The Pennsylvania State University

The Graduate School

ASSOCIATIONS AMONG NEURAL SENSITIVITY TO NEGATIVE FEEDBACK, CAREGIVER PUNISHMENT, AND CHILDHOOD EXTERNALIZING BEHAVIOR

A Thesis in

Human Development and Family Studies

by

Sarah Terrell

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

August 2023

The thesis of Sarah Terrell was reviewed and approved by the following:

Lisa M. Gatzke-Kopp
Professor of Human Development and Family Studies
Director, Dual-title program in Social and Behavioral Neuroscience
Thesis Advisor

Sunhye (Sunny) Bai
Assistant Professor of Human Development and Family Studies

Douglas M. Teti
Professor of Human Development and Family Studies, Psychology, and Pediatrics
Head of the Department of Human Development and Family Studies

ABSTRACT

Research with antisocial adolescents and adults has found that the ability to form associations between inappropriate behavior and negative consequences is compromised, in part, due to low neural sensitivity to punishment cues. However, little is known about the relation between punishment sensitivity and behavior problems in childhood. It is also unknown whether neural responses to acute feedback in a laboratory setting corresponds with children's sensitivity to real-world feedback about their behavior, such as punishment from caregivers. In the present study I addressed these gaps by examining neural sensitivity to negative feedback in a sample of kindergarten children (n = 207) with elevated levels of externalizing behavior problems. To appropriately capture the rapid time course of feedback processing I examined an event-related potential, the feedback-related negativity (FRN), as a marker of sensitivity to punishment cues. Caregivers self-reported on how frequently they used several punishment strategies and children's externalizing behavior symptoms. I found that children with smaller FRN deflections to negative feedback had more externalizing behavior problems, which suggests that these children may experience difficulties learning from negative feedback about the appropriateness of their behaviors. I also found that FRN amplitude was not significantly correlated with caregiver punishment, nor did it moderate associations between caregiver punishment and children's externalizing behavior problems. More research is necessary to evaluate the ecological validity of the FRN, and to determine if neural sensitivity to negative feedback influences children's responses to parental discipline across development.

TABLE OF CONTENTS

LIST OF FIGURES vii

LIST OF TABLES viii

Chapter 1 Introduction 1

Externalizing Behavior and Sensitivity to Negative Feedback 2
The Feedback-Related Negativity (FRN) and Reinforcement Learning Theory 5
The FRN and Externalizing Behavior 8
The Ecological Validity of the FRN: Caregiver Punishment as an Example 12
The Present Study 14

Chapter 2 Method 16

Participants 16
Externalizing Behavior 17
Punishment 18
Psychophysiological Assessment 21
Protocol 21
Go/No-Go Task 21
EEG Recording and Data Processing 24
Statistical Analysis 27

Chapter 3 Results 29

Punishment Profiles 29
Low Threat, Low Physical Punishment 32
High Threat, Occasional Spanking 32
High Threat, High Physical Punishment 32
Multiple Linear Regression Models 33
Association Between Child FRN Amplitude and Externalizing Behavior 35
Association Between Caregiver Punishment and Child FRN Amplitude 35
Interaction Between Punishment and FRN Amplitude to Predict Externalizing Behavior 37

Chapter 4 Discussion 39

FRN Amplitude and Externalizing Behavior 39
Associations Among Caregiver Punishment, FRN Amplitude, and Externalizing Behavior 41
Latent Profiles of Caregiver Punishment 41
Caregiver Punishment and FRN Amplitude 42
FRN Amplitude as a Moderator of Associations Between Caregiver Punishment and Externalizing Behavior 44
Limitations and Future Research 45

Conclusions 46

REFERENCES 48

LIST OF FIGURES

Figure **1**: Go/no-go task trial structure. 22

Figure **2**: Grand average FRN waveform and scalp topography. 26

Figure **3**: Three subgroups of caregiver punishment. 31

Figure **4**: FRN amplitude associations with externalizing behavior and caregiver punishment. 36

Figure **5**: Association between FRN amplitude and externalizing behavior, grouped by caregiver punishment subgroups. 38

LIST OF TABLES

Table **1**: Descriptive statistics and bivariate associations for study variables. 19

Table **2**: Fit indices from latent profile analysis of caregiver punishment..............................30

Table **3**: Multiple regression analysis results. 34

Chapter 1

Introduction

A primary goal of childhood is the development of regulatory control over aggressive and oppositional impulses, particularly as children transition into school. In order to accomplish this, young children rely heavily on external sources of feedback about the appropriateness of their behavior (Denham et al., 2000; Tan et al., 2020). External feedback may come from family members, teachers, or even peers as children learn socially acceptable ways to express negative emotions such as anger or frustration. Yet there is substantial variation in how sensitive individuals are to feedback about their behavior, and difficulties learning from external feedback may contribute to problems with self-regulation and externalizing behavior disorders (Dadds & Salmon, 2003; Portengen et al., 2021; Sagvolden et al., 2005). The feedback-related negativity (FRN) is an event-related potential that is reflective of individual differences in sensitivity to external feedback about behavioral performance (San Martín, 2012; Nieuwenhuis et al., 2004). Several studies in adolescents and adults have observed associations between relatively lower FRN amplitudes and higher symptoms of externalizing behavior problems (e.g., Carter Leno et al., 2016; Sheffield et al., 2015). However, it is unclear whether this association would be observed in younger children, and whether lower amplitude in response to discrete feedback in a laboratory setting is associated with children's sensitivity to real-world feedback about their behavior. If FRN amplitude is significantly correlated with common sources of negative external feedback that young children typically receive, such as punishment from caregivers, this would demonstrate that the FRN has strong ecological validity. Further, studies have yet to consider whether well-replicated associations between caregiver punishment and children's externalizing behavior problems differ based on a child's FRN amplitude. It is possible that children who are more sensitive to negative feedback may have lower levels of externalizing behavior when receiving higher amounts of discipline. In contrast, higher amounts of discipline may exacerbate behavior problems in children who are less sensitive to negative feedback, especially if punishment is harsh or coercive. Addressing this gap could inform for whom the effects of caregiver punishment are more or less effective or harmful.

Externalizing Behavior and Sensitivity to Negative Feedback

Caregivers shape children's behavior through proactive actions, such as providing structure and role modeling, as well as through reactive actions. Reactive responding can include tactics such as reinforcing good behaviors or reframing negative emotions, but also punishing inappropriate behavior (Eisenberg et al., 2001; Hastings et al., 2007; Newland & Crnic, 2011). Sensitive and developmentally appropriate discipline in response to children's misbehavior, such as a brief timeout to calm down or explaining why a behavior was inappropriate, helps children form associations between behavior and consequences and leads to fewer behavior problems in children over time (Choe et al., 2013; Mendez et al., 2016; Pearl et al., 2014; Pinquart, 2017). On the other hand, extensive research has documented strong associations between harsh and punitive caregiving behaviors—such as spanking, hitting with an object, yelling, or other strong expressions of anger—and aggressive and antisocial behavior problems across childhood and adolescence (Choe et al., 2013; Gershoff, 2002; Lee et al., 2013a; Patterson et al., 1989; Pearl et al., 2014; Pinquart, 2017; Shaw & Bell, 1993). These associations stem from transactional processes, as children presenting with challenging behavior may elicit frustration and higher amounts of discipline from their caregivers (see Yan et al., 2021, for a meta-analysis of child-driven effects). In turn, caregivers may exacerbate children's behavior problems with the use of harsh or physical punishments by inadvertently modeling aggression as a means to solve problems, demonstrating that hitting others is acceptable, and instilling negative emotions such as fear or anger in children (Durrant & Ensom, 2012; Hastings et al., 2007; Lansford et al., 2011; Mendez et al., 2016). In support of this, several studies have found evidence for a dose-response relationship between the frequency of physical punishment and the severity of child aggressive and antisocial behavior (Lee et al., 2013b; Ma & Grogan-Kaylor, 2017; MacKenzie et al., 2013), and numerous meta-analyses have shown that parenting-based interventions are effective at treating children's behavior problems when they guide caregivers to reduce use of harsh punishment strategies and increase use of positive parenting strategies (Dretzke et al., 2009; Li et al., 2021; Mingebach et al., 2018; Tarver et al., 2014; Tully & Hunt, 2015). Males may be particularly vulnerable to harsh discipline, as they receive higher amounts of harsh, physical punishment than girls, and this sex difference has been shown to partially explain sex differences in conduct problem levels (Lysenko et al., 2013; Meier et al., 2009). In addition to associations between overly reactive, harsh discipline and children's externalizing behavior, nonexistent or lax discipline may deprive children of necessary opportunities to learn appropriate behavioral regulation strategies, which also contributes to the development of externalizing symptoms (McKee et al., 2008). Overall, the types of punishments caregivers use to provide corrective feedback, as well as the overall amount of corrective feedback provided, are important factors to consider in the socialization of children's behavior.

While a large body of research with children has focused on the role that parenting behaviors play in the development of externalizing behavior problems, it is unknown whether children with behavior problems simply didn't have appropriate corrective feedback, or if they may also be less capable of adapting their behavior in response to feedback. Research with adolescents and adults suggests that there may be a deficit in feedback processing. Three systematic reviews covering late childhood through adulthood have found evidence that individuals with antisocial behavior problems exhibit behavioral and psychophysiological deficits consistent with low sensitivity to punishment (Byrd et al., 2014; Matthys et al., 2013; Murray et al., 2018). Specifically, these reviews find that antisocial individuals have hypoactive physiological arousal in the presence of punishment cues (e.g., low heart rate and skin conductance), have less neural activity during punishment in brain regions involved in associative learning (e.g., striatum, anterior cingulate cortex), and persist in reward-seeking behavior even when punishment is imminent (Byrd et al., Gregory et al., 2015; Huang et al., 2019; Matthys et al., 2013; Murray et al., 2018; Schwenck et al., 2017; Shannon et al., 2009). In contrast, a smaller number of studies have found that a subset of antisocial individuals characterized by heightened emotional reactivity and impulsivity have a *hyper*active physiological response to punishment cues and *more* neural activation during punishment in brain regions responsible for associative learning (Cohn et al., 2015; Corr, 2010; Marshall et al., 2020; Murray et al., 2018). This suggests that some antisocial individuals may have an amplified processing of punishment cues but still fail to select optimal behaviors, possibly due to difficulties regulating emotions in service of goal-directed behavior. Taken together, there may be heterogeneity in the processes underlying the association between sensitivity to negative feedback and behavior problems, such that both diminished and heightened neural responses to punishment cues may contribute to risk for externalizing psychopathology.

More research is necessary to elucidate the development of maladaptive feedback processing and its underlying neural processes in individuals with externalizing behavior problems. First, relatively little is known about the relation between feedback processing and externalizing behavior problems in early and middle childhood, although the few studies that have examined these associations found that deficits in feedback processing may be present early in development. For example, Matthys and colleagues (2004) found that 7- to 12-year-old boys with externalizing disorders had lower skin conductance levels in response to punishment than typically developing boys, and Humphreys and Lee (2011) found that 5- to 10-year-olds with externalizing disorders were less likely than healthy controls to change their behavior after punishment. Additional work with childhood samples is essential to replicate these findings. Second, although feedback processing occurs rapidly in milliseconds (San Martín, 2012), most studies that have examined brain activity during feedback processing and its associations with externalizing behavior have employed fMRI techniques (e.g., Gregory et al., 2015; Huang et al., 2019; Murray et al., 2018; Schwenck et al., 2017; Shannon et al., 2009), which has excellent spatial precision but poor temporal precision. Research in this area would benefit from more studies with measurement techniques that appropriately capture the timescale of feedback processing, such as event-related potential studies.

The Feedback-Related Negativity (FRN) and Reinforcement Learning Theory

The FRN event-related potential is a negative-going deflection that peaks around 250 to 300 milliseconds after receiving feedback about behavioral accuracy (San Martín, 2012; Miltner et al., 1997; Nieuwenhuis et al., 2004). The FRN waveform is elicited by both positive and negative external feedback, but the deflection tends to be largest or most negative for feedback about an error or negative outcome (see San Martín, 2012 for a literature review). Additionally, FRN amplitude has been shown to negatively correlate with self-reported sensitivity to punishment (Massar et al., 2012; Santesso et al., 2011). The FRN has a frontocentral scalp distribution, and the results from source localization and fMRI studies have shown that the anterior cingulate cortex is likely the neural generator of the FRN (Hauser et al., 2014; Nieuwenhuis et al., 2004; Ullsperger et al., 2014). The FRN is frequently elicited in computer tasks such as go/no-go or flanker experimental paradigms, and visual stimuli are often used to provide feedback (San Martín, 2012; Ullsperger et al., 2014). Examples of visual feedback stimuli that have been used in studies with children to elicit the FRN include frowning human or cartoon faces (e.g., Grabell et al., 2017; Shephard et al., 2014) and symbols that indicate money or points have been lost (e.g., coin with a slash through it, red square; e.g., Ding et al., 2017; Groen et al., 2007; Lees et al., 2021).

