locked error and correct waveforms for clinically referred (*N* = 14) and control (*N* = 18) preschool children at sites Fz, FCz, Cz, and Pz.

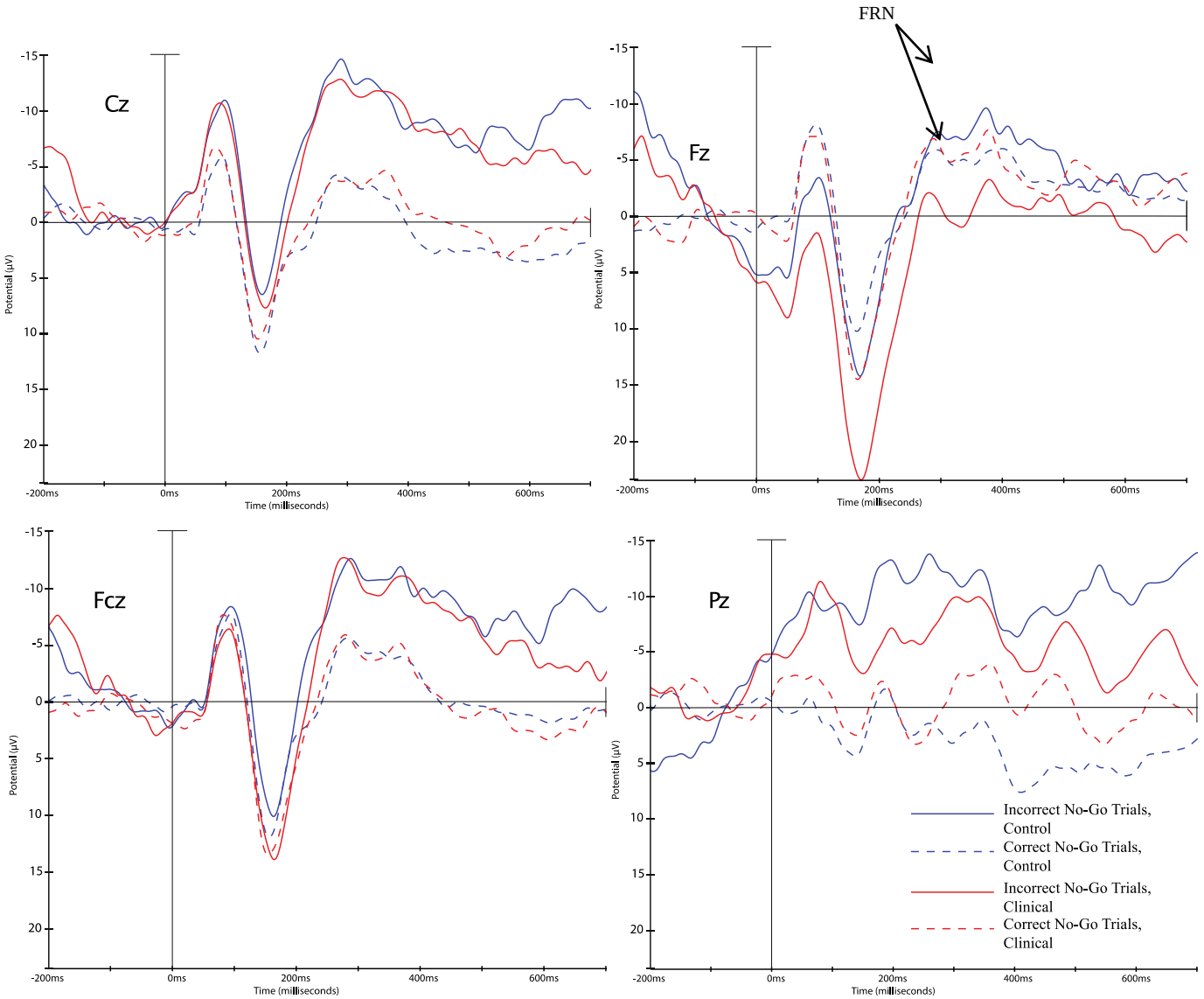

Figure 2.3. Response locked positive and negative feedback waveforms for clinically referred (*N* = 14) and control (*N* = 18) preschool children at sites Fz, FCz, Cz, and Pz.

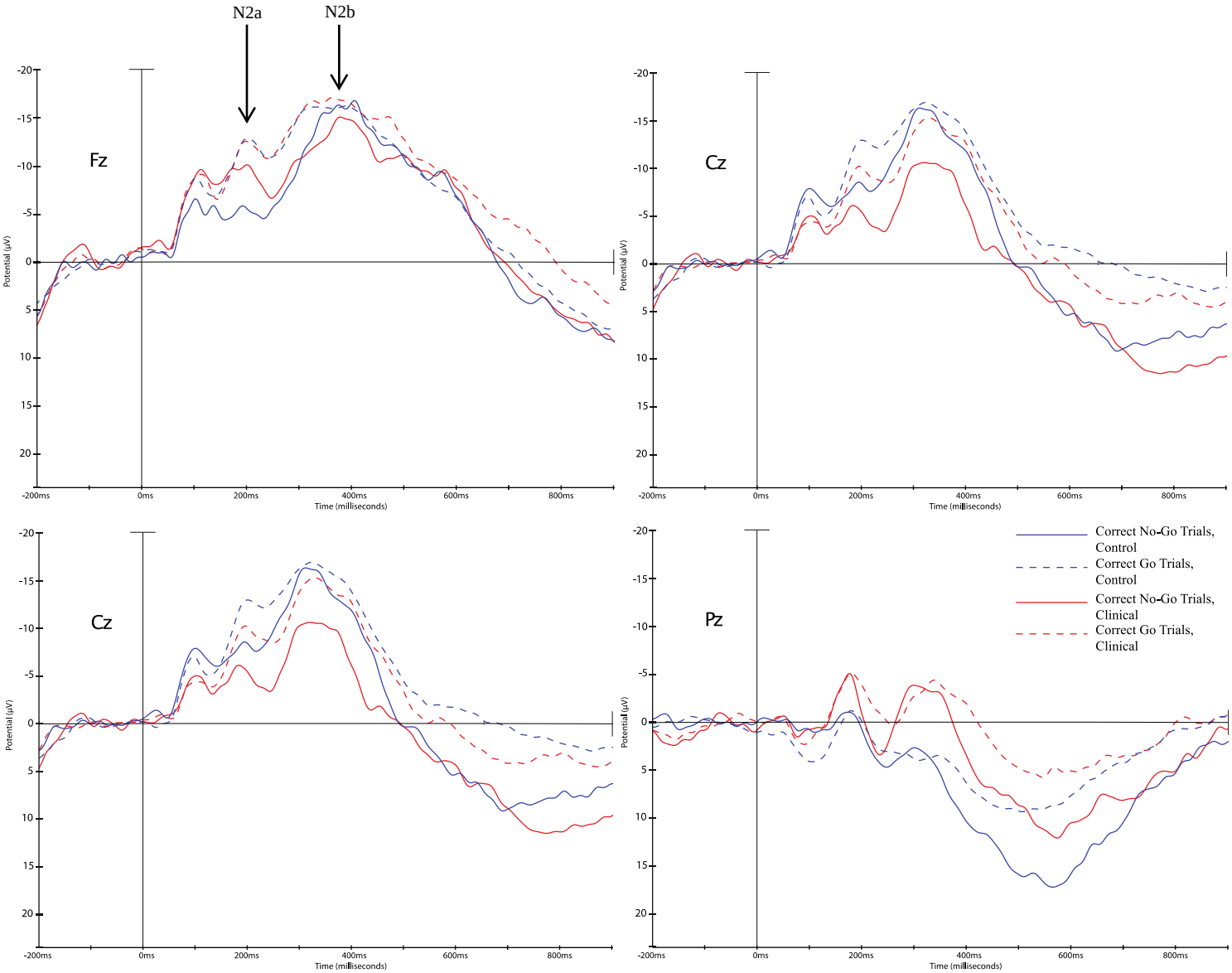

Figure 2.4. Response locked Inhibitory-N2 waveforms for clinically referred (*N* = 14) and control (*N* = 18) preschool children at sites Fz, FCz, Cz, and Pz.

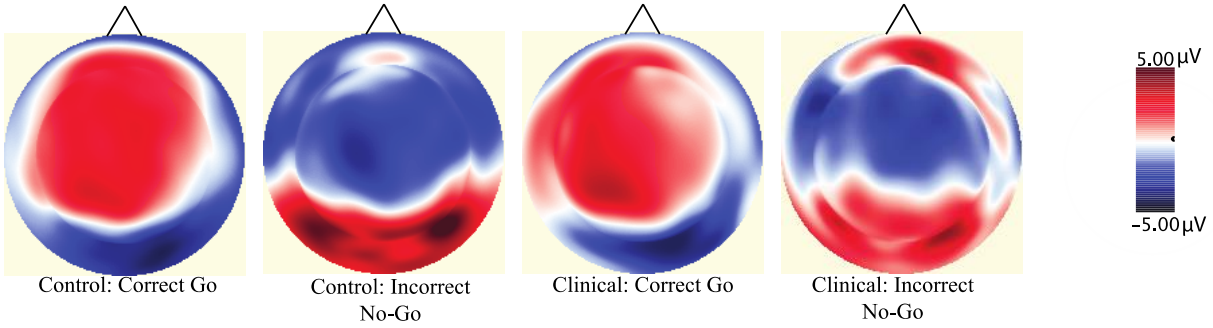

Figure 2.5. Scalp distribution for control and clinically referred preschool children for incorrect no-go and correct go trials. Scalp distribution shows average voltage at -25 milliseconds post-response. Amplitude scale represents 95% of the data.

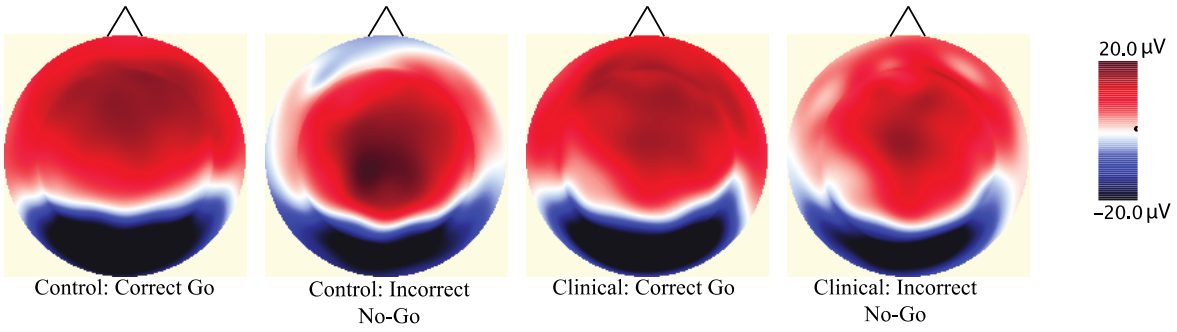

Figure 2.6. Scalp distribution for control and clinically referred preschool children for incorrect no-go and correct go trials. Scalp distribution represents average voltage at 350 milliseconds post-response. Amplitude scale represents 95% of the data.

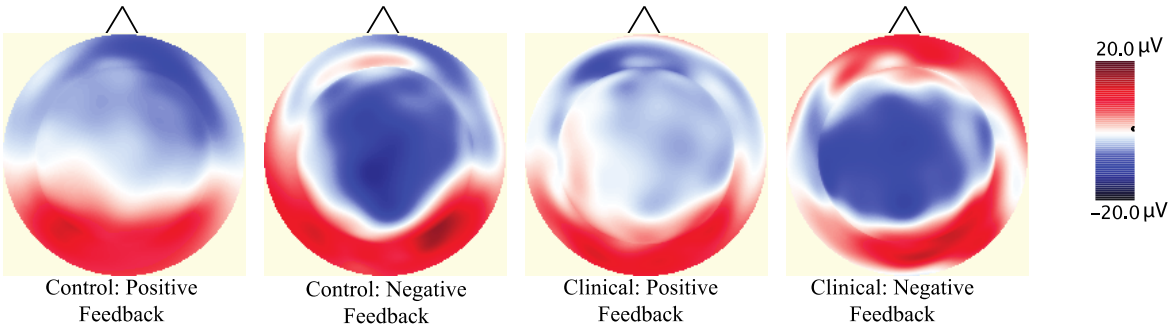

Figure 2.7. Scalp distribution for control and clinically referred preschool children for positive and negative feedback. Scalp distribution represents average voltage at 365 milliseconds post-feedback. Amplitude scale represents 95% of the data.

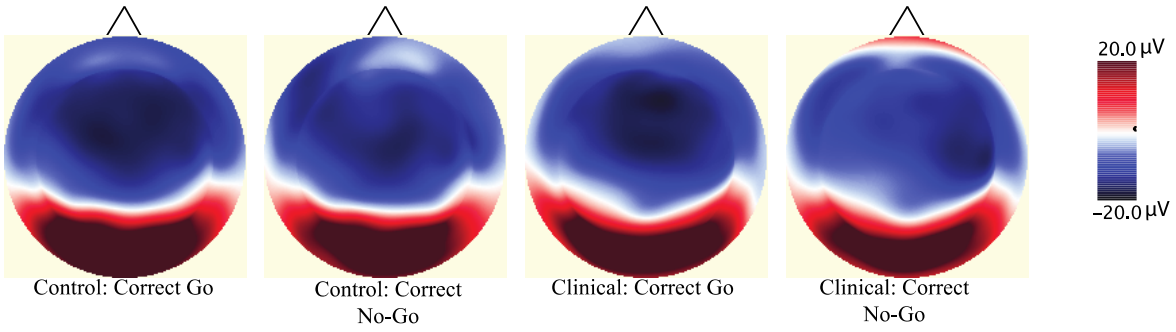

Figure 2.8. Scalp distribution for control and clinically referred preschool children for correct go and correct no-go trials. Scalp distribution represents average voltage 400ms post-event. Amplitude scale represents 95% of the data.

Chapter IV

Links Between Executive Function Micro-processes, Emotion Reactivity, and Emotion Regulation in Early Childhood Externalizing Behavior Problems

The development of competent emotion regulation (ER) is a critical milestone of early childhood. Whereas infants are reliant on caregivers to regulate their emotional states, preschool children are beginning to successfully regulate their emotions independently (Kopp, 1989). Moreover, during the preschool period individual differences in children's emotion reactivity and regulation forecast social and academic functioning (Rubin, Copland, Fox, & Calkins, 1995; Graziano, Reavis, Keane, & Calkins, 2007), and most notably, risk for psychopathology (Southam-Gerow & Kendall, 2002). Preschoolers who are especially poor at responding to emotional challenges, particularly strong negative emotions such as anger and frustration, are more likely to develop persistent externalizing and antisocial behavior problems (Mullin & Hinshaw, 2007).

Preventing and intervening with early onset externalizing behavior problems depends on a better understanding of the inner workings of emotion reactivity and regulation. Suppose a parent tells a preschool-age child they must put a favorite toy away, and even though this makes the child upset because they don't want to do it, they are able to comply instead of having a tantrum. How does the child accomplish this? More specifically, what are the neural mechanisms that must come online to manage negative emotion independently? Despite the importance of emotion regulation in early childhood and its link to psychopathology, the neural mechanisms that underpin independent ER have been largely unexplored in preschool age children. Hence, the goal of the current study was to test a complex model of the neural foundations of early emotion regulation. There were two aims: 1) to determine the neural correlates associated with preschool children's emotion *reactivity* and *regulation*; and 2) to test how emotion reactivity,

emotion regulation, and the neural mechanisms linked to these constructs work together to explain individual differences in early externalizing behavior problems. In what follows, I review the development of emotion regulation early childhood, with a focus on developmental psychopathology, and highlight two major gaps in our understanding of how children respond to emotional challenges: the cognitive micros-processes young children mobilize for emotion regulation purposes, and whether these micro-processes differentially relate to emotion reactivity and regulation. Next, I describe event related brain potential (ERP) components hypothesized to underpin the processing of negative events. Finally, I hypothesize how these ERP components might relate to early onset externalizing behavior through associations with emotion reactivity and regulation.

Emotion Regulation in Early Childhood

Emotion Regulation is an intensively studied but vaguely defined over-arching construct describing adaptive, goal directed processes for modulating the intensity, time-course, and valence of emotional experiences (Barret & Campos, 1987; Thompson, 1994). Developmentally, advances in emotion regulation reflect the maturation of motoric and cognitive abilities (Calkins & Hill, 2007; Sroufe, 1996). For example, infants who can orient themselves towards and away from emotion-inducing stimuli, and can self-soothe with thumb sucking, grow into toddlers and preschool children who can physically manipulate their environments, and possess more advanced executive function (EF) skills such as attention, mental representation, and working memory (Best & Miller, 2010) to achieve emotion-driven goals. Thus, it has been hypothesized that controlling negative emotion becomes more sophisticated, and more independent, during the preschool years because children begin to mobilize these newly

mastered executive function skills and apply them to affectively salient conflicts and events (Kopp, 1989).

Indeed, executive function skills are associated with emotion regulation competence in early childhood. For example, Carlson and Wang (2007) examined individual differences in preschool children's inhibitory control, as assessed by their performance during laboratory-based tasks. Preschool children who showed higher levels of inhibitory control were better able to regulate their behavior during emotional challenges than others (Carlson & Wang, 2007). Furthermore, American preschool children with higher maternal-ratings of IC responded to an emotional challenge with less cortisol reactivity and a faster return to baseline cortisol levels (Grabell et al., under review). Children with early-onset externalizing behavior problems not only have deficits in emotion regulation (Martel, 2009), they perform more poorly than peers on a broad range of executive function tasks. (Séguin & Zelazo, 2005). This suggests that children with early-onset externalizing behavior problems may have more difficulty than peers mobilizing executive function skills in situations when emotional challenges occur. Still lacking, however, is an understanding of which executive function skills are especially important for ER, and which may be less so. Furthermore, there has been little investigation of how the neural correlates of specific EF skills relate to competent or incompetent ER in preschool-age children.

Executive function is a heterogeneous construct (Anderson, 2002). Even the subcomponents of EF, such as Inhibition, comprise multiple micro-processes such as delay of gratification versus inhibitory control (Olson, Schilling, & Bates, 1999). Furthermore, these micro-processes can be isolated and measured as Event Related Brain Potentials (ERPs) and detected in preschool children (Grammer et al., 2014; Grabell, Studies 1 and 2 of dissertation). With ERP techniques, the electrophysiological magnitude and timing of cognitive micro-

processes can be examined in a way that cannot be captured by questionnaire or behavioral measures. The goal of this study was to examine multiple ERPs in order to test, in much more detail, which cognitive micro-processes and their corresponding electrophysiological signals relate to children's responses to emotional challenges. Furthermore, as described below, the current study examined how parents rated their child's behavior during different but related phases of responding to an emotional challenge: emotion reactivity and emotion regulation.

Emotion Reactivity versus Emotion Regulation

Like executive function, the construct Emotion Regulation is multi-faceted (Cole, Martin, & Dennis, 2004). Cole and colleagues (2004) define the interaction between emotion, cognition, and behavior as falling into two categories: "Emotion as regulating"- instances where activated emotion results in behavioral changes; and "emotion as regulated"- instances where the individual volitionally changes the parameters (e.g. length, intensity) of the activated emotion (but see Campos, Frankel, & Camras, 2004 for an opposing viewpoint). Eisenberg and Spinrad (2004) reframed this distinction as "reactive" emotion control, an immediate behavioral response to an emotionally-laden situation, and "effortful" emotion control, an individual's strategic attempt to modulate their emotional state. The authors argued that only the latter constitutes "emotion regulation". Consistent with this viewpoint, clinical descriptions of children with disruptive behavior problems show higher levels of "negative emotionality", defined as dispositional levels of anger and irritability (Eisenberg et al., 2005). Other studies have shown that children with disruptive behavior problems show deficits in the effortful regulation of negative emotion (Martel, 2009). In the present study, I use the terms emotion reactivity and emotion regulation to distinguish between a child's initial behavioral reaction to a salient emotional event, and their ability to effortfully regulate emotion, respectively. To date, few

studies have examined the unique contribution of emotion reactivity and regulation to externalizing problems, and to my knowledge, none in preschoolers. Furthermore, to my knowledge, this study is the first to examine the neural correlates of both emotion reactivity and emotion regulation in preschool children.

Neural Correlates of Emotion Reactivity and Regulation and Early Disruptive Behavior

In the present study preschool-age children completed a novel go no-go task that simultaneously extracted four ERP components of interest: Inhibitory-N2, Error Related Negativity (ERN), Error Positivity (Pe), and Feedback Related Negativity (FRN). As described below, these components reflect micro-processes of executive function and can be studied in the context of affective events. Moreover, previous research has shown that the amplitudes of these components differ in preschool children with high and typical levels of externalizing behavior (Grabell, Study 2 of dissertation). The current study builds on these findings by testing whether individual differences in ERP components reflecting inhibition, error detection and processing, and emotionally-valenced feedback processing relate to early onset externalizing problems via links to emotion reactivity and regulation.

Inhibitory-N2

Inhibitory control is defined as the capacity to plan and suppress inappropriate approach responses under instructions or in novel or uncertain situations (Rothbart, Ahadi, Hershey, & Fisher, 2000). When humans perform an act of inhibitory control, such as during a go no-go task, electrical activity produced by the brain can be measured. For example, when adults correctly inhibit a response to a lure stimulus in a go no-go paradigm, an EEG signal time-locked to the event shows a negative voltage deflection occurring approximately 200-400ms after the presentation of the stimulus (Eimer, 1993; Falkenstein, Hoormann, & Hohnsbein, 1999; Jodo &

Kayama, 1992). This deflection is known as the Inhibitory-N2 component. In children the Inhibitory-N2 component is typically delayed and is larger in amplitude compared to adults. These age differences are thought to reflect developmental changes in the maturity of underlying self-regulatory processes (Williams, 1999; Bedard et al., 2002; Johnstone et al., 2007). Furthermore, preschool children referred to outpatient clinics for severe disruptive behavior showed significantly smaller Inhibitory-N2 amplitudes for successful no-go trials than typical peers (Grabell, Study 2 of dissertation).

Typically, the Inhibitory-N2 component has been studied and described as an executive function process. As reviewed earlier, however, inhibitory control is closely associated with emotion reactivity and regulation. Thus, children may mobilize inhibitory control skills to manage strong negative feelings. Furthermore, evidence suggests that inhibitory control and emotion regulation share similar neural architecture. Both inhibitory control and the Inhibitory-N2 component are believed to be generated by the prefrontal cortex (PFC; Sasaki, Gemba, & Tsujimoto, 1989). In adult humans, voluntary suppression of negative emotions while viewing emotion-eliciting images was associated with greater PFC activation (Ochsner & Gross, 2002). Moreover, macaqcue monkeys with lesions to the PFC showed both impaired cognitive inhibitory control and emotion regulation (Butter, Snyder, & MacDonald, 1970; Iverson & Mishkin, 1970).

In the present study, I conceptualized the amplitude of the inhibitory-N2 component during a go-no-go act as an indicator of cognitive *and* emotional regulatory competence. It is unknown, however, if this component explains children's emotion reactivity and regulation in broader, more ecologically valid contexts, such as parent ratings. Thus, I tested whether

preschoolers with smaller Inhibitory-N2 amplitudes had poorer emotion reactivity and regulation.

Error Related Negativity

The ERP component Error Related Negativity reflects error and conflict processing (Holroy & Coles, 2002), and typically occurs -20-100ms after an error is committed (Gehring, Goss, Coles, Meyer, & Donchin, 1993). The ACC is hypothesized to generate the ERN (Gehring, Goss, Coles, Meyer, & Donchin, 1993). Like Inhibitory-N2, ERN is considered a process important to cognitive, behavioral and emotion regulation. Anatomically, the ACC underpins error monitoring and executive function, as well as the emotional evaluation of discomfort (Derbyshire et al., 1994; Rainville et al., 1997). For example, patients with lesions to the ACC showed less emotional reactivity to psychological stress than controls. Furthermore, Luu, Collin, and Tucker (2000) found that the amplitude of the ERN during a flanker task was dependent on how the participant rated themselves on a scale of negative emotionality: individuals reporting higher levels of negative emotionality showed larger amplitudes than others. Therefore, given the ACC's role in both executive function and evaluation of emotional stress, the ERN is arguably an important biomarker with implications for children's behavioral *and* emotion regulation. Largely unknown, however, is whether the ERN relates to emotion reactivity and regulation in early childhood. Preschool children referred to outpatient clinics for disruptive behavior showed no difference in the ERN compared to controls (Grabell, Study 2 of dissertation). However, this study did not test whether ERN amplitudes and latencies related to children's emotion reactivity and regulation. In the current study, I examined the relation between ERN and parent-rated emotion reactivity and regulation.

Error Positivity

The offset of the ERN typically precedes a positive voltage deflection known as Error Positivity, or Pe, occurring between 200-400 milliseconds after a commission error (Overbeek et al., 2005). The Pe has been hypothesized to reflect the perceived saliency of errors. A recent study found that Pe amplitudes related to both how severe adults felt their errors were as well as changes in their autonomic nervous response such as heart rate and pupillary dilation (Wessel, Danielmeier, & Ullsperger, 2011). This suggests that amplitude of Pe is connected to both a conscious awareness of errors and a "visceral" response to the perceived emotional salience of errors. Some research suggests that the Pe is also an important component for emotion and behavioral regulation in early childhood. Preschool children referred to clinics for disruptive behavior had smaller Pe amplitudes than healthy controls at frontal midline sites (Grabell, Study 2 of dissertation). Still unclear, however, is whether the relation between Pe and early externalizing behavior problems can be explained by specific deficits in emotion reactivity and regulation. The current study further explores how emotion reactivity and regulation might explain the relation between Pe amplitudes and preschool externalizing behavior.