According to the reinforcement learning theory of the FRN and the related ERN event-related potential (Holroyd & Coles, 2002), there is a generalized neural system for error processing and reinforcement learning. This system uses an “actor-critic architecture” to resolve reinforcement learning problems. Specifically, several “actors” or neural regions, including the prefrontal cortices and limbic regions, collectively exert their influence on the motor cortex to shape behavior. The basal ganglia, located in the midbrain and base of the frontal lobe, act as the “critic” by encoding the effectiveness of a particular behavioral outcome and revising ongoing predictions about optimal behavior accordingly. If a behavioral outcome was better than expected, the basal ganglia signal a phasic increase in the activity of midbrain dopamine neurons (i.e., a positive reward prediction error). If the outcome was worse than expected, the basal ganglia instead signal a phasic decrease in the activity of midbrain dopamine neurons (i.e., a negative reward prediction error). These reward prediction error signals, in turn, are received by the anterior cingulate cortex, which is located in the medial frontal cortex. The anterior cingulate cortex acts as a “control filter” via its direct projections to the motor cortex, through which it influences the motor cortex to select the optimal future behavior for the task at hand (Cavanagh et al., 2010; Paus, 2001). This framework predicts that the FRN is generated when the anterior cingulate cortex receives the negative reinforcement learning signal from the midbrain dopamine system. When there is a phasic decrease in midbrain dopamine neuron activity, the amplitude of the FRN signal is thought to increase or become more negative with the corresponding disinhibition of apical dendrites in motor neurons of the anterior cingulate cortex (Holroyd & Coles, 2002; San Martín, 2012; Nieuwenhuis et al., 2004; Ullsperger et al., 2014). The magnitude of the FRN waveform to negative feedback has been shown to correspond with improved behavioral accuracy in subsequent task trials, which provides evidence that the anterior cingulate cortex guides behavioral adaptation (Bellebaum & Daum, 2008; Frank et al., 2005; Luu et al., 2003). Therefore, larger FRN deflections (i.e., more negative amplitude) are theorized to reflect more neural sensitivity to negative feedback about behavior, whereas smaller FRN deflections (i.e., less negative amplitude) reflect less neural sensitivity to negative feedback (Santesso et al., 2011).

In addition to individual differences in sensitivity to feedback, it has been demonstrated that FRN amplitude may also vary as a function of age. The FRN has been studied in children as young as 2.5 years of age (Meyer et al., 2014), though studies in early and middle childhood are limited. A couple longitudinal studies collectively spanning the ages of 5 to 14 years have found that FRN amplitude decreases or becomes less negative across childhood into adolescence (Arbel et al., 2018; Lees et al., 2021), and a few cross-sectional studies have shown that children ranging from 8 to 12 years in age have larger or more negative FRN amplitudes when compared to adolescents or adults (Crowley et al., 2013; Ferdinand et al., 2016; Shephard et al., 2014). This is in contrast to both longitudinal and cross-sectional studies that show the amplitude of the error-related negativity increases or becomes more negative over this time period, reflecting progressive self-monitoring of one’s own behavior (Buzzell et al., 2017; Davies et al., 2004; Lees et al., 2021; Wiersema et al., 2007). Collectively, these findings suggest that children may rely more heavily on external feedback about their behavior than adolescents or adults (Ferdinand & Kray, 2014), and that feedback about behavioral appropriateness may aid the development of self-monitoring capabilities in children (Lees et al., 2021). These developmental changes correspond with the maturation of the neural systems subserving reinforcement learning and behavior regulation, including the anterior cingulate cortex, during childhood (Hämmerer & Eppinger, 2012; Kolk & Rakic, 2022; Velanova et al., 2008). Given the importance of external feedback for shaping children's behavior at a time when these neural systems are developing, studies that examine the FRN in young children are essential.

FRN amplitude has also been shown to vary as a function of biological sex. Studies in humans and rodents have shown that, compared to females, males have a more protracted maturation of the prefrontal cortices (Kaczkkurkin et al., 2019; Markham & Juraska, 2002; Mutlu et al., 2013; Premachandran et al., 2020). In-line with this literature, a recent study in a sample of 9- to 12-year-olds found that boys had smaller or less negative FRN deflections than girls in response to punishment stimuli, including both monetary and social feedback cues (i.e., a coin with a slash through it and a frowning face), and were less likely than girls to switch their behavior to a more optimal response after punishment (Ding et al., 2017). Further, Santesso et al. (2011) found that males had smaller or less negative FRN deflections than females during adolescence and young adulthood. Overall, these findings indicate that sex may moderate FRN amplitude such that males have less negative amplitudes than females. These sex differences have been documented as early as 9 years-of-age (Ding et al., 2017), although it is unclear precisely when in development these sex differences first appear.

The FRN and Externalizing Behavior

To date, only a few studies have examined associations between FRN amplitude and externalizing behavior, most of which have been conducted with adult or adolescent samples. In comparison, many studies have reported associations between a diminished ERN amplitude, thought to reflect lower self-monitoring during behavioral errors, and elevated externalizing behavior problems across childhood and adolescence (see Lutz et al., 2021 and Pasion & Barbosa, 2019 for meta-analyses). Of note, one recent meta-analysis concluded that the ERN could inform targeted intervention efforts for externalizing behavior problems, as providing feedback about behavior should improve error detection and self-monitoring capabilities (Lutz et al., 2021). This assumes that individuals with externalizing behavior problems are sensitive to external feedback and can learn to appropriately monitor their own behavior when receiving such feedback. Although numerous fMRI studies have demonstrated that antisocial adults and adolescents may experience deficits in feedback processing (e.g., Gregory et al., 2015; Huang et al., 2019; Murray et al., 2018; Schwenck et al., 2017; Shannon et al., 2009), few event-related potential studies have empirically evaluated this assumption, especially in childhood samples.

Findings have been mixed for the few studies that have examined associations between externalizing behavior and FRN amplitude. While studies have primarily reported that a *smaller* FRN deflection (i.e., less sensitive to feedback) is associated with externalizing symptoms, a couple studies have reported that a *larger* FRN deflection (i.e., more sensitive to feedback) is associated with externalizing symptoms. For example, Sheffield et al. (2015) found that, in a community sample of adolescents, a smaller FRN amplitude was associated with higher levels of externalizing behavior. Similarly, in adult samples, Massar et al. (2012) found that a smaller FRN was associated with more risk-taking behaviors, and Carter Leno et al. (2016) found that smaller FRN deflections in response to social and non-social feedback cues were associated with more psychopathic traits. In contrast, Pfabigan et al. (2011) found that antisocial adults, compared to a healthy control group, had larger FRN amplitudes in response to numerical feedback stimuli, but no differences in response to emotional faces feedback stimuli. Other studies have found that FRN amplitude is negatively correlated with hostility in adolescents and adults (Yi et al., 2012) and trait anger in adults (Rodrigues et al., 2020), characteristics that are closely related to externalizing behavior problems. Further, in a sample of maltreated preschool-aged children, Roos et al. (2015) found that larger FRN deflections were associated with more impulsivity.

A couple factors may contribute to these mixed findings for the association between FRN amplitude and externalizing symptoms. First, there is heterogeneity in the presentation of externalizing psychopathology. Individuals with comorbid internalizing and externalizing problems tend to present with more emotion regulation difficulties, including cognitive biases towards emotionally negative stimuli, compared to individuals with "pure" externalizing problems (Aldao et al., 2016). This explanation is consistent with findings that internalizing disorders such as anxiety and depression are associated with larger FRN amplitudes in response to negative feedback (Gu et al., 2010; Rappaport & Barch, 2020; Tobias & Ito, 2021), as well as findings that larger FRN amplitudes are associated with emotional difficulties such as trait anger (Rodrigues et al., 2020) and hostility (Yi et al., 2012). Further, children who have comorbid internalizing and externalizing problems have larger ERNs after behavioral errors than children with only externalizing behavior problems (Stieben et al., 2007). In contrast, individuals with "pure" externalizing syndromes may exhibit a more blunted emotional profile that corresponds with poor fear conditioning and low sensitivity to punishment cues (Matthys et al., 2013). This aligns with findings that smaller FRN amplitudes are associated with externalizing behavior (Sheffield et al., 2015) and psychopathic traits (Carter Leno et al., 2016). A second consideration is that experiences of maltreatment or adversity may lead some individuals to become hypervigilant to threat or punishment cues. This hypervigilance could be protective in harsh environments, but may also be associated with excessive emotional arousal and difficulties regulating behavior in more benign or ambiguous contexts (Jaffee, 2017). This explanation is consistent with Roos and colleagues (2015) findings that larger FRN amplitudes are associated with impulsivity in a sample of maltreated preschool-aged children. This explanation is further supported by fMRI findings that maltreated children, compared with non-maltreated children, have stronger activation of the anterior cingulate cortex after behavioral errors (Bruce et al., 2013; Lim et al., 2015). Altogether, these factors support the possibility that both smaller and larger FRN deflections may contribute to externalizing symptoms, but studies to date have only considered linear associations between these variables. It seems imperative to also consider U-shaped associations between FRN amplitude and externalizing behavior problems, as both high and low neural sensitivity to negative feedback may lead to sub-optimal behavior regulation (Northoff & Tumati, 2019).

In addition to the aforementioned mixed findings, a couple of studies have not found a significant association between the FRN and externalizing behavior. Bernat et al. (2011) found that FRN amplitude was not associated with externalizing psychopathology in adults. Notably, this sample was recruited from an undergraduate psychology course, so it is possible this sampling technique only captured a limited range of the externalizing risk spectrum. In addition, Grabell et al. (2017) compared preschool-aged children with and without high levels of disruptive behavior disorders and found no significant differences in FRN amplitude. However, this study may be underpowered to detect effects as there were only 20 children in the disruptive behavior disorder group. It is also possible that the association between FRN amplitude and externalizing behavior may emerge later in development.

Several factors make the limited literature on the FRN and externalizing behavior difficult to synthesize. First, the studies cover varied age groups, including child (Grabell et al., 2017; Roos et al., 2015), adolescent (Sheffield et al., 2015; Yi et al., 2012), and adult samples, with the majority of studies having adult samples (Bernat et al., 2011; Carter Leno et al., 2016; Massar et al., 2012; Pfabigan et al., 2011; Rodrigues et al., 2020; Yi et al., 2012). Second, the studies employed varied experimental paradigms, including mostly monetary gambling tasks (Bernat et al., 2011; Massar et al., 2012; Pfabigan et al., 2011; Sheffield et al., 2015; Yi et al., 2012) but also a flanker task (Roos et al., 2015), go/no-go tasks (Carter Leno et al., 2016; Grabell et al., 2017), and a third-party dictator game (Rodrigues et al., 2020). Different feedback stimuli were also used across these tasks. The majority of studies used either monetary stimuli (Sheffield et al., 2015) or symbols to indicate that money had been lost or gained in the incentivized task (Bernat et al., 2011; Massar et al., 2012; Pfabigan et al., 2011; Yi et al., 2012), while other studies included social feedback stimuli (Carter Leno et al., 2016; Grabell et al., 2017; Pfabigan et al., 2011). There does not seem to be any systematic differences in findings between studies that employed monetary or social feedback stimuli, but more studies using a variety of experimental paradigms and feedback stimuli are necessary to consider whether motivational salience moderates study findings. Third, the FRN was computed differently across studies, with some studies using a peak amplitude measure locked to negative feedback (Carter Leno et al., 2016; Grabell et al., 2017; Rodrigues et al., 2020; Yi et al., 2012), other studies using a difference wave where the peak amplitude to positive feedback was subtracted from the peak amplitude to negative feedback (Massar et al., 2012; Pfabigan et al., 2011; Sheffield et al., 2015), and one study including both (Roos et al., 2015). Lastly, the sampling techniques used in several studies may capture a limited range of externalizing behavior, including the recruitment of undergraduate convenience samples (Bernat et al., 2011; Massar et al., 2012; Pfabigan et al., 2011; Rodrigues et al., 2020) and healthy community samples (Carter Leno et al., 2016; Sheffield et al., 2015; Yi et al., 2012). While these studies are essential to understand the relation between feedback processing and externalizing behavior in low-risk populations, more research in high-risk populations is critical. Overall, more work is necessary to elucidate associations between the FRN and externalizing proneness across development, experimental paradigms, and severity of externalizing behavior.

The Ecological Validity of the FRN: Caregiver Punishment as an Example

It is presently unknown whether the FRN, which is typically elicited via visual feedback stimuli during lab-based computer games, is associated with ecologically valid corrective feedback that young children receive about their behavior, such as punishment from caregivers. Ecological validity, a subtype of external validity, refers to the extent that conclusions reached from lab experiments correspond with the phenomenon that is being modeled from a real-world system (Kihlstrom, 2021). While event-related potential studies are increasingly using experimental stimuli that more closely correspond to stimuli from the natural world (e.g., videos of a task “observer” to provide feedback; Carter Leno et al., 2016), it is also imperative to demonstrate that neural activity measured in the lab is associated with the real-life experience (Sonkusare et al., 2019). Given that two studies with adolescents and young adults have found that self-reported sensitivity to punishment is negatively correlated with FRN amplitude (Massar et al., 2012; Santesso et al., 2011), it is reasonable to expect that FRN amplitude would also be associated with punishment from caregivers in childhood. Individuals who are less sensitive to negative feedback are thought to have a compromised ability to learn contingencies between their behavior and feedback and adapt future behavior accordingly (Jean-Richard-dit-Bressel et al., 2019, 2021). Therefore, it is possible that less sensitive children (i.e., smaller FRN amplitude) may be less responsive to punishment and may fail to adjust inappropriate behaviors. Over time, this may elicit more frequent and/or harsher types of punishment from caregivers. In contrast, children who are more sensitive to corrective feedback (i.e., larger FRN amplitude) may require less feedback to learn socially appropriate behaviors and may therefore elicit less punishment overall from their caregivers. In-line with this logic, FRN amplitude may also moderate associations between punishment from caregivers and children’s behavior problems. Specifically, higher amounts of punishment, especially if it is harsh or physically punitive, may exacerbate behavior problems in children who are less sensitive to feedback about their behavior. These children may not process relevant information about the appropriateness of their own behavior from excessive or harsh punishment, and may instead learn to mimic aggressive behaviors from their caregivers (Hastings et al., 2007; Patterson et al., 1989; Shaw & Bell, 1993). Conversely, higher amounts of punishment may be associated with lower levels of externalizing behavior in children who are more sensitive, regardless of the type of punishment, although sensitive children may experience other detrimental outcomes such as internalizing disorders if punishment is excessive or harsh (Afifi et al., 2012; Durrant & Ensom, 2012).