Feedback Related Negativity

The Feedback Related Negativity component is a negative voltage deflection, generated by the ACC, occurring approximately 250ms after the presentation of a positive or negative outcome (Gehring & Willoughby, 2002; Hajcak, Holroyd, Moser, & Simons, 2005). The FRN is hypothesized to reflect an individual's perception of the positive or negative valence of an event. In adults, FRN amplitudes are larger for negative outcomes than positive outcomes, suggesting the FRN is sensitive to events associated with negative affect (Gehring & Willoughby, 2002). Whether preschool children also generate an FRN sensitive to negative outcomes is unclear, largely due to a paucity of research on FRN in preschoolers. In one study,

preschoolers showed no difference in FRN amplitudes for positive and negative events in a prize-guessing task (Mai et al., 2011). However, in another study preschoolers had larger FRNs following negative outcomes during a go no-go task that provided performance-based, emotionally valenced feedback (Grabell, Study 1 of dissertation). Thus, the sensitivity of the FRN to negative affective events may be modulated by task characteristics in this age range. Furthermore, FRNs associated with positive and negative performance-based feedback were not different in preschool children with high levels of externalizing behavior compared to controls (Grabell, Study 2 of dissertation). These findings suggest that preschool children have a sensitivity to negative events, especially when outcomes are tied to performance, but individual differences in FRN amplitudes do not necessarily relate to early externalizing behavior. Given the sensitivity of the FRN to outcomes associated with negative affect, it is possible that FRN amplitudes relate to young children's emotion reactivity and regulation. To my knowledge this has never been tested.

The Present Study and Hypotheses

Research has shown specific ERP components relate to the construct Emotion Regulation in adults and older children. Recent evidence suggests that these ERP components may also be linked to externalizing behavior problems during the preschool years. To better understand why these components signal risk for externalizing problems early in life, we must test models that examine multiple ERP components together, and test their relation to emotion reactivity and regulation. My main goal was to test whether the neural correlates of inhibition, error detection, error processing, and emotionally-valenced feedback processing relate to children's externalizing behavior indirectly through associations with parent-rated emotion reactivity and regulation. My hypotheses were as follows:

1) Maternal-rated emotion reactivity and emotion regulation would uniquely predict individual differences in early externalizing behaviors.

2) Amplitude of Inhibitory-N2, ERN, Pe, and FRN would uniquely predict emotion reactivity and regulation. Specifically, I hypothesized that smaller magnitude amplitudes and later latencies of these components would predict poorer emotion reactivity and emotion regulation.

Given evidence that children with externalizing behavior problems have deficits in emotion reactivity, emotion regulation, and executive function, these variables may relate to each other differently in typical versus high risk preschoolers. An exploratory goal was to determine whether the relation of these ERP components to emotion reactivity, regulation, and externalizing behavior was moderated by whether children were referred to clinics for externalizing behavior problems.

Methods

Participants

Participants included preschool children clinically referred for externalizing behavior problems and their normally developing peers. Twenty-four children ages 3 and a half to 5 years (*M* = 59 months, *SD* = 8.76 months; 41% female) were recruited from three outpatient mental health clinics affiliated with a large local university due to concerns for disruptive behavior. All were right handed or identified as ambidextrous. Based on maternal report, 52.9% of the children identified as Caucasian, 23.5% identified as African American, and 23.5% identified as mixed-race. Parents completed a phone screen with a study team member to verify that their concerns about their child were consistent with an early onset disruptive behavior disorder. Furthermore, children were screened for, and excluded, if they endorsed any of the following criteria:

diagnosis of mental retardation, autism spectrum disorder, psychosis, significant medical condition, epilepsy, or history of head injury resulting in loss of consciousness. Children whose parents endorsed disruptive behavior comorbid with other behavior problems, such as mood or anxiety problems, were included in the study if they otherwise met diagnostic criteria for a disruptive behavior disorder.

Of the 24 children who enrolled in the study, 9 failed to yield usable ERP data due to not providing sufficient artifact-free trials. In addition, one child was later revealed to have a mild form of epilepsy and was excluded. Furthermore, of the 14 children included in the present analyses, some children provided enough artifact-free trials to examine certain ERP components but not others. Therefore, 13 children yielded enough artifact-free trials to examine Inhibitory-N2, 10 children had enough good trials to examine ERN and Pe, and seven children had enough good trials to examine FRN.

In addition, thirty-seven typically developing preschool-age children (M = 57.9 months, SD = 7.8 months; 50% female) were recruited from area preschools via community flyers and web advertisements. Based on maternal report, 75% of the sample identified as Caucasian, 13.8% as mixed-race, 5.6% as African American, and 5.6% as Asian. All were right handed or identified as ambidextrous. Children were excluded from the study if they met any of the following criteria: diagnosis or concerns consistent with any DSM-IV disorder of mood or behavior, diagnosis of mental retardation or developmental delay, autism spectrum disorder, or psychosis; medical condition; or use of medication affecting mood or attention. Of the 37 participants, 18 failed to yield usable ERP data due to the following reasons: did not generate enough artifact free trials (16) and equipment failure (2). Of the remaining 19 children, 15

provided enough artifact-free trials to examine Inhibitory-N2, 18 had enough trials to examine ERN and Pe, and 13 had enough trials to examine FRN.

Thus, 32 children, combined between the two groups, were included in the present analyses. As described below, because the two groups overlapped substantially in maternal reports of externalizing behaviors, they were combined for the purposes of examining externalizing behavior as a continuous outcome.

Procedure

Adapted Go No-Go Task

Participants completed a child-friendly Go No-Go task developed by Grammer, McDermott and colleagues (Grammer et al., 2014, McDermott et al., 2014). In the present study, I adapted the task to provide performance-based emotionally-valenced feedback (see Grabell, Study 1 of dissertation). Children were told that were going to play a computer game called "Zookeepers" to win a toy. The task had 8 trial blocks; each block consisted of 40 trials. Children were instructed to click a button each time they saw an animal picture (go stimuli), with the exception of an orangutan picture (lure stimuli). Children completed two practice blocks, the first without lure stimuli and the second with lure stimuli, to ensure they understood the task. Children were awarded special animal stickers after each trial block, regardless of performance, to increase motivation. Research assistants were trained to praise children on their speed, regardless of their performance, rather than their accuracy to ensure children made enough errors for analyses.

Stimuli were weighted such that the lure stimuli were randomly selected 25% of the time. As shown in Figure 1, for every correct no-go trial (child correctly abstained from hitting the button), the child was presented with a happy face after 500ms of black screen. For every

incorrect no-go trial (child accidentally hits the button), the child was presented with an unhappy face after 500ms of black screen. This 500ms gap was designed to separate ERN and FRN waveforms. Happy and unhappy faces were designed to be as similar as possible in terms of their size, percentage of yellow to black pixels, and position on the screen to ensure these stimuli characteristics did not influence waveforms.

Furthermore, beginning with the practice block, and continuing through all trial blocks, a dynamic algorithm was used to ensure participants had a sufficient number of correct and incorrect no-go trials by adjusting the stimulus duration. The purpose of the dynamic timing algorithm was to ensure that all children, regardless of their inhibitory skills, would make approximately the same number of errors, and thus encounter the same number of emotion eliciting events across the task. The duration of go and no-go stimuli decreased by 100ms increments each time children completed a successful no-go trial. Similarly, go and no-go stimuli duration increased by 100ms increments each time children made an error on a no-go trial. Adjustments in duration were capped such that go and no go stimuli could be no faster than 800 milliseconds and no slower than 1800 milliseconds. Speed adjustments did not affect the duration of black screen, fixation cross, or feedback presentation.

Prior to EEG recording, children were seated in a comfortable chair and engaged in rapport building with the research assistants. This included reading a picture book together about animals in a zoo, and administrating an assent script in child friendly language. Parents were allowed to remain in the room with their child during both the assent and EEG recording.

EEG data was recorded using a 128 channel child-friendly Geodesic Sensor Net (Tucker, 1993). Impedance for all electrodes was kept below 50 KΩ, and all recordings were referenced to the vertex, Cz. The EEG signal was amplified using a 0.01-100 Hz bandpass and digitized at

500 Hz. The electro-oculogram (EOG) was monitored with 6 electrodes placed bilaterally in the external canthi (Ch 128 and 125), supraorbital (Ch 25 and 8) and infraorbital (Ch 127 and 126) regions. Recording in every channel was vertex-referenced. Data was recorded and processed using Net Station 4.1 (EGI software).

Once acquired, the data was lowpass filtered below 20 Hz. The continuous EEG was segmented into epochs starting at 200ms before the onset of either the stimulus or response and lasting until 1000ms after the stimulus/response onset. Segmented files were scanned for artifacts with the Artifact Detection NS tool for excessive muscle activities, eye blinks and eye movements.

Segments were marked for artifact if the running average of activity exceeded pre-defined thresholds for eye movement (55 μV), blinks (100 μV), and bad channels (200μV). Following this automated process, segments were manually inspected. Segments with more than 10 bad channels were excluded from analyses. In segments with less than 10 bad channels, and no movement artifacts, spherical spline interpolation was used to replace bad channels using values from neighboring channels (Gratton, Coles, and Donchin, 1983). Children with at least 6 good segments in each trial were included in analyses.

Artifact-free ERN, FRN, and Inhibitory-N2 segments were averaged separately and then re-referenced against the average of all channels. A baseline correction was performed for -200 to -100ms for ERN segments, -100 to 0ms for FRN segments, and -100ms to 0ms for Inhibitory N2 segments. Based on visual inspection of the grand averaged ERPs, and in accordance with previously published reports, I defined ERN as the largest negative deflection between -25 and 50ms after the response onset, Pe as the largest positive deflection between 200 and 500ms after the response onset, FRN as the largest negative deflection between 350 and 450ms after the

feedback onset, and Inhibitory-N2 as the largest negative deflection between 200 and 450ms after presentation of no-go stimuli on correct trials. Furthermore, I made manual adjustments for a small number of children who showed peak amplitude of these components outside, but within 50ms of, these predefined windows of interest. Group differences in the peak amplitude of ERP components were tested using t-tests.

Measures

Parent Ratings of Emotion Reactivity and Regulation

The parent who brought the child to the lab (30 mothers, 2 fathers) completed the Child Behavior Questionnaire (CBQ; Rothbart, 1989), a 109-item measure of child temperament. Parents were asked to rate how much each question applied to their child on a 7- point scale. In the present study, specific items from the Anger/Frustration and Positive Anticipation subscales were used to examine the construct of Emotion Reactivity, and specific items from the Inhibitory Control subscale were used to examine the construct of Emotion Regulation (Rothbart, Ahadi, Hershey, and Fisher, 2003). As described below, a team of experts first selected individual CBQ items based on whether they described emotion reactivity or emotion regulation processes. Next, I examined the inter-correlation of these selected items. Items that correlated with each other were summed to create separate emotion reactivity and emotion regulation scale scores.

Emotion Reactivity Scale

The Anger/Frustration subscale of the CBQ is a rating of the child's negative emotionality (e.g. "Gets angry when told s/he has to go to bed"). In the present study, reverse coded items in the Anger/Frustration scale (e.g. "Rarely protests when another child takes his/her toy away") correlated poorly with items describing affirmative expressions of anger (e.g. "Gets

mad when provoked by other children"). Therefore, only the affirmative items were used in analyses (see Appendix). Reliability of the anger reactivity items was excellent (alpha = .86).

The Positive Anticipation subscale of the CBQ is a rating of the child's excitement and/or anticipation for expected pleasurable events (e.g. "Shows great excitement when opening a present"). Like the Anger/Frustration scale, inter-correlation of items was poor due to reverse coded items (e.g. "Remains pretty calm about upcoming desserts like ice cream"). Thus only affirmative items were examined (e.g. "When s/he sees a toy she wants, gets very excited about getting it"). Reliability of Positive Anticipation reactivity was good (α= .71).

In order to examine individual differences in overall emotion reactivity, anger/frustration and positive anticipation scale scores were averaged together to create an emotion reactivity composite.

Emotion Regulation Scale

Inhibitory Control is a rating of the child's capacity to plan and suppress inappropriate actions (e.g. "Can lower his/her voice when asked to do so," "Can wait to enter new activities if s/she asked to"). Furthermore, some items on the CBQ-IC scale describe inhibitory control in more affectively neutral contexts ("Is good at games like 'Simon Says', etc.") while other items more specifically describe mobilization of inhibitory control for emotion regulation ("Is able to resist laughing or smiling when it isn't appropriate"), or describe competent inhibitory control in a situation that would typically elicit emotion ("Is usually able to resist temptation when told s/he is not supposed to do something"). In the present study, we combined four such items from the inhibitory control scale (items 93, 100, 104, and 105) to create an "emotion regulation" composite. Reliability of the emotion regulation composite was good (α = .74).

Parent Ratings of Externalizing Behavior Problems

Parents rated their children's externalizing behavior using the Child Behavior Checklist, Preschool Version (Achenbach & Rescorla, 2000). Parents rated their child's aggressive or disruptive behavior (e.g. "hits others") on a three-point scale. Reliability of the CBCL externalizing behavior problems scale score was excelled (α= .94).

Analysis Plan

Path modeling using MPlus (Muthén & Muthén, 1998) was used to test the relation between ERP amplitudes, parent-rated emotion reactivity and regulation, and parent-rated externalizing behavior problems. Missing data were handled using Full Information Maximum Likelihood (FIML). After examining zero-order correlations between variables, I first tested how ERP amplitudes directly predicted externalizing behavior in the total sample. Next, I tested whether ERP components related to externalizing behavior indirectly via links to emotion reactivity and regulation. Finally, I explored whether relations between ERP components, emotion reactivity and regulation, and externalizing problems were moderated by whether children had been referred for mental health services.

Results

Descriptive Statistics

Socio-demographic characteristics are shown in Table 3.1. The clinical and non-clinical samples did not differ in relation to age, gender, or ethnicity. Children in the control group had mothers who went significantly farther in school compared to children in the clinically referred group. Although clinically referred children had significantly higher ratings of externalizing behavior than non-clinically referred children, only 40% of the clinically referred children had externalizing behavior t-scores above the clinical cutoff. Furthermore, the distribution of externalizing scale scores showed significant overlap between clinically referred and non-

clinically referred preschool children (clinically referred range: 51-77; non-clinically referred range: 28-67) suggesting that the groups of children represented a continuous range of externalizing behaviors as opposed to a taxonomic difference.

Behavioral Measures

Consistent with other studies (e.g. Grammer et al., 2014) children had faster reaction times for incorrect no-go trials than for correct go trials. Mean reaction times were 595ms (*SD* = 55ms) for go trial and 478ms (*SD* = 62ms) for no-go trials. The mean accuracy was 81% for go trials and 72% for no-go trials. As stated previously, the pre-set duration of go and no-go stimuli was dynamically adjusted throughout the task based on the child's performance on no-go trials. The average pre-set duration for go and no trials was 909ms (*SD* = 88ms).

ERP Waveforms

As seen in Figures 3.1, 3.2, and 3.3, waveforms showed clear ERN, Pe, FRN, and Inhibitory-N2 components at midline sites. (For more detailed analyses of waveforms between clinically referred and non-clinically referred preschool children, see Grabell, Study 2 of dissertation.) In the present study, we examined Inhibitory-N2 for correct no-go trials, ERN and Pe for incorrect no-go trials, and FRN for both negative and positive outcomes. Furthermore, because amplitudes for each ERP component was highly correlated across midline sites, only one site for each component was included in subsequent analyses. Based on visualization of the waveforms and in accordance with previous literature, I examined Inhibitory-N2 and ERN components at site Cz, Pe at site Pz, and FRN at site FCz.

Bivariate Correlation between Study Variables

Bivariate correlations (See Table 3.2) revealed that parent-rated emotion reactivity and emotion regulation were marginally associated. Both parent-rated emotion reactivity and

regulation were significantly correlated with externalizing behaviors. Furthermore, amplitude of Inhibitory-N2 was significantly correlated with emotion regulation and marginally correlated with externalizing behavior. The relations were such that children with larger magnitude N2 amplitudes tended to have better emotion regulation skills and lower levels of externalizing problems. Amplitudes of ERN, Pe, and FRN did not correlate with emotion reactivity, regulation, or externalizing behaviors. In addition, latencies of ERP components were not related to emotion reactivity, regulation, or externalizing problems.

Because 37% of the sample had missing data for FRN due to artifacts, and FRN was not correlated with emotion reactivity, regulation, or externalizing behavior, FRN was not included in the path models.

Path Models to Emotion Reactivity, Regulation, and Externalizing Behavior

First, a model testing direct paths from ERP component amplitudes and latencies to externalizing behavior revealed no significant relations. Therefore, I could not test whether emotion reactivity and regulation mediated these paths. Next, I tested whether Inhibitory-N2, ERN, and Pe amplitudes predicted parent-rated emotion reactivity and regulation. Furthermore, this model tested the unique contribution of emotion reactivity and regulation to externalizing problems. As shown in Figure 3.4, both parent rated emotion reactivity and emotion regulation significantly predicted externalizing problems such that higher emotion reactivity and poorer emotion regulation were associated with more severe levels of externalizing behavior.

In addition, amplitude of Inhibitory-N2 was significantly related to parent-rated emotion regulation such that children with larger magnitude Inhibutory-N2 amplitudes had better emotion regulation. Furthermore, amplitudes of Inhibitory-N2 and Pe were associated with emotion reactivity such that larger magnitude Inhibitory-N2 (i.e. more negative), and smaller magnitude

Pe (i.e. less positive) amplitudes were associated with more severe emotion reactivity. There were no significant direct paths between ERP component amplitudes and externalizing behavior.

Moderating Effect of Externalizing Behavior Problems

The sample size of the current study was not large enough to estimate path models separately by clinically referred and non-referred groups using multi-group analysis. Therefore, I examined zero order correlations between study variables separately by group. As shown in Table 3.1, in typical preschoolers only, ERN amplitude was significantly negatively correlated with externalizing behavior problems such that smaller ERN amplitudes (i.e. less negative) were associated with lower levels of externalizing behavior. In addition, Pe amplitude was marginally negatively correlated with emotion regulation ratings in typical preschoolers, such that larger Pe amplitudes (i.e. more positive) were associated with poorer emotion regulation. As shown in Table 3.2, in preschoolers referred to outpatient clinics, Pe amplitude was significantly *positively* correlated with emotion regulation, such that larger Pe amplitudes (i.e. more positive) were associated with better emotion regulation. A scatter plot (see Figure 3.5) comparing the relation between Pe amplitude and emotion regulation revealed that the negative relation between Pe and emotion regulation in the typical preschoolers was due to a single outlier, which when removed, resulted in a non-significant relation. Finally, in clinically referred preschoolers, amplitude of FRN following negative outcomes was significantly negatively related with emotion regulation such that larger FRN amplitudes (i.e. more negative) were associated with better emotion regulation.

Discussion

The goal of this study was to test whether neural correlates of four different cognitive micro-processes related to preschool children's externalizing behavior problems indirectly

through links to emotion reactivity and regulation. The micro-processes and their associated ERP components were: response inhibition (Inhibitory-N2), error detection (ERN), error processing (Pe), and emotionally-valenced feedback processing (FRN). I hypothesized that smaller amplitudes of these components would uniquely relate to poorer ratings of emotion reactivity and regulation, which would in turn relate to more severe externalizing behavior problems. Furthermore, an exploratory goal was to determine whether relations between the ERP components, emotion reactivity and regulation, and externalizing behavior were moderated by the child's level of externalizing behavior.

Findings revealed that amplitudes of these ERP components related to early externalizing behavior problems through indirect links to emotion reactivity and regulation. However, my findings also showed specificity as to which ERP components were important for emotion reactivity and regulation, and which preschool children showed these associations. In what follows, I review and interpret these findings.

In the present study, I used items from the CBQ Anger/Frustration, Positive Anticipation, and Inhibitory Control subscales to create two separate scales measuring the constructs Emotion Reactivity and Emotion Regulation. These two constructs were moderately associated with each other and uniquely related to externalizing behavior. This finding further validates the theory that emotion eliciting events result in distinct reactive and regulatory behaviors (Cole, 2004; Eisenberg, 2004).

Smaller Inhibitory-N2 amplitudes predicted poorer emotion regulation in the total sample. This suggests that the neural process of inhibiting a response may be especially important for successful emotion regulation, underscoring its important in the etiology of early onset externalizing behavior. This finding complements data from other studies showing an

association between inhibitory control and emotion regulation in preschoolers (Carlson & Wang, 2007; Grabell et al., under review). However, to my knowledge, this study is the first to reveal a relation between the electrophysiological marker of inhibition and both emotion reactivity and regulation in preschool children.

Although amplitudes of Inhibitory-N2 related to emotion regulation in the total sample, when the sample was split by clinically referred and non-referred children, zero-order correlations were non-significant for both groups. Given that children referred to clinics for externalizing behavior showed significantly smaller Inhibitory-N2 amplitudes than typical peers (Grabell, Study 2 of dissertation), individual differences in this component may be more relevant to discriminating between high and low risk groups rather than predicting variance within those groups.

Furthermore, in the total sample, smaller Pe amplitudes were associated with poorer emotion reactivity, but were unrelated to emotion regulation. This suggests that preschool children who show deficient evaluation of the saliency of errors and conflicts may be more reactive to emotion eliciting events. Moreover, zero-order correlations revealed that Pe was significantly associated with emotion regulation in clinically referred preschoolers but not their typical peers. Although this study could not test *how* evaluation of negative events might serve to facilitate better emotion reactivity and regulation in preschoolers, previous studies have shown that adults who were better able to reappraise and reframe negative events showed superior emotion regulation skills (Ochsner & Gross, 2008). Thus, allocation of cognitive resources to reflect on negative events may similarly play a role in responding to emotional challenges, both immediately and effortfully. Not surprisingly, clinically referred preschoolers were rated as having higher emotion reactivity and lower emotion regulation skills than typical children.

Therefore, small Pe amplitudes may be characteristic of especially poor ER and signal risk for persistent externalizing behavior problems.

Finally, although ERN and FRN amplitudes did not relate to emotion reactivity, regulation, or externalizing behavior in the full sample, ERN amplitudes were associated with externalizing behavior in non-referred preschoolers, and FRN amplitudes were associated with emotion regulation in clinically referred preschoolers. Specifically, non-clinically referred preschool children with larger magnitude ERN amplitudes had higher ratings of externalizing behavior than non-clinically referred peers, and clinically referred preschoolers with smaller FRN amplitudes had lower ratings of emotion regulation than clinically-referred peers. Given that these children did not have clinically significant behavior problems, however, the nature of this relation is unclear. Other studies have shown a positive relation between ERN amplitudes and level of anxiety in children (Ladouceur, Dahl, Birmaher, Axelson, & Ryan, 2006). Even though typical preschool sample was not characterized as having high levels of anxiety, a positive relation between ERN and externalizing behavior may nonetheless capture this process. Associations between FRN and Pe with emotion reactivity and regulation in clinically-referred preschoolers are interesting given that both these components relate to processing negative events. Thus, electro-physiological "under-reaction" to appraising negative affective events may be linked to maladaptive responses to emotional challenges. Of course, small Ns in each group prevent these analyses from being anything more than exploratory. Future research is needed to determine if preschool children at different levels of risk show different neural correlates of emotion and behavioral regulation.

To summarize, my findings do not suggest that preschool children who respond poorly to emotional challenges have global deficits in the neural processes underlying prevention,

recognition, and processing of negative events. Instead, preventing negative events from occurring through inhibition, and processing them after they've occurred, may be the skills most important for emerging, independent emotion regulation.

Strengths and Weaknesses

To my knowledge, the current study is the first to examine the neural processes associated with preschool children's responses to emotional challenges in daily life. The use of a paradigm capable of measuring multiple ERP components allowed me to test whether specific micro-processes of EF related to emotion reactivity and recovery, as opposed to general deficits. In addition, the use of path modeling allowed me to examine the unique contribution of individual ERP components to emotion reactivity and regulation, as well as the unique contribution of these latter processes to externalizing behavior.

Although the sample size in the current study was commensurate to other ERP studies, particularly given the challenging population I examined, the smaller sample size may have affected results. Specifically, non-significant relations between ERP components and emotion reactivity and regulation may have been due to a lack of power. Furthermore, a larger sample of clinically referred and non-referred preschool children would have allowed for more rigorous testing of the moderating effect of externalizing behavior problems.

The current study was driven by a lack of understanding of how preschool children mobilize specific executive function skills to emotion regulation strategies. However, I only examined the association between ERP components and emotion reactivity and regulation, and therefore causation cannot be inferred. I encourage future research to build on these findings, and use different paradigms, to better understand the neural mechanisms that are mobilized during emotion reactivity and regulation.

Implications and Future Directions

Although it has been well established that increases in executive function correspond with increases in emotion regulation, the link between the two may be due to a specific set of sub-processes. A more detailed understanding of how micro-processes of EF are mobilized for competent emotion regulation may lead to the development of interventions that directly repair these skills in children at risk for chronic behavior problems. Furthermore, determining the developmental continuity of the neural correlates of emotion regulation is also an important direction for future research. The neural processes that explain adaptive and maladaptive responses to emotional challenges may change as children age and develop more advanced cognitive skills. A greater understanding of how the developing brain learns to respond to and regulate emotion will greatly advance our understanding of developmental psychopathology.