The Present Study

The first aim of the present study was to consider whether neural sensitivity to negative feedback, as indexed by the amplitude of the feedback-related negativity (FRN), was associated with externalizing behavior symptoms in middle childhood. Specifically, to have sufficient power to detect effects, I examined this association in a sample of kindergarten children who had elevated levels of behavior problems and presented with the full range of aggressive and oppositional behaviors at school-entry. I explored two competing hypotheses. The first hypothesis is that the association between FRN amplitude and externalizing behavior is linear, such that a less negative FRN amplitude is associated with more externalizing behavior problems. A second hypothesis is that the association between FRN amplitude and externalizing behavior is U-shaped, such that both less negative and more negative FRN amplitudes are associated with more externalizing behavior problems. Additionally, since a study of 9- to 12-year-olds (Ding et al., 2017) and a study of adolescents and young adults (Santesso et al., 2011) each found that males had less negative FRN amplitudes than females, I considered whether the association between FRN amplitude and externalizing behavior problems was moderated by sex. I expected that if a less negative FRN amplitude was associated with externalizing symptoms that this association may be specific to males. Conversely, it is also possible that sex differences in FRN amplitude may not manifest until later in development, in which case the association would not be moderated by sex in a sample of kindergartners.

For the second and third study aims, I examined associations among FRN amplitude, punishment from caregivers, and externalizing behavior. Since the overall amount and types of punishment that children receive are both associated with externalizing behavior problems (Choe et al., 2013; McKee et al., 2008), I first conducted a latent profile analysis to identify homogenous subgroups of children who experienced similar styles and frequencies of punishment from their caregivers. I expected that some groups of children received punishments that were sensitive and developmentally appropriate, such as brief timeouts or conversations about the behavior problem, whereas other children may have received punishments that were more coercive or physically punitive. I also thought that a group of children may have experienced low levels of all types of punishment, consistent with a profile of parental laxness. For the second study aim, I considered whether a child's FRN that was elicited in a laboratory context was associated with punishment from caregivers, a form of real-world negative feedback that children receive. I hypothesized that children who are less sensitive to negative feedback (i.e., less negative FRN amplitude) may have more difficulty learning associations between their behavior and punishment, and may therefore elicit higher amounts or harsher types of punishment from their caregivers. For the third aim, I considered whether the relation between punishment from caregivers and child externalizing behavior differs based on a child's FRN amplitude. I hypothesized that children with a less negative FRN amplitude would have higher amounts of behavior problems if they received higher amounts of punishment, especially if they received punishments that were more coercive or physically punitive. In contrast, I thought that children who were more sensitive to negative feedback (i.e., more negative FRN amplitude) would have lower amounts of externalizing behavior problems if they received higher amounts of punishment, regardless of the types of punishment experienced.

Chapter 2

Method

Participants

Data for this study are drawn from a longitudinal clinical trial of a school-based intervention for children with early onset aggression (see Gatzke-Kopp et al., 2012 for details regarding study design and Gatzke-Kopp et al., 2015 for information about the social skills training intervention). Briefly, all kindergarten teachers from 10 elementary schools in an urban school district completed a 10-item screening questionnaire (items selected from the Teacher Observation of Classroom Adaptation – Revised; Werthamer-Larsson et al., 1991) to report on aggressive and oppositional behavior for each student in their classroom. Sample items included "breaks rules" and "cruelty, bullying, or meanness to others." Each item was rated on a 6-point Likert scale ranging from 1 (*almost never*) to 6 (*almost always*) and summed to create a total score. Children rated as being in the top quartile on aggressive and oppositional behavior (M = 31.1, SD = 10.5, range = 11 to 60) within each classroom were recruited (n = 207) and randomly assigned to the control or intervention condition. Children who scored in the lowest quartile on externalizing behavior problems (M = 11.2, SD = 2.1, range = 10 to 20) within each classroom were also recruited for a comparison group (n = 132). Following recruitment, in the fall and winter of kindergarten, a baseline psychophysiological assessment was conducted with all children. Caregivers were also asked to complete questionnaires about their family and child's behavior, and teachers completed additional surveys on children's behavioral adjustment at school. After the intervention was completed, follow-up assessments were conducted with children in the spring of 1st and 2nd grade. Children provided verbal assent and caregivers and teachers provided informed consent for study participation. The Pennsylvania State University IRB approved all study procedures.

All data used in the present study are from the baseline assessment that took place prior to intervention implementation and focus on the subset of children with elevated externalizing symptoms (*n* = 207). This subsample was selected in order to maximize power to detect associations between externalizing symptoms and FRN amplitude, as the full spectrum of externalizing severity was represented within this sample. Children had a mean age of 5.98 years (*SD* = 0.39, range = 5.18 to 7.33) and 66% were male (*n* = 137) and 34% were female (*n* = 70). Consistent with the racial demographics of the region, approximately 73% of children were African American, 19% were Hispanic/Latino(a), 8% were White, and less than 1% were Asian (*n*s = 151, 39, 16, and 1, respectively). Out of the 150 caregivers who reported family income, 72% were below the U.S. Census Bureau's federal poverty threshold (*n* = 108), based on total income and family size. Caregivers reported that they experienced financial stress an average of 1.23 months out of the past year (*SD* = 1.77, range = 0.0 to 8.0 months), including difficulty paying rent or a mortgage, paying utility bills, or buying groceries.

Externalizing Behavior

Caregivers reported on children's externalizing behavior using the *aggressive/oppositional behavior* scale from the Child Behavior Questionnaire. The Child Behavior Questionnaire is a 26-item measure with five scales on child emotional and behavioral adjustment, which were created using items from the Teacher Observation of Classroom Adaptation (TOCA-R; Werthamer-Larsson et al., 1991) and the Teacher Social Competence Scale (Conduct Problems Prevention Research Group, 1990). Frequency of behaviors are rated on a 6-point Likert scale for each item, ranging from 1 (*almost never*) to 6 (*almost always*). Seven items are averaged to create the *aggressive/oppositional behavior* scale score (Cronbach's α = .87). Example items from the scale include "yells at others", "knowingly breaks rules", "breaks things on purpose", and "hits, pushes, or shoves." Higher scores reflect higher levels of externalizing behavior problems. The full spectrum of externalizing behavior was present in the sample (*M* = 2.8, *SD* = 1.0, range = 1.1 to 6.0).

Punishment

Caregivers reported on the frequency they use different disciplinary strategies to handle children's behavior problems using the Discipline Questionnaire (Conduct Problems Prevention Research Group, 1999). The Discipline Questionnaire is a 10-item measure that assesses the frequency caregivers use different disciplinary strategies on a scale that includes 0 (*never*), 1 (*less than once a month*), 2 (*about once a month*), 3 (*a few times a month*), 4 (*about once a week*), 5 (*a few times a week*), and 6 (*almost every day*). For the present study, a subset of 7-items that focused on punitive disciplinary strategies was selected (Cronbach's α = .81). These punishment items include "calmly talking about the behavior problem", "sending the child to his or her room or somewhere else to be alone", "raising your voice or yelling", "threatening a spanking", "threatening another kind of punishment", "giving a swat or spanking", and "hit or tried to hit child." The full range of the scale was represented for each punishment item (all ranges = 0.0 to 6.0), and means and standard deviations for each item are shown in Table 1. All 7-items were included in a latent profile analysis to identify subgroups of children who experienced similar types and amounts of punishment from their caregivers.

Table 1: Descriptive statistics and bivariate associations for study variables.

Variables	1.	2.	3.	4.	5.	6.	7.
1. FRN amplitude	-						
2. Externalizing behavior	.19*	-					
3. Calmly talk about problem	-.01	.40***	-				
4. Timeout	-.01	.40***	.36***	-			
5. Raise voice or yell	-.02	.36***	.30***	.33***	-		
6. Threaten spanking	-.01	.29***	.21**	.33***	.53***	-	
7. Threaten other punishment	.04	.35***	.29***	.47***	.37***	.45***	-
8. Give swat or spanking	.04	.41***	.29***	.38***	.49***	.63***	.47***
9. Hit or tried to hit child	.16	.28***	.20**	.22**	.28***	.40***	.27***
10. Age	.11	-.06	-.06	.05	-.05	-.10	-.04
11. Financial stress	-.12	.15*	.11	.09	.06	.09	.10
12. FRN trial count	.21*	.12	.05	.03	-.02	.07	-.08
13. Sex	*t*(146) = -0.67	*t*(196) = -1.53	*t*(196) = -1.04	*t*(196) = -1.81	*t*(196) = -0.60	*t*(196) = -2.19*	*t*(195) = -0.73
n	148	198	198	198	198	198	197
M (SD) or *n* (%)	-9.5 (5.4)	2.8 (1.0)	4.9 (1.5)	3.9 (1.7)	4.8 (1.6)	3.2 (2.2)	3.5 (2.1)
Range	-26.3 to 4.1	1.1 to 6.0	0.0 to 6.0	0.0 to 6.0	0.0 to 6.0	0.0 to 6.0	0.0 to 6.0

Note. Variables 3-9 are items from the Discipline Questionnaire (Conduct Problems Prevention Research Group, 1999). Financial stress is the number of months in the past year caregivers reported difficulty paying rent or a mortgage, paying utility bills, or buying groceries. Bivariate associations with sex are two-sided t-tests; all other reported associations are Pearson correlations.

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

Table 1 (continued): Descriptive statistics and bivariate associations for study variables.

Variables	8.	9.	10.	11.	12.	13.
1. FRN amplitude						
2. Externalizing behavior						
3. Calmly talk about problem						
4. Timeout						
5. Raise voice or yell						
6. Threaten spanking						
7. Threaten other punishment						
8. Give swat or spanking	-					
9. Hit or tried to hit child	.52***	-				
10. Age	-.11	-.01	-			
11. Financial stress	.05	-.03	-.01	-		
12. FRN trial count	.14	.13	.03	-.01	-	
13. Sex	$t(196) =$ -1.78	$t(195) =$ -1.79	$t(197) =$ 0.44	$t(192) =$ -0.30	$t(165) =$ -1.91	-
n	198	197	199	194	167	207
M (SD) or *n* (%)	1.9 (1.8)	1.2 (1.6)	6.0 (0.4)	1.2 (1.8)	17.2 (11.4)	137 male (66%)
Range	0.0 to 6.0	0.0 to 6.0	5.2 to 7.3	0.0 to 8.0	6.0 to 68.0	-

Note. Variables 3-9 are items from the Discipline Questionnaire (Conduct Problems Prevention Research Group, 1999). Financial stress is the number of months in the past year caregivers reported difficulty paying rent or a mortgage, paying utility bills, or buying groceries. Bivariate associations with sex are two-sided t-tests; all other reported associations are Pearson correlations.
* $p < .05$, ** $p < .01$, *** $p < .001$.

Psychophysiological Assessment

Protocol

Psychophysiological assessments were conducted in a recreational vehicle that was outfitted as a mobile laboratory and decorated with a child-friendly outer space theme. The recreational vehicle was driven to elementary schools during the school day for on-site data collection, which reduced participant burden while ensuring consistency of the assessment environment. To reduce apprehension about the physiological assessments, each kindergarten classroom was allowed to tour the space with their teacher prior to study enrollment.

Trained research assistants explained the tasks and obtained verbal assent from each child prior to placement of a 32-channel EEG cap (described below), as well as electrodermal and cardiac electrodes. Only the EEG data are examined here. Children were seated at a computer to complete the assessments. First, children were instructed to sit quietly and imagine they were traveling through space for two minutes. During this time a video of a moving starfield was shown on the computer monitor and baseline physiological data were collected. Children then participated in an incentivized go/no-go task (described below) and emotion induction task (not assessed in current study; see Gatzke-Kopp et al., 2012 for details).

Go/No-Go Task

The go/no-go task (adapted from Lewis et al., 2006) used child-friendly stimuli, which consisted of 45 different cartoon drawings that children were told were alien critters they needed to “zap.” Children were instructed to press a button on a response box each time one of the cartoon drawing stimuli was presented (go trial), but to withhold pressing the button if the presented stimulus was identical to the preceding stimulus (no-go trial). A diagram of the trial structure is shown in Figure 1. Before beginning the task research assistants informed children that they would earn points for correct responses and lose points for incorrect responses. If enough points were accumulated during the task children would be able to choose a toy from a prize bag. Children were not told how many points were necessary to win the prize so that they would maintain motivation for the full duration of the task.