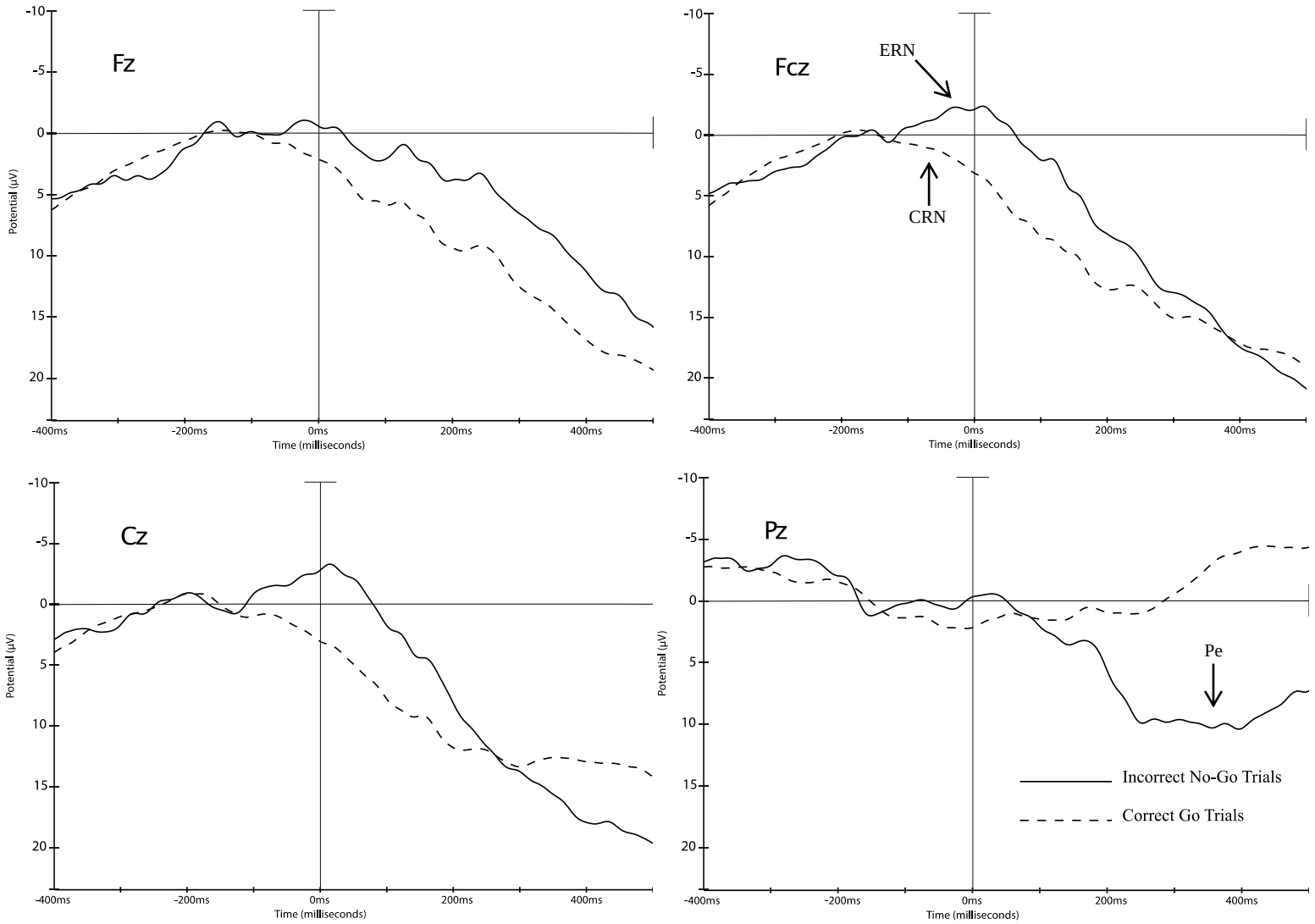

Figure 3.1. Response locked error and correct waveforms at sites Fz, FCz, Cz, and Pz (N = 32).

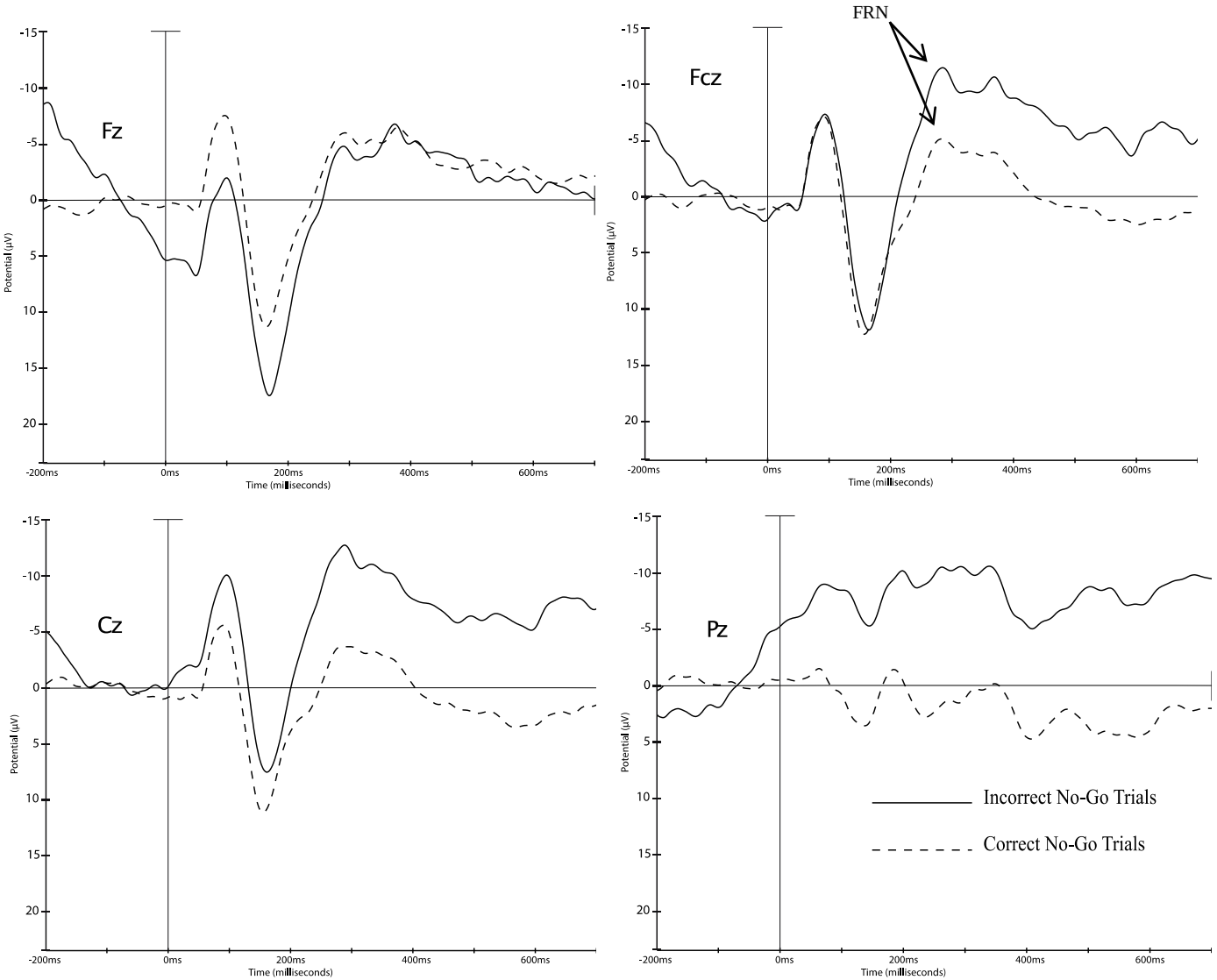

Figure 3.2. Response locked FRN waveforms for correct and incorrect no-go trials at sites Fz, FCz, Cz, and Pz (N = 32).

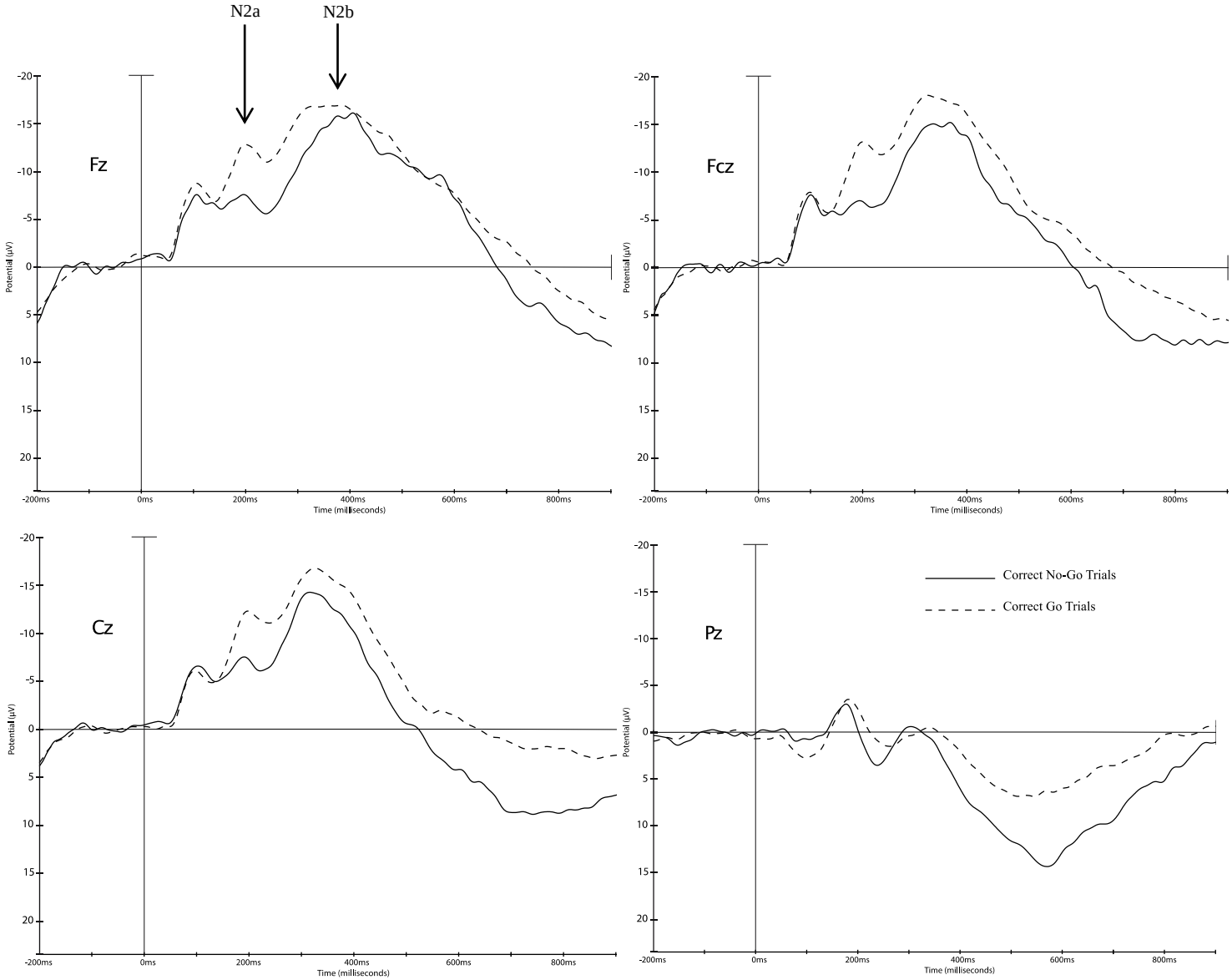

Figure 3.3. Response locked Inhibitory-N2 waveforms for correct go and no-go trials at sites Fz, FCz, Cz, and Pz (N = 32).

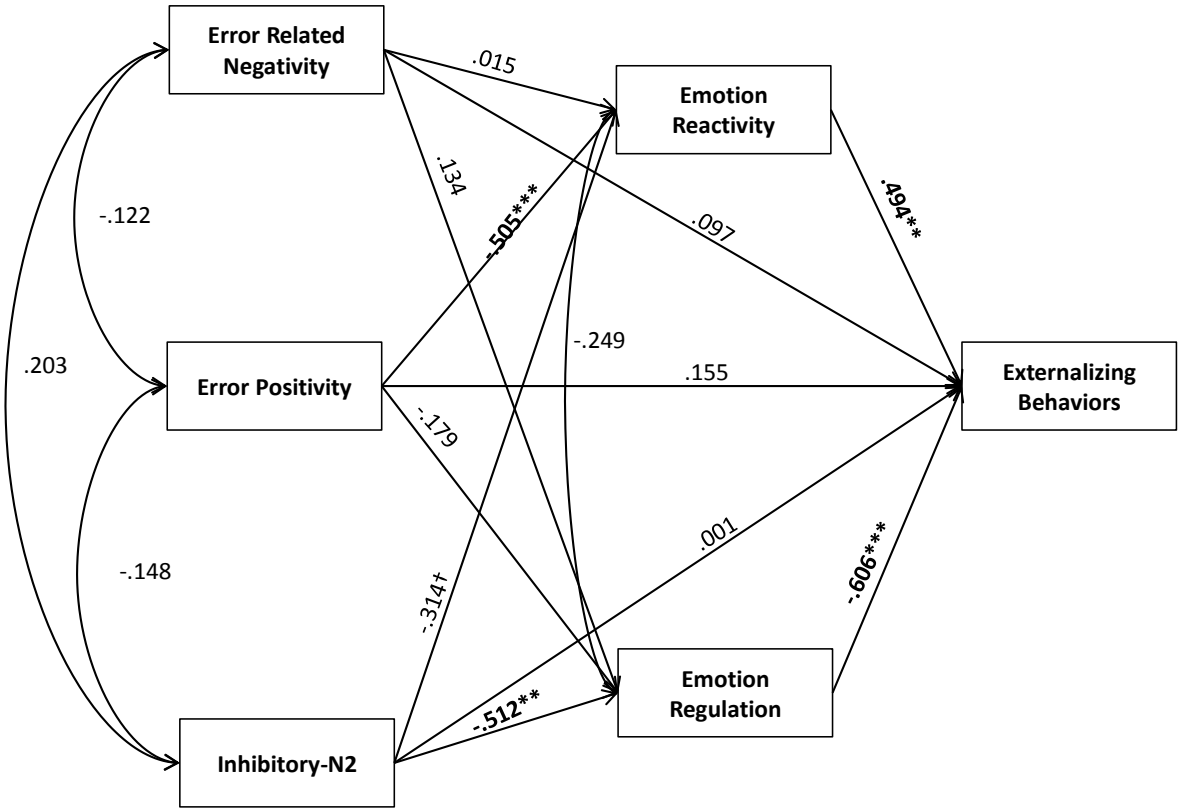

Figure 3.4. Path model testing relations between ERP components, parent rated emotion reactivity and regulation, and parent-rated externalizing behavior problems. Significant parameters highlighted in bold.
Note. †p<.10, *p<.05, **p<.01, ***p<.001.

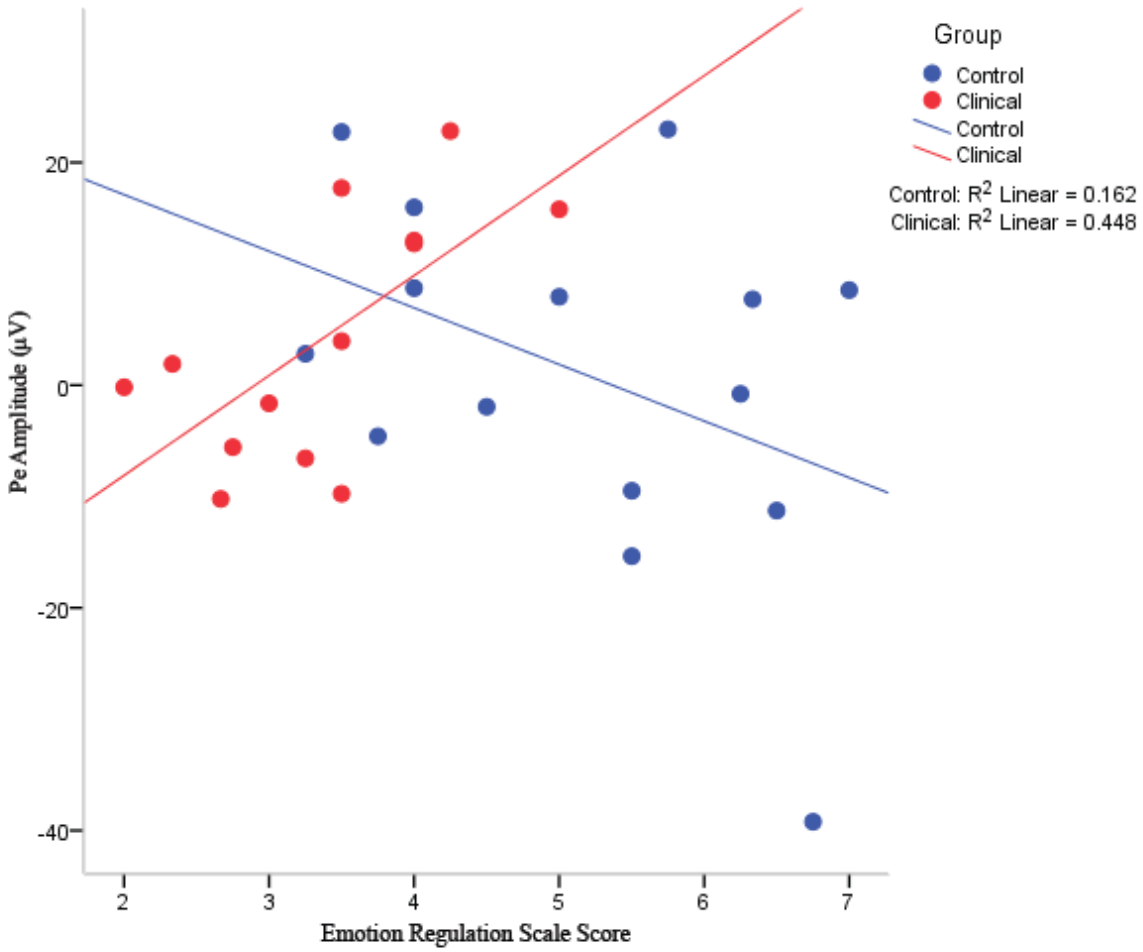

Figure 3.5. Relation between Pe amplitude and parent-rated emotion regulation for clinically referred and typical preschool children. *Note.* When outlier removed, relation between Pe and emotion regulation non-significant for typical preschool children.

Table 3.1. Correlation coefficients for study waveform amplitudes with emotion reactivity, emotion regulation, and externalizing behavior scale scores for control preschoolers.

Waveform	Emotion Reactivity	Emotion Regulation	Externalizing Behavior
ERN	-.214	.119	-.567*
Pe	-.086	-.428†	.137
Inhibitory-N2	.006	-.384	.076
Incorrect FRN	-.090	.296	-.288
Correct FRN	.249	-.212	-.080

Note. †$p < .10$, *$p<.05$

Table 3.2 Correlation coefficients for study waveform amplitudes with emotion reactivity, emotion regulation, and externalizing behavior scale scores for clinically referred preschoolers.

Waveform	Emotion Reactivity	Emotion Regulation	Externalizing Behavior
ERN	-.243	-.054	.085
Pe	-.078	.650*	-.427
Inhibitory-N2	-.047	-.169	.486
Incorrect FRN	-.421	-.650*	.135
Correct FRN	-.301	-.391	-.101

Note. †$p < .10$, *$p<.05$

Chapter V

The Function of Cognitive Micro-Processes in Adaptive and Maladaptive Responses to Emotional Challenges: Integrating Findings and Implications for Preschool-Onset Externalizing Behavior Problems

Risk for chronic and persistent externalizing behavior problems may depend on how well preschool children learn to manage emotional challenges. The mobilization of executive function skills to achieve adaptive goals in emotion-laden contexts may be essential for developing competent, independent emotion regulation in early childhood (Kopp, 1989; Zelazo, 2007). To date, empirical support for integrated executive function and emotion regulation has been primarily limited to examining general associations between the two constructs (e.g. Carlson & Wang, 2007). Understanding the mechanics of emotion regulation, especially in ways that inform how externalizing behavior problems develop, requires examining these constructs, and their inter-relation, at previously under-explored levels of analysis. Specifically, there is a relative lack of research examining how the smallest subcomponents of executive function, cognitive micro-processes, uniquely relate to emotion regulation. Similarly, few studies examine how children respond to emotional challenges by separate reactivity and regulation phases. Finally, there is a paucity of research comparing EF-ER links in preschool children with and without externalizing behavior problems.

This final chapter summarizes the three studies presented in Chapters II, III, and IV testing, in sequential stages, a neurobiological model linking cognitive micro-processes, emotion reactivity and regulation, and early externalizing behavior problems. The overall aim of this dissertation was to test how electrophysiological waveforms associated with the onset of negative affective events related to: 1) each other; 2) parent-rated emotion reactivity and regulation and; 3) externalizing behavior problems in preschool children.

In what follows, I briefly review the findings of each study in order and place each study's findings the context of their respective literature. Next, I describe how findings across the three studies expand our understanding of the development of both normative emotion regulation and early onset externalizing behavior problems. I then describe implications for the development, intervention, and prevention of persistent externalizing behavior problems. Finally, I conclude this chapter by reviewing the limitations of these three studies and proposing recommendations for future research.

Overview of Dissertation Studies

The three studies presented in this dissertation examined Event Related Potential components recorded from preschool children with and without externalizing behavior problems. Across studies, all children completed the same adapted go no-go task and received performance-contingent, emotionally valenced feedback. At the same time, each study had a distinct hypothesis as to what these ERP components would relate to, and how relations between ERP components and/or other constructs would inform aspects of normative or non-normative development. Each study examined a separate and sequentially more encompassing aspect of a theoretical neurobiological model of emerging emotion regulation described in Chapter I.

As described below, each of the three studies contributed unique evidence as to how the smallest components of executive function, cognitive micro-processes, explain the development of emotion regulation and corresponding behavioral regulation.

Error and Feedback Processing in Preschool Children

Study 1 in Chapter II examined and compared ERP components associated with two different types of negative emotion-inducing events: committing an error and receiving negative feedback. Eighteen typically developing preschool age children completed the aforementioned

adapted go no-go task. First, Study 1 findings demonstrated the feasibility of the adapted go no-go paradigm to extract clear ERN, Pe, and FRN components in preschool age children. This is consistent with other studies demonstrating that these three components are present and measurable in preschool age children (Grammer et al., 2014; Mai et al, 2011). However, these studies measured either ERN and Pe or FRN, but not all together. Thus Study 1 demonstrates the unique ability of an adapted go no-go task to measure ERN, Pe, and FRN simultaneously within the same sample of children.

Furthermore, typical preschool children examined in Study 1 showed FRN amplitudes that were significantly larger for negative feedback trials than positive feedback trials. This is in contrast to literature showing that the FRN in children, unlike adults, is not more sensitive to negative feedback (Mai et al., 2011; Hammerer, Li, Muller, & Lindenberger, 2011).

Finally, Study 1 findings revealed interesting associations between ERN, Pe, and FRN. Specifically, I found evidence that, at certain midline sites, amplitudes of ERN and Pe were positively correlated. Preschool children who had larger ERN amplitudes at site Cz tended to also have larger Pe amplitudes at site FCz. This finding is novel in that, to my knowledge, no previous study has examined the association between ERN and Pe in children this young.

In addition, amplitudes of Pe and FRN linked to negative feedback were negatively correlated with each other at site Pz. Preschool children who had smaller Pe amplitudes following errors at Pz tended to have larger FRN amplitudes for negative outcomes linked to the error. As stated previously, this is the first study to examine and compare ERN, Pe, and FRN together in preschool children. Thus, the negative association between Pe and FRN represents a novel finding.

Neural Mechanisms of Emotion Dysregulation in Preschool Children with Disruptive Behavior Disorders

Study 2 in Chapter III compared ERN, Pe, FRN, and Inhibitory-N2 amplitudes in preschool children clinically referred for externalizing behavior problems and typical peers. Findings indicated significant differences in the characteristics of these waveforms across the two groups. Consistent with other studies (Grammer et al., 2014), in the typical preschool children Pe amplitudes following ERN trials were significantly larger than amplitudes for corresponding CRN trials at site Pz. For clinically referred preschoolers, however, Pe amplitudes following ERN trials were not larger than amplitudes following CRN trials at any site. Furthermore, between groups, children with the highest levels of externalizing behavior problems had significantly smaller Pe amplitudes than typical peers at Fz. These findings are consistent with a smaller number of studies showing that older children with ADHD have smaller Pe amplitudes (Wiersema, Van der Meere, & Roeyers, 2005). However, the finding that Pe amplitudes differed between groups is novel in that I examined children younger than five years old, and children referred for disruptive behaviors like aggression and anger rather than problems with hyperactivity and attention specifically. Moreover, I found no group differences in ERN amplitudes. This is in contrast to studies showing that older children with externalizing behavior problems have smaller ERN amplitudes (Stieben et al., 2007).

Interestingly, FRN waveforms were nearly identical in clinically referred and typical preschool children. Like typical peers, preschoolers with externalizing behavior problems showed larger FRN amplitudes following negative outcomes than following positive outcomes. In addition, FRN amplitudes for both negative and positive outcomes were the same between

groups. To my knowledge, this finding is novel in that Study 2 was the first to explore the characteristics of the FRN in preschool children with externalizing behavior problems.

Finally, in Study 2 I measured and compared the Inhibitory-N2 waveform in typical and clinically referred preschoolers. Both groups showed Inhibitory-N2 waveforms characterized by smaller amplitudes for correct no-go trials than correct go trials. This is in contrast to findings in adults typically showing larger N2 amplitudes for correct no-go trials (Kiefer, Marzinzik, Weisbrod, Scherg, & Spitzer, 1998), as well as some published reports on slightly older children with ADHD (Spronk, Jonkman, Kemner, 2008). However, other evidence suggests that smaller amplitudes for Inhibitory-N2 no-go trials, compared to corresponding go trials, might be typical in preschool children (e.g. Zelazo, 2006; Grammer, personal communication). Moreover, clinically referred preschool children showed significantly smaller Inhibitory-N2 amplitudes than typical peers at site Cz. This is consistent with the aforementioned study by Stieben and colleagues (2007) showing that older children with externalizing behavior problems had smaller Inhibitory-N2 amplitudes compared to peers.

Links between Cognitive Micro-Processes, Emotion Reactivity, and Emotion Regulation in Early Childhood Externalizing Behavior Problems

Study 3 in Chapter IV tested the unique contribution of ERN, Pe, FRN, and Inhibitory-N2 waveforms to parent-rated emotion reactivity and regulation. In addition, Study 3 tested the unique contribution of emotion reactivity and regulation to externalizing behavior problems. Typical and clinically referred preschool children examined separately in Study 2 were combined in order to examine externalizing behavior problems as a continuous outcome measure.

Specific items from the CBQ anger/frustration, positive anticipation, and inhibitory control subscales were used to create separate emotion reactivity and emotion regulation

composites. These scales showed good reliability and were moderately correlated with each other. Furthermore, emotion reactivity and recovery scales uniquely contributed to early onset externalizing behaviors. Higher parent-rated emotion regulation and lower rated emotion reactivity predicted more severe externalizing behavior problems. These findings build on previous scholarly work theorizing that emotion reactivity and emotion regulation are distinct but related facets of the construct Emotion Regulation (e.g. Eisenberg & Spinrad, 2004).

Links between ERP waveforms, emotion reactivity, and emotion regulation were tested using a comprehensive path model. Results showed a significant negative relation between Inhibitory-N2 amplitudes and parent-rated emotion regulation. This relation was such that children with larger Inhibitory-N2 amplitudes had better parent-rated emotion regulation. Previous research has shown that the amplitude of Inhibitory-N2 is influenced by more emotionally challenging conditions in children (Lewis et al., 2006). Study 3 expands the Lewis et al. findings by showing that Inhibitory-N2 amplitudes predicted how parents rated their child's response to hypothetical "every day" emotion challenges.