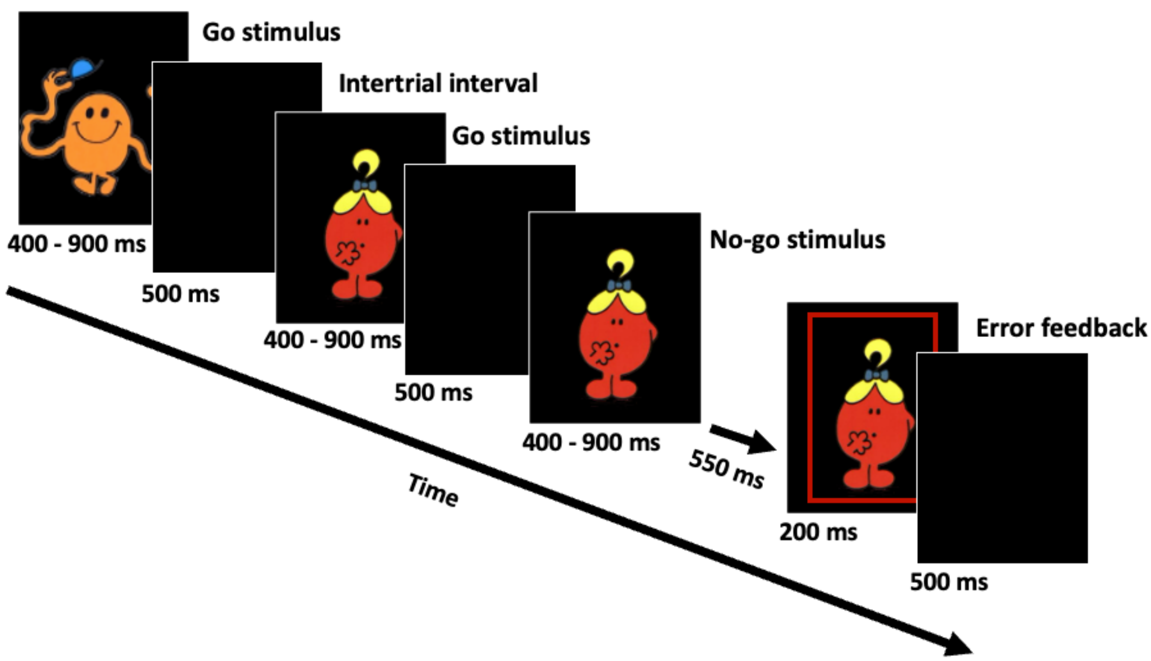

Figure 1: Go/no-go task trial structure.

Note. Children were directed to press a button on a response box each time a cartoon character stimulus was presented (go trials), but to withhold pressing the button if the same cartoon character was presented consecutively (no-go trials). If a child made an error by either pressing the button on a no-go trial (error of commission) or failing to press the button on a go trial (error of omission) then a red rectangle appeared after a brief delay to frame the stimulus and provide the child with error feedback.

Children first completed a practice round to familiarize with the task and allow the research assistant to calibrate the rate of stimulus presentation. Specifically, the initial response window length was adjusted to ensure that each child's error rate was between 40 and 60% on no-go trials. The interstimulus interval was dynamically adjusted throughout the task to maintain this error rate. In the event that a response was given to a no-go trial (error of commission), or there was a failure to respond to a go-trial during the allocated time (error of omission), children were given feedback by framing the stimulus with a large red rectangle approximately 550 ms after the error (see Figure 1). The feedback stimuli remained on the screen for 200 ms, and this trial-level feedback was used to derive the FRN. In addition, children were given an overall assessment of their performance approximately every 10 trials (jittered) by visually representing cumulative points with a thermometer. This was paired with a cartoon face that was smiling and giving a thumbs up if points were earned since the last overall assessment, or frowning and giving a thumbs down if points were lost.

The go/no-go task was 10 minutes long when administered and included 225 go-trials and 105 no-go trials. These trials were uniformly distributed across three blocks such that there were 75 go-trials and 35 no-go trials per block. Between blocks children were given a 30 second rest. Since the broader study considered the effects of an intervention on children's social and emotional development, an affective manipulation was incorporated into the task design. In the 1^{st} and 3^{rd} blocks, the number of points awarded each trial by the scoring algorithm strongly rewarded correct responses and weakly punished incorrect responses (reward condition). This led to an overall accumulation of points during these blocks. In the 2^{nd} block, the scoring algorithm was reversed so that the number of points awarded per trial weakly rewarded correct responses and strongly punished incorrect responses (frustrative non-reward condition). This condition led to an overall loss of points and was designed to induce frustration (see Gatzke-Kopp et al., 2015, for more information). This affective manipulation was unrelated to the research questions for the present study, so only data from the 1st and 3rd blocks of the task (reward condition) are examined here.

EEG Recording and Data Processing

EEG was recorded using the 32-channel elastic stretch BioSemi headcap in conjunction with the Active Two BioSemi system (BioSemi, Amsterdam, Netherlands). Electrodes were placed at standard 10-20 montage locations. The point of intersection between the nasion/inion line and the line from one temporal mandibular joint to the other was used to center the Cz electrode during cap placement. Left and right mastoid electrodes were used as reference channels during recording. Four facial electrodes were placed on the supraorbital ridge centered under pupils and 1 centimeter outside of the participants' left and right outer canthi in order to aid in eyeblink detection and artifact removal during data processing. Data were recorded using a 512 Hz sampling rate with ActiView Software version 8.0 by BioSemi.

Offline data processing was completed using Brain Vision Analyzer version 2.0 software (Brain Products GmbH, Gilching, Germany). Data were re-referenced to the common average and filtered using a 1-30 Hz bandpass filter, which is recommended for EEG research with young children (Yordanova & Kolev, 2007). These settings were applied to minimize the impact of low-frequency delta, which is prevalent in young children and thought to reflect developmental immaturity, and to preserve power in the theta frequencies that are thought to primarily contribute to FRN amplitude (Cavanagh et al., 2010, 2012; Crowley et al., 2014). Incorrect responses from no-go trials were segmented from -200 ms to 800 ms around the large red rectangle feedback stimulus. Trials were baseline-corrected to the mean amplitude from the 200 ms preceding the feedback stimulus. Segments were marked as artifacts and removed if they contained a voltage value outside the range of -75 μV to 75 μV, or a voltage step greater than 100 μV between sampling points. Eye blink artifacts were remedied using the eye movement correction procedure developed by Gratton and colleagues (1983).

Consistent with prior studies of the FRN in children (Gong et al., 2014; Grabell et al., 2017; Lees et al., 2021; Roos et al., 2015; van Meel et al., 2005), FRN average amplitude was extracted at electrode site Fz. The FRN was derived using a sliding average window with a 50% overlap, and the average amplitude was calculated in 20 ms segments across the 200-400 ms following feedback. Subjects with fewer than six trials after data processing were excluded due to low trial count ($n = 19$). The average number of trials retained for the FRN was 19.0 ($SD = 10.9$, range 6 to 68). Although some research suggests that six trials are sufficient for a stable ERP index (Olvet & Hajcak, 2009), there was a positive correlation between FRN amplitude and FRN trial count ($r = .21$, $p = .01$) such that children with less negative FRN amplitudes had more included error trials. The mean, standard deviation, and range for the FRN are reported in Table 1, and the grand average FRN waveform and scalp topography are presented in Figure 2.

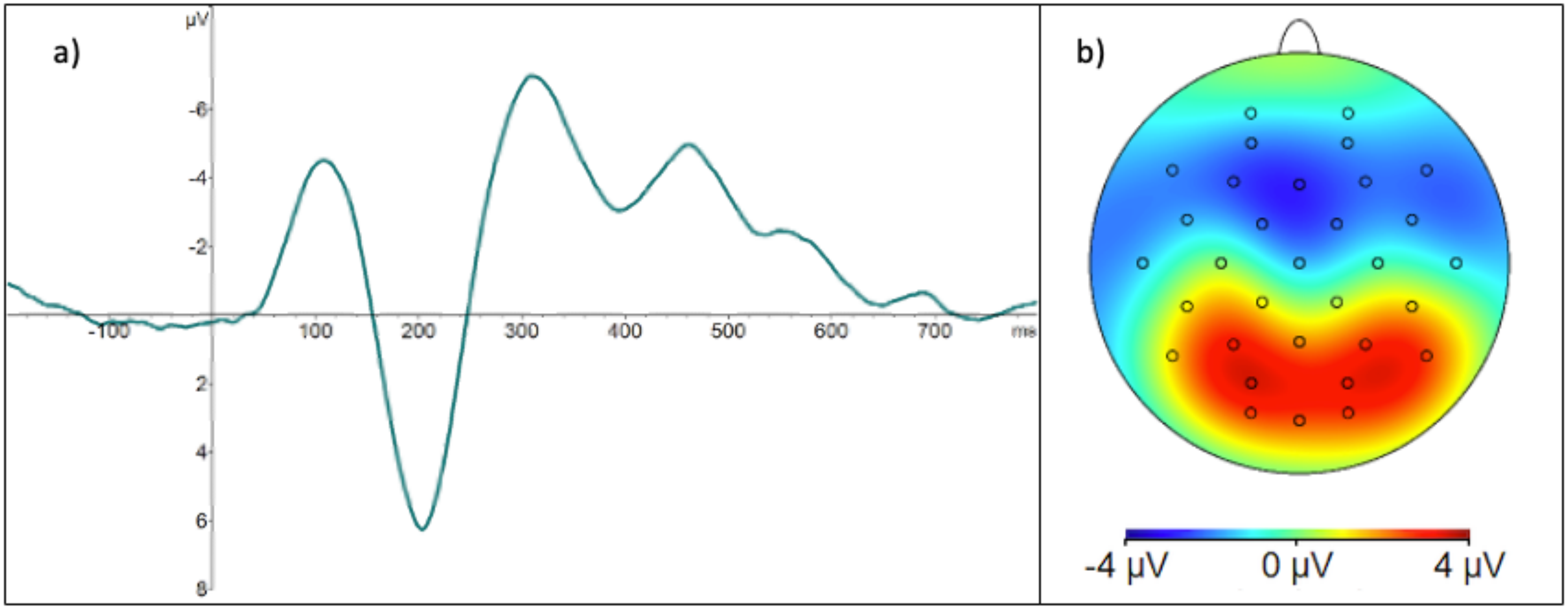

Figure 2: Grand average FRN waveform and scalp topography.

Note. The grand average FRN waveform at electrode site Fz is presented in (a). Polarity is oriented with negative plotted upwards. The FRN scalp topography is presented in (b) and is plotted as the average amplitude during the 200 to 400 ms following feedback stimuli presentation.

Statistical Analysis

First, a latent profile analysis of the seven punishment items was conducted to identify distinct subgroups of children who experienced different types and amounts of punishment from their caregivers. The best fitting model from the latent profile analysis was selected based on several fit indices and interpretability of the profile solutions (Nylund et al., 2007; Spurk et al., 2020). Fit indices included Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), entropy, and the Bootstrap Likelihood Ratio Test (BLRT). Lower AIC and BIC typically indicate better model fit, but in latent profile analysis AIC and BIC values often continue to decrease as more profiles are extracted. It is therefore best to consider where the improvement in model fit plateaus, or no longer provides substantial improvements in fit when more profiles are extracted (Bauer et al., 2022). Higher entropy values denote that the model was able to return well-separated solutions; a cut-off of .80 is often used for sufficient profile separation. Lastly, a non-significant BLRT indicates that the *k* class solution does not fit significantly better than the *k*-1 class solution, so the *k*-1 class solution should be retained as the best-fitting solution (Nylund et al., 2007; Spurk et al., 2020). After selecting the best-fitting solution, I examined posterior probabilities for the solution, or the probability that cases within each profile were classified correctly (Bauer et al., 2022; Oberski, 2016; Williams & Kibowski, 2016). Nine caregivers did not complete the Discipline Questionnaire and were therefore excluded from latent profile analysis. For the remaining cases (n = 198), item-level missing data (0.001% missing across all cases) was multiply imputed during the latent profile analysis using missForest, a non-parametric and iterative imputation method (Stekhoven & Bühlmann, 2012).

Next, I used multiple linear regression to examine associations among FRN amplitude, externalizing behavior, and punishment (Cohen et al., 2003). Variables were only included in models as covariates if they were significantly associated with either externalizing behavior or FRN amplitude (Maxwell et al., 2018). All continuous variables were mean-centered prior to use in interaction product terms, and punishment profiles were contrast coded to test for group differences in regression analysis (Schad et al., 2020). Unstandardized effect sizes are reported for all regression results to aid in interpretability (Pek & Flora, 2018). Missing data were multiply imputed in all regression models using multivariate imputation by chained equations, an iterative method that imputes each incomplete variable using a separate model (van Buuren & Groothuis-Oudshoorn, 2011). The *n*s for all study variables are reported in Table 1.

All analyses were conducted with R version 4.2.0 (R Core Team, 2022). The tidyLPA package was used for latent profile analysis (Rosenberg et al., 2018) in conjunction with the missForest package (Stekhoven & Bühlmann, 2012) for multiple imputation of missing data. The mice package (van Buuren & Groothuis-Oudshoorn, 2011) was used for multiple imputation in regression analysis. Figures were created using the ggplot2 package (Wickham et al., 2016).

Chapter 3

Results

Punishment Profiles

All fit indices from the latent profile analysis are shown in Table 2. I examined fit indices for one- to six-profile solutions. Entropy was highest for the two-profile solution, but all solutions fell above the .80 cut-off used for sufficient profile separation. AIC and BIC each indicated that the three-profile solution was the best fit, as these fit indices' values only gained incremental improvement in model fit as four- or more profile solutions were extracted. BLRT failed to become non-significant, indicating that each k class solution fit better than the k-1 class solution, so was therefore not used to guide selection of the best-fitting class. Overall, entropy indicated that a two-profile solution fit best, whereas AIC and BIC each suggested that a three-profile solution fit best. I therefore fit both a two-profile and three-profile solution, but found the three-profile solution to be more readily interpretable. Further, the three-profile solution included profiles that were more homogenous within-group and heterogeneous between-groups than the two-profile solution. As a result, I selected the three-profile solution as the best-fitting solution. Average posterior probabilities were high for all three profiles (94.6 for the first profile, 92.6 for the second profile, and 98.7 for the third profile), indicating a high probability that cases within each profile were classified correctly. The average frequency that caregivers in each of the three profiles used the different types of punishment is plotted in Figure 3 and described below.

Table 2: Fit indices from latent profile analysis of caregiver punishment.

Class	AIC	BIC	Entropy	BLRT
1	3953.40	3999.44	1.00	.01
2	3699.61	3771.96	.95	.01
3	3518.45	3617.10	.88	.01
4	3441.56	3566.51	.91	.01
5	3391.78	3543.04	.90	.01
6	3339.12	3516.68	.92	.01

Note. AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion, BLRT = Bootstrap Likelihood Ratio Test.

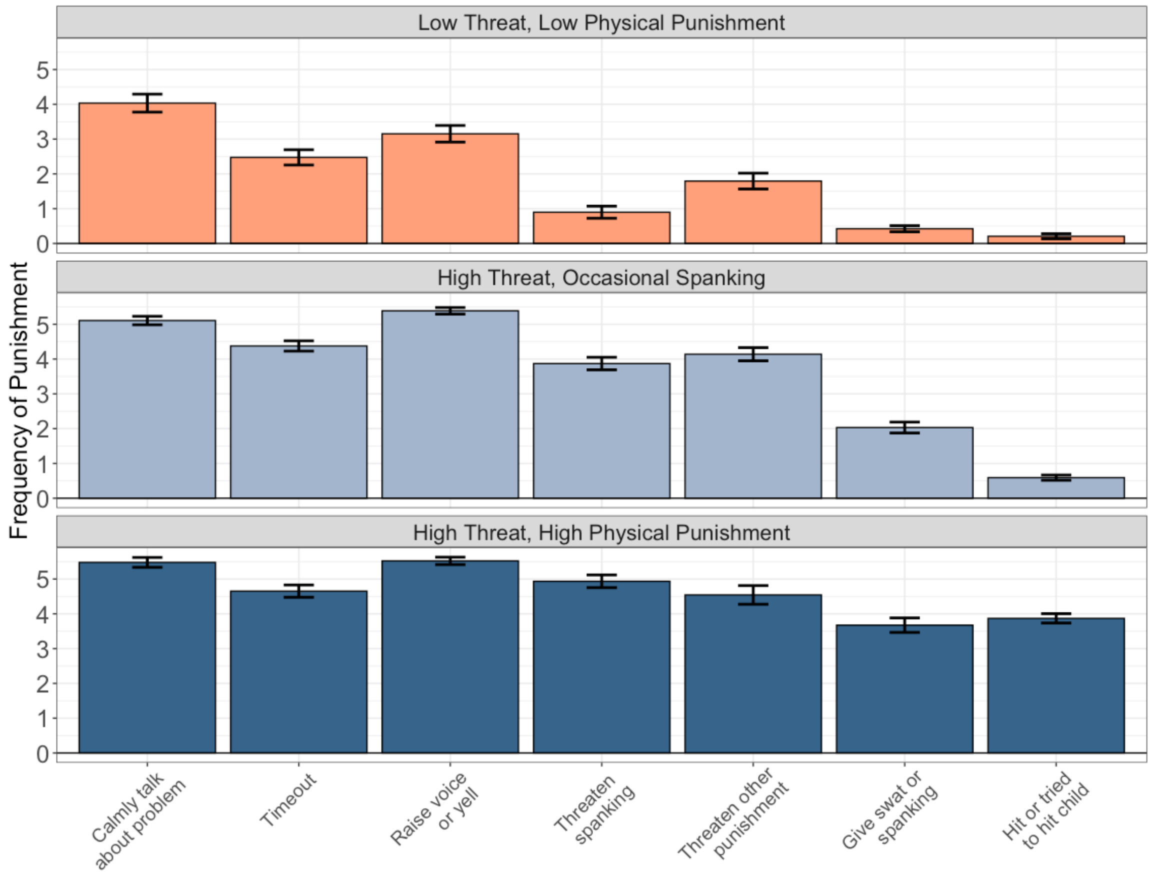

Figure 3: Three subgroups of caregiver punishment.

Note. Three subgroups of caregiver punishment were identified using latent profile analysis: a low threat, low physical punishment group (n = 59), a high threat, occasional spanking group (n = 93), and a high threat, high physical punishment group (n = 46). Punishment items are from the Discipline Questionnaire (Conduct Problems Prevention Research Group, 1999). Error bars represent standard error of the mean.

Low Threat, Low Physical Punishment

The first profile was approximately 30% of the sample (*n* = 59; 33 males, 26 females). This group of caregivers was characterized by infrequent use (or no use) of threatening spankings and other types of punishment, as well as infrequent use (or no use) of swatting/spanking and hitting or trying to hit their child. This group reported moderately frequent use of other types of punishment, including calmly talking about the problem, using timeout, and raising their voice or yelling.

High Threat, Occasional Spanking

The second profile was comprised of 47% of the sample (*n* = 93; 62 males, 31 females). This group of caregivers reported frequent use of threatening spankings and other types of punishment, but reported only occasional use of swatting/spanking, and infrequent use (or no use) of hitting or trying to hit the child. This group also reported frequent use of other types of punishment, including calmly talking about the problem, using timeout, and raising their voice or yelling.

High Threat, High Physical Punishment

The third profile included 23% of the sample (*n* = 46; 36 males, 10 females). This group of caregivers reported frequent use of threatening spankings and other types of punishment, and frequent use of swatting/spanking and hitting or trying to hit the child. This group also reported frequent use of other types of punishment, including calmly talking about the behavior problem, using timeout, and raising their voice or yelling.calmly talking about the problem, using timeout, and raising their voice or yelling.

Multiple Linear Regression Models

The main results from the multiple regression analysis are shown in Table 3. Punishment profiles were contrast coded for all regression analysis, such that contrast 1 compared children who experienced high threat and any amount of physical punishment (High Threat, Occasional Spanking + High Threat, High Physical Punishment profiles) to children in the Low Threat, Low Physical Punishment profile. Contrast 2 compared children in the High Threat, Occasional Spanking profile to children in the High Threat, High Physical Punishment profile.

Table 3: Multiple regression analysis results.

Model	Predictors	B	SE	95% CI
Is FRN amplitude associated with externalizing behavior?				
Model 1a	FRN (linear)	0.04*	0.02	(0.01; 0.07)
Model 1b	FRN (quadratic)	-0.002	0.002	(-0.01; 0.002)
Is punishment associated with FRN amplitude?				
Model 2	Punishment (profile contrast 1)	-0.41	0.69	(-1.77; 0.95)
	Punishment (profile contrast 2)	0.60	0.59	(-0.56; 1.77)
Does the association between punishment and externalizing behavior differ based on FRN amplitude?				
Model 3	Punishment (profile contrast 1) x FRN	0.04	0.02	(-0.01; 0.08)
	Punishment (profile contrast 2) x FRN	-0.01	0.02	(-0.05; 0.03)
	Punishment (profile contrast 1)	0.60***	0.12	(0.36; 0.83)
	Punishment (profile contrast 2)	0.26*	0.10	(0.06; 0.47)
	FRN	0.03	0.02	(-0.005; 0.06)

Note. All models control for financial stress and FRN trial count. Predictors are mean-centered in models with interaction terms. Punishment profiles were contrast coded, such that contrast 1 compared children who experienced high threat and any amount of physical punishment (High Threat, Occasional Spanking + High Threat, High Physical Punishment profiles) to children in the Low Threat, Low Physical Punishment profile. Contrast 2 compared children in the High Threat, Occasional Spanking profile to children in the High Threat, High Physical Punishment profile.

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

Association Between Child FRN Amplitude and Externalizing Behavior

First, I examined whether FRN amplitude was significantly associated with externalizing behavior while controlling for financial stress and FRN trial count. I fit both linear and quadratic models. There was a significant linear association such that a less negative FRN amplitude was associated with higher levels of externalizing behavior (B = 0.04, SE = 0.02, 95% CI, 0.01 to 0.07, p = .02). This association was not moderated by sex (B = -0.01, SE = 0.03, 95% CI, -0.07 to 0.06, p = .83). There was no significant quadratic association between FRN amplitude and externalizing behavior (B = -0.002, SE = 0.002, 95% CI, -0.01 to 0.002, p = .38). A plot of the linear bivariate association between FRN amplitude and externalizing behavior is shown in Figure 4a.

Association Between Caregiver Punishment and Child FRN Amplitude

Next, I considered whether the contrast-coded punishment profiles were associated with children's FRN amplitude while controlling for financial stress and FRN trial count. I found that children who experienced high threat and any amount of physical punishment (High Threat, Occasional Spanking + High Threat, High Physical Punishment profiles) did not have a significantly different FRN amplitude than children in the Low Threat, Low Physical Punishment profile (contrast 1; B = -0.41, SE = 0.69, 95% CI, -1.77 to 0.95, p = 0.55). Further, children in the High Threat, Occasional Spanking profile did not significantly differ in FRN amplitude from children in the High Threat, High Physical Punishment Profile (contrast 2; B = 0.60, SE = 0.59, 95% CI, -0.56 to 1.77, p = .31). A plot of the bivariate association between the punishment profiles and FRN amplitude is shown in Figure 4b.

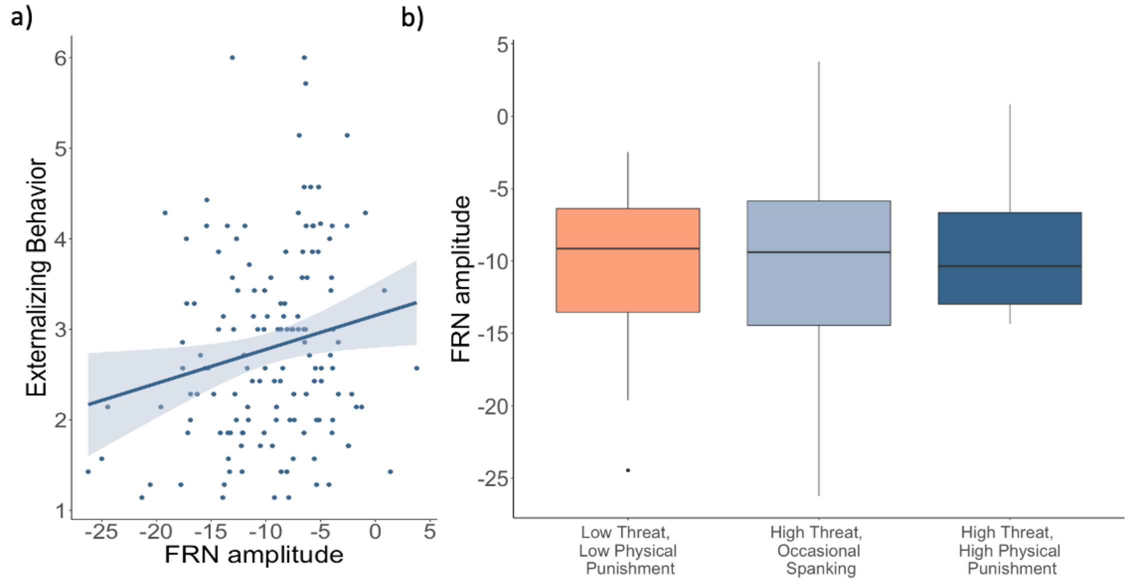

Figure 4: FRN amplitude associations with externalizing behavior and caregiver punishment.

Note. Children's FRN amplitude was significantly associated with their externalizing behavior (a), but not profiles of caregiver punishment (b). Shaded region in Figure 4a represents standard error.

Interaction Between Punishment and FRN Amplitude to Predict Externalizing Behavior

Lastly, I considered whether the relation between caregiver punishment and children's externalizing behavior differed based on children's FRN amplitude. Specifically, I considered whether the contrast-coded punishment profiles interacted with FRN amplitude to predict externalizing behavior while controlling for financial stress and FRN trial count. I found that there was no significant interaction between contrast 1 and FRN amplitude to predict externalizing behavior (B = 0.04, SE = 0.02, 95% CI, -0.01 to 0.08, $p = .12$). Further, there was no significant interaction between contrast 2 and FRN amplitude to predict externalizing behavior (B = -0.01, SE = 0.02, 95% CI, -0.05 to 0.03, $p = 0.68$). There were significant main effects such that children who experienced high threat and any amount of physical punishment (High Threat, Occasional Spanking + High Threat, High Physical Punishment profiles) had higher levels of externalizing behavior than children in the Low Threat, Low Physical Punishment profile (contrast 1; B = 0.60, SE = 0.12, 95% CI, 0.36 to 0.83, $p < .001$). Further, children in the High Threat, High Physical Punishment profile had higher levels of externalizing behavior than children in the High Threat, Occasional Spanking profile (contrast 2; B = 0.26, SE = 0.10, 95% CI, 0.06 to 0.47, $p = 0.01$). A plot of the association between FRN amplitude and externalizing symptoms, grouped by the caregiver punishment profiles, is shown in Figure 5.