In addition, Pe amplitudes were significantly negatively related to parent-rated emotion reactivity, such that children with smaller Pe amplitudes had poorer emotion reactivity. A recent study on adults showed that larger Pe amplitudes were associated with rating errors as being more emotionally salient (Wessel, Danielmeier, & Ullsperger, 2011). Results from Study 3 therefore build on these finding by showing a link between Pe amplitudes and how parents rated their child's reactivity to anger- or excitement-inducing events. Opposite to Wessel and colleagues' findings, smaller Pe amplitudes were associated with higher rating of emotion reactivity.

Finally, ERN amplitudes did not significantly relate to emotion reactivity, emotion regulation, or externalizing behavior problems in the path model. As stated previously, studies on older children found that pre-teens with externalizing behavior problems showed smaller ERN amplitudes than typical peers (Stieben et al., 2007). This non-finding also contrasts with other studies showing that children with anxiety disorders show larger ERN amplitudes than peers (Hajcak, Franklin, Foa, & Simons, 2008). To my knowledge, this is the first study to examine if ERN amplitudes predicted parent-rated emotion reactivity and regulation in preschool children.

To explore whether level of externalizing behavior problems moderated the relation between ERP components, parent-rated emotion reactivity and regulation, and externalizing behavior, bivariate correlations were run separately by group. Due to small sample sizes in the subgroups these correlations were considered exploratory. In typical preschool children only, ERN amplitudes were negatively correlated with externalizing behavior, such that typical children with smaller ERN amplitudes had lower externalizing behavior problems than typical peers. In clinically referred preschool children only, Pe amplitudes were positively correlated with emotion regulation, such that clinically-referred children with larger Pe amplitudes had higher parent ratings of emotion regulation.

In addition, FRN amplitudes linked to negative outcomes were significantly negatively correlated with emotion regulation. Clinically referred children with smaller FRN amplitudes following negative outcomes had poorer parent-rated emotion regulation than clinically referred children with larger FRN amplitudes.

To date, a small number of studies have looked at whether children with and without externalizing behavior problems differ in the amplitude of certain ERP components (e.g. Stieben et al., 2007). To my knowledge, Study 3 is the first to show whether the *relation* between ERP

components and other measures of well-being, such as emotion regulation, differ in clinically referred versus typical preschool children.

To summarize, I used a novel paradigm to simultaneously measure ERN, Pe, FRN, and Inhibitory-N2 amplitudes and test links to parent-rated emotion reactivity, emotion regulation, and early onset externalizing behavior problems. Across studies, some findings complemented and expanded the known literature on how these constructs relate to each other. Other findings did not replicate or contradicted what other studies have found. Finally, some analyses examined novel, never before tested links between executive function components, responses to emotional challenges, and externalizing behavior problem. Below, I interpret these findings and consider implications for how management of emotional challenges develops in early childhood, and implications for the etiology of externalizing behavior problems.

Implications for the Development of Emotion Reactivity and Regulation

Children have distinct electrophysiological signals sensitive to negative affect

I expected that simultaneously measuring and comparing multiple ERP components related to the onset of negative affective events would elucidate their relative development in early childhood. For example, evidence from other studies examining ERN and FRN separately in preschool children (Grammer et al., 2014; Mai et al., 2011) suggests that children in this age range show an ERN sensitive to errors, but not an FRN sensitive to negative outcomes. In Study1, however, when outcomes were linked to how the child performed on the preceding no-go trial, preschool children showed larger FRN amplitudes for negative outcomes.

Therefore, we must consider that how the preschool brain processes negative feedback is more complex than indicated in previously published findings. Unlike adults, the sensitivity of the FRN in early childhood to negative outcomes may be more dependent on the context in

which the negative feedback occurs. Specifically, unlike a gambling task, children across the three studies received feedback infrequently, and they could theoretically anticipate which type of feedback they would receive based on their performance on no-go trials. This is consistent with other studies showing that amplitude of the FRN is influenced by the frequency of feedback and the degree to which the participant can predict the valence of the feedback (Folstein & Van Petten, 2008; Hajcak, Moser, Holroyd, & Simons, 2007). Moreover, in gambling-like tasks such as the task used in the Mai et al. study, the 500ms prior to feedback are essentially identical across trials. In my adapted go no-go task, however, errors always preceded negative feedback while correct responses always preceded positive feedback. Thus, prior negative events may play a role in "priming" the sensitivity of the FRN to negative feedback. Indeed, in Study 1, I found that the Pe, a component occurring after the ERN and before the FRN on incorrect trials, predicted individual differences in FRN amplitudes following negative feedback. Future research is needed to further explore the role of error reflection in preschool children's sensitivity to subsequent negative feedback.

Cognitive micro-processes relate to the normative development of emotion regulation

I expected that data on multiple ERP components related to processing negative events, specifically, making errors and receiving negative feedback, would provide insight into the normative development of emotion regulation. As described below, specific cognitive micro-processes may play a role in early emotion regulation at both small time scales and in broad contexts.

The three studies presented in this dissertation were guided by a theoretical framework

postulating that EF skills are mobilized during ER. Across studies, I found evidence that EF cognitive micro-processes are associated with the onset and management of negative affective events. First, in Study 1, I looked at time-locked EEG activity immediately before and after negative events, such as errors and negative feedback. Consistent with other studies (e.g. Grammer et al., 2014, Mai et al., 2011), I saw clear electrophysiological waveforms before and after the onset of these events. These waveforms, such as the ERN and FRN, are generated by the prefrontal cortex and anterior cingulate cortex; circuitry that also underpin EF skills in affectively neutral contexts (e.g. Casey et al., 2011). Therefore, results from Study 1 replicate and extend previous ERP studies showing that important regulatory circuitry activates the instant negative affective events occur.

Furthermore, in Study 3 I found individual differences in how these ERP waveforms predicted parent-rated emotion reactivity and regulation. First, these analyses were novel in that the level of measurement was very different between constructs. For example, previous studies have looked at EF via behavioral performance or parent ratings and examined associations with corresponding behavioral performance or parent ratings of ER (e.g. Carlson & Wang, 2007). In other words, these studies often use the same measurement method, or same time scale, to examine both constructs. In Study 3, by comparison, I compared EF and ER at highly contrasting levels of analysis. Specifically, across studies, I used Event Related Potential technique to examine EF cognitive micro-processes. Thus, EF was operationalized as a biological marker reflecting basic and discrete subcomponents in a very small window of time. Individual differences in these ERP components related to parent ratings of emotion reactivity and emotion regulation using CBQ items. Specifically, in Study 3 I measured parent's perceptions of their child's responses to emotional challenges referenced from repeated daily

observations. Moreover, the hypothetical emotional challenges described in CBQ items might involve multiple complex mental processes evolving over an extended period of time. Yet despite these strong methodological differences, I found evidence that individual differences in preschooler's ERP waveforms, reflecting cognitive micro-processes of EF, predicted how parents evaluated their child's responses to emotional challenges. As such, this finding underscores the importance of considering cognitive micro-processes in theoretical models of emotion regulation. Cognitive micro-processes mobilized at the onset of emotional challenges may play an important role in how preschool children subsequently regulate their behavior in a wide range of contexts. However, as described below, I found evidence that certain ERP components related to emotion reactivity or regulation while other components did not.

In Study 3, when clinically referred and typical preschool children were combined, individual differences in Inhibitory-N2 amplitudes related to emotion regulation. This builds on other studies showing a link between response inhibition skills and superior emotion regulation (Carlson & Wang, 2007). However, this finding is also unique in that it suggests that PFC activity within 400ms of a cue to inhibit may be crucial in explaining how children regulate anger and frustration in other contexts.

In addition, individual difference in Pe related to parent-rated emotion reactivity, such that smaller Pe amplitudes predicted more severe parent-rated emotion reactivity. In contrast, ERN and FRN amplitudes were unrelated to parent-rated emotion reactivity in the total sample. This pattern of findings is particularly interesting given that CBQ emotion reactivity items such as "gets frustrated when makes a mistake" describe emotional challenges implying multiple underlying processes: awareness of the onset of the negative event, gauging whether the outcome of the event was positive or negative, and gauging the emotional salience of the event. All these

processes could theoretically be "mobilized" and manifested as subsequent emotion reactivity. Thus, results from Study 3 suggest that reflecting on how bad the event was, rather than awareness that it occurred or that it was bad and not good, plays a crucial role subsequent emotion and behavior dysregulation. Moreover, the direction of the relation between Pe and parent-rated emotion reactivity was such that children who had greater electrophysiological activity during the Pe window had more modulated emotion reactivity. Larger Pe amplitudes may reflect greater exertion of cognitive resources to reflect on the meaning of the error. In turn, greater processing and reflecting of errors may minimize subsequent dysregulated emotion and behavior in preschool children. This complements research on adult populations showing that superior ability to reflect and reappraise negative events predicted better emotion regulation skills (Ochsner & Gross, 2008). Clearly, however, more research is needed to better understand the relation between Pe and emotion reactivity.

Implications for defining the construct "Emotion Regulation"

As discussed in previous chapters, Emotion Regulation is an important developmental construct that requires a sharper definition (Eisenberg & Spinrad, 2004). Specifically, the degree to which Emotion Regulation overlaps with the construct Executive Function, and whether it comprises categorically different responses to emotional challenges has been the subject of debate (e.g. Cole, Martin, & Dennis). For example, it has been suggested that emotion is always regulated (Campos et al., 2004) and may be a type of EF as opposed to a truly distinct construct (Zelazo, 2007). Consistent with this orientation, results across the three studies presented in this dissertation showed that, when negative affective events occur, regulatory circuitry is involved. For example, the emotion reactivity scale was designed to separate "activated emotion" from subsequent regulation as much as possible. Findings showed that individual differences in

emotion reactivity were associated with Pe waveforms reflecting subsequent error processing. This suggests that even behaviors that appear to be expressions of negative emotion without regulation are nonetheless associated with electrophysiological waveforms rooted in regulatory circuitry.

To summarize, findings from Study 1 and 3 do not support viewing the construct Emotion Regulation as a homogenous skill that is separate from other types of self-regulation. Rather, future researchers should consider emotion regulation and executive function as an integrated mechanism, interacting at the lowest-order components, and important for different aspects of responding to emotional challenges. Moreover, this theoretical model allows us to consider the development of typical and maladaptive behavioral regulation as different outcomes of the same underlying mechanism. Below, I explore how findings across the three studies elucidate our understanding of earl onset externalizing behavior problems.

Implications for the Development of Externalizing Behavior Problems

The relation of cognitive micro-processes, and their neural correlates, to early onset externalizing behavior problems

Deficient self-regulation, which includes deficits in executive function and emotion regulation, are core etiological factors in externalizing behavior problems (Martel, Gremillion, Roberts, von Eye, & Nigg, 2010). To date, studies examining deficits in executive function or emotion regulation tend to examine these constructs at higher order composite levels (e.g. Séguin, & Zelazo, 2005). An objective of this dissertation was to examine how the neural precursors of EF skills predict emotion and behavior dysregulation in preschool children. To my knowledge, no published study has examined the neural correlates of self-regulation deficits in preschool children with externalizing behavior problems.

Findings from Study 2 revealed that, even at an early age, children with externalizing behavior problems have brains with different electrophysiological responses to cognitive and emotional challenges. An advantage of the adapted go no-go task was the ability to measure multiple ERP components. Thus, I was able to pinpoint which neural processes might be most deficient early externalizing behavior problems. In Study 2, results showed that Inhibitory-N2 and Pe amplitudes for children with high levels of externalizing behavior problems were smaller than typical peers. In contrast, clinically referred preschool children showed the same ERN and FRN amplitudes as non-disordered peers.

These findings build on our understanding of self-regulation deficits in children with Disruptive Behavior Disorders in several important ways. Previously, researchers have shown that children with externalizing behavior problems have difficulty inhibiting responses, for example, such as when instructed not to play with a toy (Trentacosta & Shaw, 2009). Findings in Study 2 demonstrated that we see this deficit as electrophysiological activity generated by the ACC within 400ms of a cue to inhibit.

In addition, previous research has shown that preschool children are more likely to show emotion dysregulation, such as temper tantrums, when they make a mistake (Calkins, 2002). In Study 2, I was able to examine initial error awareness and subsequent error processing as separate but related neural processes. Results from Study 2 suggest that the relation between making errors and externalizing behavior isn't due impairment in registering the initial occurrence of the error (ERN). Rather, subsequent processing of the salience of errors may be deficient in children with early onset externalizing behavior problems. That Inhibitory-N2 and Pe related to disruptive behavior, but ERN and FRN did not, suggests that self-regulation problems may begin during a critical 200-400ms window after a cue to inhibit a response, or after an error

commission. Preschool children with externalizing behavior problems first show deficient electrophysiological activity 200-400ms after the onset of an event associated with an emotional challenge. As described below, the direction of these findings also have important implications for understanding the etiology of Disruptive Behavior Disorders.