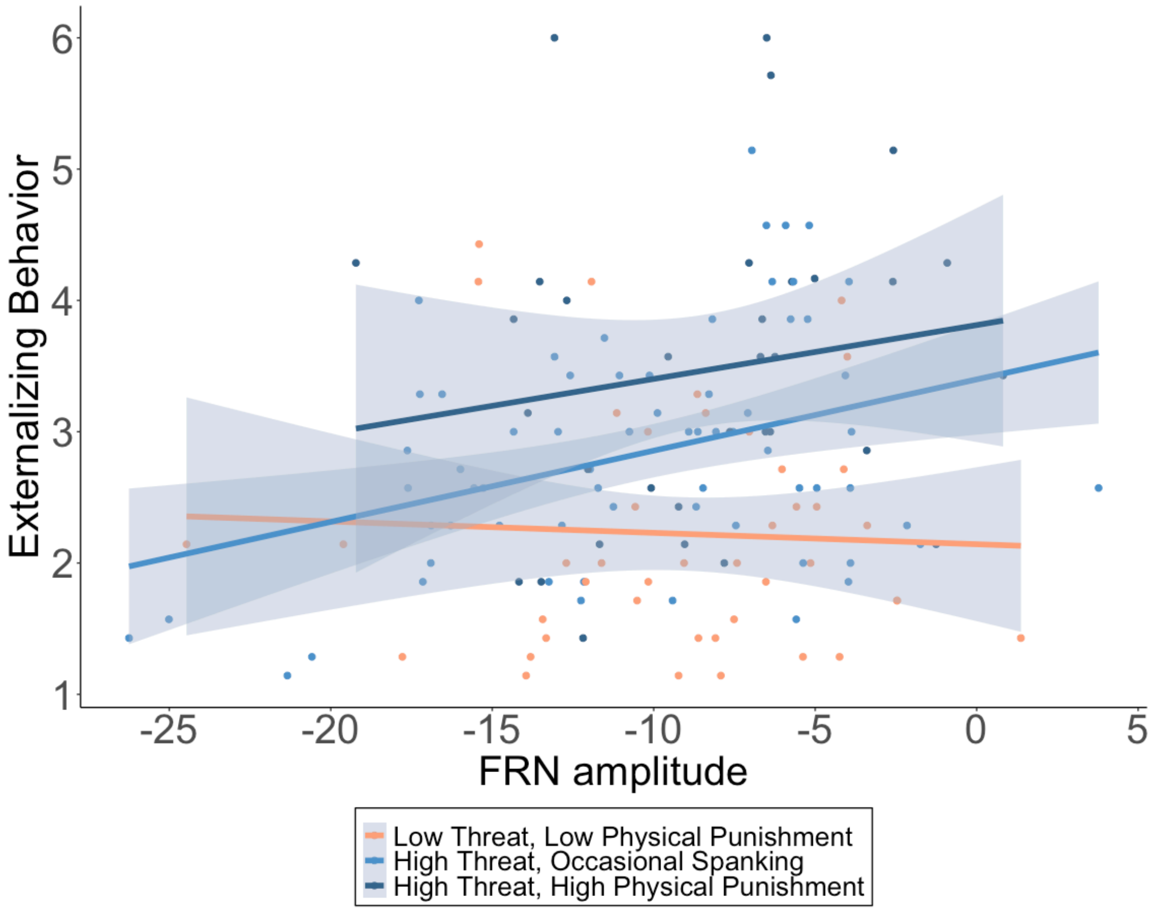

Figure 5: Association between FRN amplitude and externalizing behavior, grouped by caregiver punishment subgroups.

Note. The association between type of caregiver punishment and externalizing behavior did not differ significantly based on a child's FRN amplitude. There was a significant main effect of caregiver punishment profiles on children's externalizing symptoms, such that children in the High Threat, High Physical Punishment group had the highest levels of externalizing symptoms, followed by children in the High Threat, Occasional Spanking group. Shaded regions represent standard errors.

Chapter 4

Discussion

The present study examined whether neural sensitivity to negative feedback, as indexed by the feedback-related negativity (FRN) event-related potential, was associated with externalizing behavior in a sample of children presenting with the full range of externalizing symptoms. I also considered whether FRN amplitude, which is elicited via negative feedback in a laboratory setting, is associated with caregiver punishment, a type of negative feedback that children receive in the real-world. Lastly, I examined whether FRN amplitude moderated associations between caregiver punishment and externalizing behavior problems. I found that FRN amplitude is negatively correlated with child externalizing behavior problems, such that less negative FRN amplitudes are associated with higher levels of externalizing symptoms. However, I did not find evidence that FRN amplitude is associated with caregiver punishment, or that the association between caregiver punishment and child externalizing behavior differed based on a child's FRN amplitude. Below I discuss in detail how blunted sensitivity to negative feedback may confer risk for behavior problems in young children, and factors that may influence the ecological validity of these findings.

FRN Amplitude and Externalizing Behavior

Since previous studies have reported mixed findings regarding the association between FRN amplitude and externalizing behavior, I tested two competing hypotheses with the analysis – that the association could be linear (i.e., less negative amplitude confers risk) or U-shaped (both less and more negative amplitude confers risk). The present sample had elevated externalizing behavior problems and the full range of symptom severity was represented, so there was sufficient power to detect associations between feedback processing and externalizing behavior. I did not find evidence of a U-shaped association, but did find a significant negative linear association such that a less negative or more blunted FRN amplitude was associated with higher levels of externalizing behavior problems. This finding is consistent with a profile of low sensitivity to punishment cues, and parallels findings in adolescents and adults that a smaller FRN amplitude is associated with higher levels of externalizing and risk-taking behaviors (Massar et al., 2012; Sheffield et al., 2015), as well as psychopathic traits (Carter Leno et al., 2016). According to the reinforcement learning theory of the FRN (Holroyd & Coles, 2002), smaller FRN deflections signify that there are disruptions or inefficiencies in the neural pathways responsible for learning contingencies and adapting behavior. Some possible explanations include underactivity in midbrain dopamine neurons, disrupted neural connectivity between the basal ganglia and anterior cingulate cortex, or immature neural activity within the anterior cingulate cortex.

Importantly, the prefrontal cortices develop substantially across childhood and adolescence (Hämmerer & Eppinger, 2012; Kolk & Rakic, 2022; Velanova et al., 2008), so it is possible that a subset of children in the present sample will become more sensitive to punishment cues over time. Further, although the present study did not observe sex differences in FRN amplitude or moderation of study findings by sex, males tend to experience a more protracted development of the prefrontal cortex than females across childhood and adolescence (Kaczkkurkin et al., 2019; Markham & Juraska, 2002; Mutlu et al., 2013; Premachandran et al., 2020). It is therefore possible that sex differences may emerge later in development when group differences in prefrontal cortex maturation become more apparent, such that males may be more susceptible to ongoing difficulties with behavioral regulation. This is consistent with prior studies of the FRN in late childhood and adolescence, which have found that males have smaller FRN amplitudes than females in response to punishment cues (Ding et al., 2017; Santesso et al., 2011) and are less likely than females to optimally adapt behavior after punishment (Ding et al., 2017).

Previous findings that heightened sensitivity to negative feedback (i.e., more negative FRN amplitude) is associated with antisocial behavior in adults (Pfabigan et al., 2011), as well as hostility and trait anger in adolescents and adults (Rodrigues et al., 2020; Yi et al., 2012), may be driven by comorbidity with internalizing symptoms. An additional consideration is that associations between a more negative FRN amplitude and externalizing symptoms may emerge over time in the context of chronic stress or maltreatment. Constant exposure to environmental cues of threat may sensitize some individuals to negative feedback, which could lead to difficulties regulating emotions and behavior in the context of punishment cues. This is consistent with previous findings that a more negative FRN amplitude is associated with impulsivity in a sample of maltreated preschool-aged children (Roos et al., 2015) and that maltreated children have more activation of the anterior cingulate cortex after behavioral errors (Bruce et al., 2013; Lim et al., 2015).

Associations Among Caregiver Punishment, FRN Amplitude, and Externalizing Behavior

Latent Profiles of Caregiver Punishment

To better characterize punishment from caregivers, I conducted a latent profile analysis and identified three unique profiles of punishment in this sample. Contrary to my predictions, I did not identify a profile of parental laxness or low levels of all punishment strategies. This may be due to the characteristics of the present sample, as African American and Hispanic/Latino(a) caregivers are, on average, stricter and exert more control over their children's behavior than White caregivers, possibly due to cultural differences or heightened sociocontextual risk (e.g., discrimination, safety concerns in disadvantaged neighborhoods; Halgunseth et al., 2006; Richman & Mandara, 2013). Further, all three groups engaged in moderate to high levels of more inductive forms of discipline, including talking with the child about the behavior problem and using timeouts. The groups primarily differed in their use of harsher or more coercive punishment strategies, such as yelling at, threatening, or hitting the child. Caregivers in the first profile engaged in little to no use of harsher discipline strategies (Low Threat, Low Physical Punishment group). In contrast, caregivers in the second profile reported that they frequently threatened disciplinary action, including threatening to spank their children, but only occasionally actually spanked their children (High Threat, Occasional Spanking group). Caregivers in the third profile reported that they often threatened disciplinary action and often hit or spanked their children (High Threat, High Physical Punishment group). To examine whether children in these three profiles of caregiver punishment differed in FRN amplitude or externalizing behavior, I contrast-coded the groups. This allowed me to consider whether children who received any amount of threatening or physical punishment from their caregivers differed from children who did not typically receive these types of punishment, and to consider whether children who received occasional spankings differed from children who received high amounts of physical punishment from their caregivers.

Caregiver Punishment and FRN Amplitude

I found that there was no significant association between caregiver punishment and FRN amplitude. Children in all three profiles of caregiver punishment had similar distributions of FRN amplitudes. This result did not support the hypothesis that children who were less sensitive to negative feedback would have more difficulty learning associations between their behavior and punishment, and would therefore elicit higher amounts or harsher types of discipline from their caregivers. This null finding should be considered within the context of two possible validity concerns. First, it seems possible that FRN amplitude, while capturing sensitivity to feedback in an incentivized lab-based computer task, may not capture sensitivity to real-world feedback that children receive in their daily lives. This suggests that the FRN event-related potential has limited ecological validity when elicited in laboratory settings, such that lab-based findings may not extend to feedback processing in other contexts. This is in contrast to previous findings in adolescents and adults that self-reported sensitivity to punishment is associated with FRN amplitude (Massar et al., 2012; Santesso et al., 2011). These disparate findings suggest that there could be developmental differences in the ecological validity of FRN amplitude, such that the association between the FRN and sensitivity to real-world punishment unfolds over time. Conversely, the task design may be important for the real-world relevance of the FRN. Massar et al. (2012) and Santesso et al. (2011) each used gambling tasks, whereas the present study used a Go/No-Go task. These task designs differ in their outcome probabilities, as gambling tasks may include more unexpected losses that are known to elicit larger FRN deflections (see Martín, 2012, for a review).

A second validity concern is that the use of a self-report measure of caregiver discipline could have negatively impacted measurement validity, as self-reports of parenting behaviors are prone to recall bias and social desirability in responding (Morsbach & Prinz, 2006). Further, compared to high socioeconomic status families, Herbers and colleagues (2017) found that low socioeconomic status families have lower concordance between self-report and observational measures of parenting. Specifically, low-income families who were rated by observers as more punitive and controlling were more likely to rate themselves lower on these parenting behaviors. This disagreement between self-report and observational measures may reflect cultural differences across income brackets in the appropriateness of certain parenting behaviors (Herbers et al., 2017). An additional consideration is the possibility that, regardless of the disciplinary tactic employed, some caregivers may simply be less effective at making clear the contingent associations between the child's inappropriate behavior and the disciplinary consequences.

FRN Amplitude as a Moderator of Associations Between Caregiver Punishment and Externalizing Behavior

I did not find support for the third hypothesis that FRN amplitude would moderate associations between caregiver punishment and children's externalizing symptoms. Regardless of FRN amplitude, children who received higher amounts of harsh discipline had more externalizing behavior problems. Specifically, children in the High Threat, Occasional Spanking profile had more behavior problems than children in the Low Threat, Low Physical Punishment profile, and children in the High Threat, High Physical Punishment profile had more behavior problems than children in the High Threat, Occasional Spanking profile. This is consistent with previous findings that harsh disciplinary strategies are associated with higher levels of behavior problems in children, but inductive disciplinary strategies are associated with fewer behavior problems (Lee et al., 2013b; Ma & Grogan-Kaylor, 2017; MacKenzie et al., 2013).

The finding that FRN amplitude did not moderate associations between caregiver punishment and children's externalizing behavior problems has a couple possible explanations. First, this null finding may be due, in-part, to potential concerns in the present study with measurement validity of the caregiver punishment measure, as well as the ecological validity of the FRN. It is possible that FRN amplitude may differ as a function of context, and that the FRN elicited in the present lab-based Go/No-Go task may not correlate well with the neural response that is elicited when children receive corrective feedback from their parents. Conversely, a significant moderation effect may emerge over time as transactional processes unfold between caregivers and children (Choe et al., 2013; Pearl et al., 2014; Verhoeven et al., 2010). In kindergarten, children are still learning socially appropriate strategies for regulating negative emotions and impulsive behavior, so it is possible that any behavior problems that result from the interaction of punishment and feedback processing deficits may not manifest until later in childhood or adolescence.