Electrophysiological "under-activity" signals risk for early externalizing behavior problems

Based on a limited number of studies on older children with disruptive behaviors or ADHD (e.g. Stieben et al., 2007), I expected that preschool children with externalizing behavior problems would show smaller amplitudes of specific ERP components. In Study 2, preschool children clinically referred for externalizing behavior problems showed smaller Inhibitory-N2 and Pe amplitudes than peers. Moreover, in Study 3, smaller amplitudes of Inhibitory-N2 and Pe were associated with poorer parent-rated emotion regulation and more severe emotion reactivity. These findings suggest that, although disruptive behaviors are often characterized by more intense anger and dysregulated behavior in response to negative events (American Psychiatric Association, 2013), these behaviors may not be due to neural networks "over reacting" to errors and negative feedback. This is in contrast to research on anxiety disorders showing that anxious children generate larger ERNs when errors are made (Ladouceur, Dahl, Birmaher, Axelson, & Ryan, 2006). Thus, findings across Studies 2 and 3 underscore the "regulatory" role of components like Inhibitory-N2 and Pe. Preschool children with Disruptive Behavior Disorders appear to have weaker functioning of critical cognitive micro-processes that may help typical children regulate emotion and behavior.

Relation of EF to ER in early externalizing behavior problems

The aim of Study 2 was to look at which components discriminated clinically referred from typical preschool children. Study 3 builds on these findings by examining whether these components explained variation of emotion reactivity and regulation within clinically referred preschool children.

Although I found that Inhibitory- N2 amplitudes were smaller in clinically referred preschool children, individual differences in the amplitude of this component did not explain clinically referred preschoolers' emotion reactivity and regulation. In contrast, Pe amplitudes were not only smaller in clinically referred preschool children than controls, they explained individual differences in clinically referred preschoolers' emotion regulation. Specifically, clinically referred preschoolers with the smallest Pe amplitudes had the poorest parent-rated emotion regulation.

Furthermore, whereas FRN amplitudes were similar between clinically referred and preschool children, and did not explain variation in parent-rated emotion reactivity for the total sample, FRN amplitudes associated with negative outcomes related to individual differences in clinically referred preschool children's emotion regulation. Specifically, clinically referred preschool children with the smallest FRN amplitudes associated with negative feedback had the worst parent-rated emotion regulation skills.

Although exploratory, this collection of findings suggests that the links between these two self-regulation skills may be dependent on the child's level of risk. Level of externalizing behavior problems during the preschool years may moderate the relation between specific ERP components and ecologically broader ratings of emotion reactivity and emotion regulation.

To summarize, evidence from this dissertation suggests that an inability to mobilize specific cognitive micro-processes, such as preventing errors from occurring or gauging the

salience of negative events, may underpin emotion regulation and externalizing behavior problems. Therefore, it may be possible to treat early externalizing behavior problems by directly targeting and repairing these important neural processes. Below, I describe the current state of evidence-based psychotherapy for early onset externalizing behavior problems. Next, I review new research testing the efficacy of executive function training in children and adults. Finally, I consider how findings from the studies presented in this dissertation might inform new treatments for early externalizing behavior problems.

Implications for Intervention and Prevention

Early onset externalizing behavior problems are a major risk factor for long-term impairment impacting children, their families, their communities, and ultimately the societal institutions they interact with. Finding more effective ways to prevent and treat persistent externalizing behavior problems as early as possible is imperative.

To date, evidence based interventions targeting preschool children with disruptive behavior problems primarily consist of Parent Management Training (PMT) therapies (Barkley, 1987, Kazdin & Rotella, 2008, Eyberg, Boggs, & Algina, 1995). Evidence-based PMT programs are largely rooted in operant conditioning principles to facilitate behavioral changes, specifically through the use of positive and negative reinforcement. Children are not taught these skills directly in therapy. Rather, these principles are applied as parenting strategies taught to caregivers to reduce the child's problem behaviors and increase prosocial behaviors (Kazdin & Rotella, 2008). PMT is typically structured into sequential modules including skill building in child-directed play, using praise, giving effective commands, setting up a token economy to target specific behaviors, and discipline strategies such as "time outs". Thus, PMT exerts

behavioral change externally via changes parenting behavior as opposed to targeting self-regulation directly in the child.

Treatments for childhood disruptive behavior problems designed to directly target self-regulation through skill building, such as Lochman's "Coping Power" manualized treatment (Lochman, Powell, Boxmeyer, & Jimenez-Camargo, 2011), are designed for school age children and adolescents. These programs train children to deal with negative affective challenges using a CBT framework to target controlling aggression. Thus, CBT programs such as "Coping Power" don't directly target the small-scale EF skills that may underpin emotion regulation, and moreover, may not be developmentally appropriate for preschool age children.

Recently, however, researchers have explored whether basic cognitive processes can be improved with training. This idea has gained more traction recently, particularly in adult populations focusing on more affectively neutral EF skills such as working memory (Jonides, Jaeggi, Buschkuehl, & Shah, 2012; Morrison & Chen, 2010).

Bodrova and Leong (2007) developed an executive functioning training program for preschool children called "Tools of the Mind". To my knowledge, this is the only published EF training program designed for preschool age children. The Tools of the Mind program trains self-regulation and executive function skills to improve school readiness and academic achievement in at-risk preschool children. The Tools of the Mind curriculum is integrated into the preschool classroom as a series of activities targeting a range of higher-order EF skills such as planning and attention shifting through repeated practice. To date, studies have shown that the Tools of the Mind program improved general executive function performance, academic skill building, and behavior problems in preschool children (Diamond, Barnett, Thomas, & Munro, 2007; Barnett et al., 2008).

Although Tools of the Mind demonstrated that EF skills can be improved in children as young as preschoolers, it was structured to be a more intensive program imbedded within the preschool classroom and involving significant time and resources (Bodrova & Leong, 2007). Therefore, it is important to consider other modalities that could deliver EF skill training. Recently studies have tested if a video game format can be used to practice and improve EF skills. For example, Jaeggi, Buschkuehl, Jonides, and Shah (2011) recently demonstrated the efficacy of a video game targeting working memory in older children. However, across studies, results have been mixed, with many studies showing that gains made in the training program do not generalize to novel EF tasks (Diamond & Lee, 2011).

Findings across the three studies presented in this dissertation demonstrated the efficacy of a computer program to engage multiple cognitive micro-processes important for self-regulation. Specifically, across the three studies I found that the discrete cognitive micro-processes preschool children mobilize during the zoo task could be measured as electrophysiological signals generated by the brain. In addition, I showed that the neural correlates of these cognitive micro-processes related to children's emotion reactivity and regulation, and externalizing behavior problems. Therefore, future studies may be able to test if specific cognitive micro-processes, notably Inhibitory-N2 and Pe, can be strengthened or repaired via repeated practice using a video game format.

In sum, the future of evidence based treatments for early onset externalizing behavior problems may involve targeting self-regulation deficits directly. However, these interventions are still taking form, have not been integrated into mainstream practice, and their overall efficacy is unclear. Evidence from the studies presented in this dissertation suggests that interventions

targeting specific self-regulation deficits may be feasible to design and test in preschoolers with Disruptive Behavior Disorders.

Limitations

The three studies presented in this dissertation had practical and theoretical caveats and limitations. Two notable limitations described below include studying smaller sample sizes and an inability to test causality directly.

Sample sizes across studies were within the typical range for an Event Related Potential Study (e.g. Bowman, 2012). This is particularly true given that preschool children, and children with disruptive behavior disorders, are especially challenging populations to study (Perlman, 2012). As stated previously, to my knowledge, the current dissertation presents the first known ERP data on preschool age children with Disruptive Behavior Disorders.

Thus, the three studies presented in this dissertation have methodological implications for future ERP research in early childhood, particularly studies focusing on early onset disruptive behavior disorders. Interestingly, although the paradigm used in the three studies asked children to tolerate multiple stressful events (e.g. being in a new environment, wearing the EEG net, sitting still, and completing a computer game that elicited negative emotion) the proportion of children who refused to wear the EEG cap or play the go no-go task was similar across groups. Although I did not find strong differences between children who completed the task from those who did not, qualitatively, children who did not provide ERP data seemed to be more bothered by the feel of the EEG net. In addition, a substantial proportion of children asked to discontinue the go no-go task early on because the angry face used as negative feedback upset them. Future studies may have more success acquiring ERP data from preschoolers with and without psychopathology by helping participants become more acclimated to and less anxious about the

ERP equipment. Furthermore, future studies examining the neural correlates of early emotion regulation should consider designing computer tasks that elicit negative affect without overwhelming preschool age participants.

Nonetheless, smaller sample sizes and a relative lack of power may have affected my results. Specifically, replication of the current study with more subjects may have revealed additional significant differences between clinically referred and typical preschool children in Study 2. In addition, relatively smaller sample sizes prevented me from testing a more powerful path model in Study 3, such as testing additional theoretical pathways and comparing model parameters across groups.

Second, the theoretical framework guiding the three studies presented in this chapter, as described in Chapter I, postulated that executive function skills are mobilized when children respond to an emotional challenge. This implies a causal direction: the child's emotion reactivity and regulation are the result of using executive function skills, not the other way around, or due to a third factor. In the present study, however, similar to other studies looking at links between EF and ER, I could not test this causality directly.

For example, in the adapted go no-go task used in each of the three studies, commission of errors and receiving negative feedback were designed to elicit negative emotion. Unknown, however, are how these events corresponded to the child's true emotional state at that instance. Whether experimental conditions actually elicit the emotions they are designed to study is a long-standing and unresolved problem in the field of psychology (Lazarus, 1991; James, 1884/2007). Specifically, the stimuli used as positive and negative feedback in the adapted go no-go task were simpler and more abstract compared to more nuanced, reciprocal and complex feedback preschool children receive from caregivers and peers. Thus more research is needed to

determine how well ERPs associated with task-related emotional events generalize to the emotional events children experience in everyday life. Furthermore, electrophysiological waveforms time-locked to the onset of these events were hypothesized to reflect cognitive micro-processes. Yet, as noted by others, ERP waveforms may reflect several possible underlying processes (Luck, 2005). Therefore, even though the ERP paradigm was designed to examine the timing of discrete cognitive micro-processes and the onset of negative affective events, more research is needed to unpack causal links between these two constructs.

Similarly, the path model in Study 3 was used to examine the relation of ERP components to parent-rated emotion reactivity and regulation, and the relation of these latter two measures to early externalizing behaviors. As such, I tested one specific set of theoretical pathways between these variables. However, hierarchically structured executive function and emotion regulation likely interact in a highly complex, reciprocal, and dynamic fashion (Zelazo, 2007). It is important, therefore, for future researchers to test models of emerging emotion regulation and behavior problems that test other theoretical pathways.

Conclusion

The studies presented in this dissertation connected cognitive micro-processes to emotion reactivity, regulation, and externalizing behavior problems in a novel way using ERP technique. A strength across the three studies was the use of an ERP paradigm capable of measuring multiple waveforms related to prevention, awareness, and processing of negative emotion events. These three studies demonstrated that electrophysiological signals associated with these micro-processes may play an important role in the development of either normative, competent emotion regulation, or maladaptive emotion regulation underlying early Disruptive Behavior Disorders. These findings set the state for future research and further exploration of the inner working of

self-regulation in the development of psychopathology. Advances in this area may lead to more effective intervention strategies to help at-risk children.

Appendix

Table A.1. *CBQ Anger/Frustration items used for emotion reactivity scale (highlighted in bold).*

CBQ item number	Description
14	**Gets angry when told s/he has to go to bed**
15	Rarely gets irritated when s/he makes a mistake
16	**Has temper tantrums when s/he doesn't get what s/he wants**
17	**Gets quite frustrated when prevented from doing something s/he wants to do**
18	**Gets mad when even mildly criticized**
19	**Gets angry when s/he can't find something s/he wants to play with**
20	Rarely gets upset when told s/he has to go to bed
21	**Becomes easily frustrated when tired**
22	**Gets irritable about having to eat food s/he doesn't like**
23	Rarely protests when another child takes his/her toy away
24	**Easily gets irritated when s/he has trouble with some task**
25	**Gets angry when called in from play before s/he is ready to quit**
26	**Gets mad when provoked by other children**

Table A.2. *CBQ Positive Anticipation items used for emotion reactivity scale (highlighted in bold).*

CBQ item number	Description
27	**Gets so worked up before an exciting event that s/he has trouble sitting still**
28	**When s/he sees a toy s/he wants, gets very excited about getting it**
29	**When s/he wants to do something, s/he talks about little else**
30	**Has strong desires for certain kinds of food**
31	**Looks forward strongly to the visit of loved relatives**
32	**Becomes very excited while planning for trips**
33	**Becomes very excited before an outing**
34	Is usually pretty calm before leaving on an outing
35	**Gets very enthusiastic about the things s/he does**
36	**Shows great excitement when opening a present**
37	Doesn't become very excited about upcoming television programs
38	Remains pretty calm about upcoming desserts like ice cream
39	Looks forward to family outings, but does not get too excited about them

Table A.3. *CBQ Inhibitory Control items used for emotion regulation scale (highlighted in bold).*

CBQ item number	Description
93	**Can lower his/her voice when asked to do so**
94	Is good at games like "Simon Says" etc.
95	Has a hard time following instructions
96	Prepares for trips and outings by planning things s/he will need
97	Can wait before entering into new activities if s/he is asked to
98	Has difficulty waiting in line for something
99	Has trouble sitting still when s/he is told to
100	**Is able to resist laughing or smiling when it isn't appropriate**
101	Is good at following instructions
102	Approaches places s/he has been told are dangerous slowly and cautiously
103	Is not very careful and cautious in crossing streets
104	**Can easily stop an activity when s/he is told "no"**
105	**Is usually able to resist temptation when told s/he is not supposed to do something**

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