Limitations and Future Research

The findings of the present study should be interpreted within the confines of several limitations. First, this study is cross-sectional, which provides information about a specific age group but does not inform developmental change. Since parent-child interactions influence child development dynamically over long periods of time, longitudinal studies are necessary to determine if the associations among neural sensitivity to negative feedback, externalizing behavior, and caregiver discipline change over time. However, it is noteworthy that there was an age range of five to seven years within this sample, and age was not significantly correlated with FRN amplitude. This suggests that there is at least not a strong between-person developmental association at this age. Second, children were not provided with feedback for correct responses in the present Go/No-Go task, so I could only examine the FRN for negative feedback. Prior studies of the FRN and externalizing behavior have primarily used a peak amplitude measure locked to negative feedback (Carter Leno et al., 2016; Grabell et al., 2017; Rodrigues et al., 2020; Yi et al., 2012) but some studies have used a difference wave where the peak amplitude in response to positive feedback is subtracted from the peak amplitude of the response to negative feedback (Massar et al., 2012; Pfabigan et al., 2011; Sheffield et al., 2015). Although FRN amplitude tends to be largest for negative feedback (see San Martín, 2012 for a literature review) and is most often examined using loss or error-related feedback cues, future research may consider examining the FRN in response to both positive and negative feedback cues in order to compare results more readily across studies. Lastly, the present sample is fairly homogenous, as the participants were recruited from a limited geographic region, were mainly low socioeconomic status, and were primarily African American and Hispanic/Latino(a). Although this study contributes to increased racial and socioeconomic diversity that is needed in psychophysiological science (Gatzke-Kopp, 2016), more research is necessary to determine if the results of the present study generalize across different samples.

Conclusions

The present study examined an event-related potential, the feedback-related negativity (FRN), as a marker of neural sensitivity to negative feedback in a sample of kindergarten children who were oversampled for externalizing behavior problems. I found that the association between punishment insensitivity and externalizing proneness is present early in childhood, as children with less negative FRN amplitudes in response to punishment cues had more externalizing behavior problems. These findings are at odds with recommendations from a recent meta-analysis of associations between the error-related negativity (ERN) and externalizing behavior (Lutz et al., 2021), which concluded that deficits in self-monitoring, as indicated by smaller ERN amplitudes, may be improved in individuals with behavior problems by providing external feedback about behavioral appropriateness. Since some individuals with behavior problems may also experience deficits in feedback processing, intervention efforts may instead benefit most from individualized programming after holistic assessment of several neurocognitive characteristics, including self-monitoring of behaviors and reward and punishment sensitivity (Matthys et al., 2012). The present study also found that FRN amplitude in a lab-based setting was not associated with caregiver punishment, a type of real-world negative feedback that young children receive, and FRN amplitude did not moderate associations between caregiver punishment and externalizing behavior problems. More research is needed to evaluate the ecological validity of the FRN across diverse experimental paradigms, and to examine whether associations among FRN amplitude, caregiver punishment, and externalizing behavior change across development.

References

Afifi, T.O., Mota, N.P., Dasiewicz, P., MacMillan, H.L., & Sareen, J. (2012). Physical punishment and mental disorders: Results from a nationally representative US sample. *Pediatrics, 130*(2), 184-192. https://doi.org/10.1542/peds.2011-2947

Aldao, A., Gee, D.G., De Los Reyes, A., & Seager, I. (2016). Emotion regulation as a transdiagnostic factor in the development of internalizing and externalizing psychopathology: Current and future directions. *Development and Psychopathology, 28*, 927-946. https://doi.org/10.1017/s0954579416000638

Arbel, Y., McCarty, K.N., Goldman, M., Donchin, E., & Brumback, T. (2018). Developmental changes in the feedback related negativity from 8 to 14 years. *International Journal of Psychophysiology, 132*, 331-337. https://doi.org/10.1016/j.ijpsycho.2018.01.004

Bauer, J. (2022). A primer to latent profile and latent class analysis. In Goller, M., Kyndt, E., Paloniemi, S., & Damsa, C. (Eds.), *Methods for researching professional learning and development* (pp. 243-268). Springer International Publishing. https://doi.org/10.1007/978-3-031-08518-5_11

Bellebaum, C. & Daum, I. (2008). Learning-related changes in reward expectancy are reflected in the feedback-related negativity. *European Journal of Neuroscience, 27*(7), 1823-1835. https://doi.org/10.1111/j.1460-9568.2008.06138.x

Bernat, E.M., Nelson, L.D., Stelle, V.R., Gehring, W.J., & Patrick, C.J. (2011). Externalizing psychopathology and gain-loss feedback in a simulated gambling task: Dissociable components of brain response revealed by time-frequency analysis. *Journal of Abnormal Psychology, 120*(2), 352-364. https://doi.org/10.1037/a0022124

Bruce, J., Fisher, P.A., Graham, A.M., Moore, W.E., Peake, S.J., & Mannering, A.M. (2013). Patterns of brain activation in foster children and non-maltreated children during an inhibitory control task. *Development and Psychopathology, 25*, 931-941. https://doi.org/10.1017/s095457941300028x

Buzzell, G.A., Richards, J.E., White, L.K., Barker, T.V., Pine, D.S., & Fox, N.A. (2017). Development of the error-monitoring system from ages 9-35: Unique insight provided by MRI-constrained source localization of EEG. *NeuroImage, 157*, 13-26. https://doi.org/10.1016/j.neuroimage.2017.05.045

Byrd, A.L., Loeber, R., & Pardini, D.A. (2013). Antisocial behavior, psychopathic features and abnormalities in reward and punishment processing in youth. *Clinical Child and Family Psychology Review, 17*(2), 125-156. https://doi.org/10.1007/s10567-013-0159-6

Carter Leno, V., Naples, A., Cox, A., Rutherford, H., & McPartland, J.C. (2016). Common and distinct modulation of electrophysiological indices of feedback processing by autistic and psychopathic traits. *Social Neuroscience, 11*(4), 455-466. https://doi.org/10.1080/17470919.2015.1108223

Cavanagh, J.F., Frank, M.J., Klein, T.J., & Allen, J.J.B (2010). Frontal theta links prediction errors to behavioral adaptation in reinforcement learning. *NeuroImage, 49*(4), 3198-3209. https://doi.org/10.1016/j.neuroimage.2009.11.080

Cavanagh, J.F., Zambrano-Vazquez, L., & Allen, J.B. (2012). Theta lingua franca: A common mid-frontal substrate for action monitoring processes. *Psychophysiology, 49*(2), 220-238. https://doi.org/10.1111/j.1469-8986.2011.01293.x

Choe, D.E., Olson, S.L., & Sameroff, A.J. (2013). The interplay of externalizing problems and physical and inductive discipline during childhood. *Developmental Psychology, 49*(11), 2029-2039. https://doi.org/10.1037/a0032054

Cohen, J., Cohen, P., West, S.G., & Aiken, L.S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). Lawrence Erlbaum Associates. https://doi.org/10.4324/9780203774441

Cohn, M.D., Veltman, D.J., Pape, L.E., van Lith, K., Vermeiren, R.R.J.M., van den Brink, W., Doreleijers, T.A.H., & Popma, A. (2015). Incentive processing in persistent disruptive behavior and psychopathic traits: A functional magnetic resonance imaging study in adolescents. *Biological Psychiatry, 78*(9), 615-624. https://doi.org/10.1016/j.biopsych.2014.08.017

Conduct Problems Prevention Research Group (1990). *Social Competence Scale – Teacher Version (T-COMP)*. PsycTESTS Dataset. https://doi.org/10.1037/t75897-000

Conduct Problems Prevention Research Group (1999). Initial impact of the Fast Track prevention trial for conduct problems: I. The high-risk sample. *Journal of Consulting and Clinical Psychology, 67*, 631-647. https://doi.org/10.1037/0022-006x.67.5.631

Corr, P.J. (2010). The psychoticism-psychopathy continuum: A neuropsychological model of core deficits. *Personality and Individual Differences, 48*(6), 695-703. https://doi.org/10.1016/j.paid/2009.12.023

Crowley, M.J. van Noordt, S.J.R., Wu, J., Hommer, R.E., South, M., Fearon, R.M.P., & Mayes, L.C. (2014). Reward feedback processing in children and adolescents: Medial frontal theta oscillations. *Brain and Cognition, 89*, 79-89. https://doi.org/10.1016/j.bandc.2013.11.011

Crowley, M.J., Wu, J., Hommer, R.E., South, M., Molfese, P.J., Fearon, R.M.P, & Mayes, L.C. (2013). A developmental study of the feedback-related negativity from 10-17 years: Age and sex effects for reward versus non-reward. *Developmental Neuropsychology, 38*(8), 595-612. https://doi.org/10.1080/87565641.2012.694512

Dadds, M.R. & Salmon, K. (2003). Punishment insensitivity and parenting: Temperament and learning as interacting risks for antisocial behavior. *Clinical Child and Family Psychology, 6*(2), 69-86. https://doi.org/10.1023/a:1023762009877

Davies, P.L., Segalowitz, S.J., & Gavin, W.J. (2004). Development of response-monitoring ERPs in 7- to 25-year-olds. *Developmental Neuropsychology, 25*(3), 355-376. https://doi.org/10.1207/s15326942dn2503_6

Denham, S.A., Workman, E., Cole, P.M., Weissbrod, C., Kendziora, K.T. & Zahn-Waxler, C. (2000). Prediction of externalizing behavior problems from early to middle childhood: The role of parental socialization and emotion expression. *Development and Psychopathology, 12*(1), 23-45. https://doi.org/10.1017/s0954579400001024

Ding, Y., Wang, E., Zou, Y., Song, Y., Xiao, X., Huang, W., & Li, Y. (2017). Gender differences in reward and punishment for monetary and social feedback in children: An ERP study. *PLoS ONE, 12*(3), e0174100. https://doi.org/10.1371/journal.pone.0174100

Dretzke, J., Davenport, C., Frew, E., Barlow, J., Stewart-Brown, S., Bayliss, S., Taylor, R.S., Sandercock, J., & Hyde, C. (2009). The clinical effectiveness of different parenting programmes for children with conduct problems: A systematic review of randomised controlled trials. *Child and Adolescent Psychiatry and Mental Health, 3*(1), 1-10. https://doi.org/10.1111/j.1365-2214.2009.00987_6.x

Durrant, J. & Ensom, R. (2012). Physical punishment of children: Lessons learned from 20 years of research. *Canadian Medical Association Journal, 184*(12), 1373-1377. https://doi.org/10.1503/cmaj.101314

Eisenberg, N., Losoya, S., Fabes, R.A., Guthrie, I.K., Reiser, M., Murphy, B., Shepard, S.A., Poulin, R., & Padgett, S.J. (2001). Parental socialization of children's dysregulated expression of emotion and externalizing problems. *Journal of Family Psychology, 15*(2), 183-205. https://doi.org/10.1037/0893-3200.15.2.183

Fanti, K.A. & Henrich, C.C. (2010). Trajectories of pure and co-occurring internalizing and externalizing problems from age 2 to age 12: Findings from the National Institute of

Child Health and Human Development Study of Early Child Care. *Developmental Psychology, 46*(5), 1159-1175. https://doi.org/10.1037/a0020659

Ferdinand, N.K., & Kray, J. (2014). Developmental changes in performance monitoring: How electrophysiological data can enhance our understanding of error and feedback processing in childhood and adolescence. *Behavioural Brain Research, 263*, 122-132. https://doi.org/10.1016/j.bbr.2014.01.029

Ferdinand, N.K., Becker, A.M.W., Kray, J., & Gehring, W. (2016). Feedback processing in children and adolescents: Is there a sensitivity for processing rewarding feedback? *Neuropsychologia, 82*, 31-38. https://doi.org/10.1016/j.neuropsychologia.2016.01.007

Frank, M.J., Woroch, B.S., & Curran, T. (2005). Error-related negativity predicts reinforcement learning and conflict biases. *Neuron, 47*(4), 495-501. https://doi.org/10.1016/j.neuron.2005.06.020

Gatzke-Kopp, L.M. (2016). Diversity and representation: Key issues for psychophysiological science. *Psychophysiology, 53*(1), 3-13. https://doi.org/10.1111.psyp.12566

Gatzke-Kopp, L.M., Greenberg, M.T., & Bierman, K. (2015). Children’s parasympathetic reactivity to specific emotions moderates response to intervention for early-onset aggression. *Journal of Child & Adolescent Psychology, 44*(2), 291-304. https://doi.org/10.1080/15374416.2013.862801

Gatzke-Kopp, L.M., Greenberg, M.T., Fortunato, C.K., & Coccia, Michael A. (2012). Aggression as an equifinal outcome of distinct neurocognitive and neuroaffective processes. *Development and Psychopathology, 24*(3), 985-1002. https://doi.org/10.1017/s0954579412000491

Gatzke-Kopp, L.M., Willner, C.J., Jetha, M.K., Abenavoli, R.M., Dupuis, D., & Segalowitz, S.J. (2015). How does reactivity to frustrative non-reward increase risk for externalizing symptoms? *International Journal of Psychophysiology, 98*(2), 300-309. https://doi.org/10.1016/j.ijpsycho.2015.04.018

Gershoff, E.T. (2002). Corporal punishment by parents and associated child behaviors and experiences: A meta-analytic and theoretical review. *Psychological Bulletin, 128*(4), 539-579. https://doi.org/10.1037/0033-2909.128.4.539

Gong, J., Yuan, J., Wang, S., Shi, L., Cui, X., & Luo, X. (2014). Feedback-related negativity in children with two subtypes of Attention Deficit Hyperactivity Disorder. *PLoS ONE, 9*(6), e99570. https://doi.org/10.1371/journal.pone.0099570

Grabell, A.S., Olson, S.L., Tardif, T., Thompson, M.C., & Gehring, W.J. (2017). Comparing self-regulation-associated event related potentials in preschool children with and without high levels of disruptive behavior. *Journal of Abnormal Child Psychology, 45*(6), 1119-1132. https://doi.org/10.1007/s10802-016-0228-7

Gratton, G., Coles, M.G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology, 55*(4), 468-484. https://doi.org/10.1016/0013-4694(83)90135-9

Gregory, S., Blair, R.J., Ffytche, D., Simmons, A., Kumari, V., Hodgins, S., & Blackwood, N. (2015). Punishment and psychopathy: A case-control functional MRI investigation of reinforcement learning in violent antisocial personality disordered men. *The Lancet Psychiatry, 2*(2), 153-160. https://doi.org/10.1016/s2215-0366(14)00071-6

Groen, Y., Wijers, A.A., Mulder, L.J.M., Minderaa, R.B., & Althaus, M. (2007). Physiological correlates of learning by performance feedback in children: A study of EEG event-related potentials and evoked heart rate. *Biological Psychology, 76*(3), 174-187. https://doi.org/10.1016/j.biopsycho.2007.07.006

Gu, R., Ge, Y., Jiang, Y., & Luo, Y. (2010). Anxiety and outcome evaluation: The good, the bad and the ambiguous. *Biological Psychology, 85*(2), 200-206. https://doi.org/10.1016/j.biopsycho.2010.07.001

Halgunseth, L.C., Ispa, J.M., & Rudy, D. (2006). Parental control in Latino families: An integrated review of the literature. *Child Development, 77*(5), 1282-1297. https://doi.org/10.1111/j.1467-8624.2006.00934.x

Hämmerer, D. & Eppinger, B. (2012). Dopaminergic and prefrontal contributions to reward-based learning and outcome monitoring during child development and aging. *Developmental Psychology, 48*(3), 862-874. https://doi.org/10.1037/a0027342

Hastings, P.D., Utendale, W.T., & Sullivan, C. (2007). The socialization of prosocial development. In J.E. Grusec & P.D. Hastings (Eds.), *Handbook of socialization: Theory and research* (pp.638-664). The Guilford Press.

Hauser, T.U., Iannaccone, R., Stämpfli, P., Dreschsler, R., Brandeis, D., Walitza, S., & Brem, S. (2014). The feedback-related negativity (FRN) revisited: New insights into the localization, meaning, and network organization. *NeuroImage, 84*, 159-168. https://doi.org/10.1016/j.neuroimage.2013.08.028

Herbers, J.E., Garcia, E.B., & Obradović, J. (2017). Parenting assessed by observation versus parent-report: Moderation by parent distress and family socioeconomic status. *Journal of Child and Family Studies, 26*(2), 3339-3350. https://doi.org/10.1007/s10826-017-0848-8

Holroyd, C.B & Coles, M.G. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review, 109*(4), 679-709. https://doi.org/10.1037/0033-295x.109.4.679

Huang, Y., Wu, T., Gao, Y., Luo, Y., Wu, Z., Fagan, S., Leung, S., & Li, X. (2019). The impact of callous-unemotional traits and externalizing tendencies on neural responsivity to reward and punishment in healthy adolescents. *Frontiers in Neuroscience, 13*, 1319. https://doi.org/10.3389/fnins.2019.01319

Humphreys, K.L., & Lee, S.S (2011). Risk taking and sensitivity to punishment in children with ADHD, ODD, ADHD+ODD, and controls. *Journal of Psychopathology and Behavioral Assessment, 33*(3), 299-307. https://doi.org/10.1007/s10862-011-9237-6

Ibrahim, K., Kalvin, C., Li, F., He, G., Pelphrey, K.A., McCarthy, G., & Sukhodolsky, D.G. (2021). Sex differences in medial prefrontal and parietal cortex structure in children with disruptive behavior. *Developmental Cognitive Neuroscience, 47*, 100884. https://doi.org/10.1016/j.dcn.2020.100884

Jaffee, S.R. (2017). Child maltreatment and risk for psychopathology in childhood and adulthood. *Annual Review of Clinical Psychology, 13*(1), 525-551. https://doi.org/10.1146/annurev-clinpsy-032816-045005

Jean-Richard-dit-Bressel, P., Lee., J.C., Liew, S.X., Weidemann, G., Lovibond, P.F., & McNally, G.P. (2021). Punishment insensitivity in humans is due to failures in instrumental contingency learning. *eLife, 10*, e69594. https://doi.org/10.1101/2021.04.23.441174

Jean-Richard-dit-Bressel, P., Ma, C., Bradfield, L.A., Killcross, S., & McNally, G.P. (2019). Punishment insensitivity emerges from impaired contingency detection, not aversion insensitivity or reward dominance. *eLife, 8*, e52765. https://doi.org/10.7554/elife.52765

Kaczkurkin, A.N., Raznahan, A., & Satterthwaite, T.D. (2018). Sex differences in the developing brain: Insights from multimodal neuroimaging. *Neuropsychopharmacology, 44*(1), 71-85. https://doi.org/10.1038/s41386-018-0111-z

Kihlstrom, J.F. (2021). Ecological validity and “ecological validity.” *Perspectives on Psychological Science, 16*(2), 466-471. https://doi.org/10.1177/1745691620966791

Kolk, S.M. & Rakic, P. (2021). Development of prefrontal cortex. *Neuropsychopharmacology, 47*(1), 41-57. https://doi.org/10.1038/s41386-021-01137-9

Lansford, J.E., Criss, M.M, Laird, R.D., Shaw, D.S., Pettit, G.S., Bates, J.E., & Dodge, K.A. (2011). Reciprocal relations between parents' physical discipline and children's externalizing behavior during middle childhood and adolescence. *Development and Psychopathology, 23*(1), 225-238. https://doi.org/10.1017/s0954579410000751

Lee, S.J., Altschul, I., & Gershoff, E.T. (2013a). Does warmth moderate longitudinal associations between maternal spanking and child aggression in early childhood? *Developmental Psychology, 49*(11), 2017-2028. https://doi.org/10.1037/a00031630

Lee, S.J., Taylor, C.A., Altschul, I., & Rice, J.C. (2013b). Parental spanking and subsequent risk for child aggression in father-involved families of young children. *Children and Youth Services Review, 35*(9), 1476-1485. https://doi.org/10.1016/j.childyouth.2013.05.016

Lees, T., Fry, C.M., Terrell, S., Jetha, M.K., Segalowitz, S.J., & Gatzke-Kopp, L.M. (2021). Developmental changes in external and internal performance monitoring across middle childhood: An ERP study. *International Journal of Psychophysiology, 169*, 20-33. https://doi.org/10.1016/j.ijpsycho.2021.09.002

Lewis, M.D., Lamm, C., Segalowitz, S.J., Stieben, J., & Zelazo, P.D. (2006). Neurophysiological correlates of emotion regulation in children and adolescents. *Journal of Cognitive Neuroscience, 18*(3), 430-443. https://doi.org/10.1162/jocn.2006.18.3.430

Li, N., Peng, J., & Li, Y. (2021). Effects and moderators of Triple P on the social, emotional, and behavioral problems of children: Systematic review and meta-analysis. *Frontiers in Psychology, 12*, 709851. https://doi.org/10.3389/fpsyg.2021.709851

Lim, L., Hart, H., Mehta, M.A., Simmons, A., Mirza, K., & Rubia, K. (2015). Neural correlates of error processing in young people with a history of severe childhood abuse: An fMRI study. *American Journal of Psychiatry, 172*(9), 892-900. https://doi.org/10.1176/appi.ajp.2015.14081042

Lutz, M.C., Kok, R., Verveer, I., Malbec, M., Koot, S., van Lier, P.A.C., & Franken, I.H.A. (2021). Diminished error-related negativity and error positivity in children and adults with externalizing problems and disorders: A meta-analysis on error processing. *Journal of Psychiatry and Neuroscience, 46*(6), E615-E627. https://doi.org/10.1503/jpn.20031

Luu, P., Tucker, D.M., Derryberry, D., Reed, M., & Poulsen, C. (2003). Electrophysiological responses to errors and feedback in the process of action regulation. *Psychological Science, 14*(1), 47-53. https://doi.org/10.1111/1467-9280.01417

Lysenko, L.J., Barker, E.D., & Jaffee, S.R. (2013). Sex differences in the relationship between harsh discipline and conduct problems. *Social Development, 22*(1), 197-214. https://doi.org/10.1111/sode/12002

Ma, J. & Grogan-Kaylor, A. (2017). Longitudinal associations of neighborhood collective efficacy and maternal corporal punishment with behavior problems in early childhood. *Developmental Psychology, 53*(6), 1027-1041. https://doi.org/10.1037/dev0000308

MacKenzie, M.J., Nicklas, E., Waldfogel, J., & Brooks-Gunn, J. (2013). Spanking and child development across the first decade of life. *Pediatrics, 132*(5), e1118-e1125. https://doi.org/10.1542/peds.2013-1227

Markham, J.A., & Juraska, J.M. (2002). Aging and sex influence the anatomy of the rat anterior cingulate cortex. *Neurobiology of Aging, 23*(4), 579-588. https://doi.org/10.1016/s0197-4580(02)00004-0

Marshall, K., Abate, A., & Venata, A. (2018). Posttraumatic stress symptoms and recidivism in serious juvenile offenders: Testing the mediating role of future orientation. *Journal of Child & Adolescent Trauma, 13*(1), 33-43. https://doi.org/10.1007/s40653-018-0234-8

Massar, S.A.A., Rossi, V., Schutter, D.J.L.G., & Kenemans, J.L. (2012). Baseline EEG theta/beta ratio and punishment sensitivity as biomarkers for feedback-related negativity (FRN) and risk-taking. *Clinical Neurophysiology, 123*(10), 1958-1965. https://doi.org/10.1016/j.clinph.2012.03.005

Matthys, W., Vanderschuren, L.J.M.J., & Schutter, D.J.L.G (2012). The neurobiology of Oppositional Defiant Disorder and Conduct Disorder: Altered functioning in three mental domains. *Development and Psychopathology, 25*(1), 193-207. https://doi.org/10.1017/s0954579412000272

Matthys, W., Vanderschuren, L.J.M.J., Schutter, D.J.L.G. & Lochman, J.E. (2012). Impaired neurocognitive functions affect social learning processes in Oppositional Defiant Disorder and Conduct Disorder: Implications for interventions. *Clinical Child and Family Psychology, 15*(3), 234-246. https://doi.org/10.1007/s10567-012-0118-7

Matthys, W., van Goozen, S.H.M., Snoek, H., & van Engeland, H. (2004). Response perservation and sensitivity to reward and punishment in boys with oppositional defiant disorder. *European Child & Adolescent Psychiatry, 13*(6), 362-364. https://doi.org/10.1007/s00787-004-0395-x

Maxwell, S.E., Delaney, H.D., & Kelley, K. (2018). *Designing experiments and analyzing data: A model comparison perspective* (3rd ed.). Routledge, Taylor, & Francis Group. https://doi.org/10.4324/9781315642956

McKee, L., Colletti, C., Rakow, A., Jones, D.J., & Forehand, R. (2008). Parenting and child externalizing behaviors: Are the associations specific or diffuse? *Aggression and Violent Behavior, 13*(3), 201-215. https://doi.org/10.1016/j.avb.2008.03.005

Mendez, M., Durtschi, J., Neppl, T.K., & Stith, S.M. (2016). Corporal punishment and externalizing behaviors in toddlers: The moderating role of positive and harsh parenting. *Journal of Family Psychology, 30*(8), 887-895. https://doi.org/10.1037/fam0000187

Meier, M.H., Slutske, W.S., Heath, A.C., & Martin, N.G. (2009). The role of harsh discipline in explaining sex differences in Conduct Disorder: A study of opposite-sex twin pairs. *Journal of Abnormal Child Psychology, 37*, 653-664. https://doi.org/

Meyer, M., Bekkering, H., Janssen, D.J.C., de Bruijn, E.R.A., & Hunnius, S. (2014). Neural correlates of feedback processing in toddlers. *Journal of Cognitive Neuroscience, 26*(7), 1519-1527. https://doi.org/10.1162/jocn_a_00560

Miltner, W.H.R., Braun, C.H., & Coles, M.G.H. (1997). Event-related brain potentials following incorrect feedback in a time-estimation task: Evidence for a “generic” neural system for error detection. *Journal of Cognitive Neuroscience, 9*(6), 788-798. https://doi.org/10.1162/jocn.1997.9.6.788

Mingebach, T., Kamp-Becker, I., Christiansen, H., & Weber, L. (2018). Meta-meta-analysis on the effectiveness of parent-based interventions for the treatment of child externalizing behavior problems. *PLoS ONE, 13*(9), e0202855. https://doi.org/10.1371/journal.pone.0202855

Moffitt, T.E. & Caspi, A. (2001). Childhood predictors differentiate life-course persistent and adolescent-limited antisocial pathways among males and females. *Development and Psychopathology, 13*(2), 355-375. https://doi.org/10.1017/s0954579401002097

Morsbach, S.K. & Prinz, R.J. (2006). Understanding and improving the validity of self-report of parenting. *Clinical Child and Family Psychology Review, 9*(1), 1-21. https://doi.org/10.1007/s10567-006-0001-5

Murray, L., Waller, R., & Hyde, L.W. (2018). A systematic review examining the link between psychopathic personality traits, antisocial behavior, and neural reactivity during reward and loss processing. *Personality Disorders: Theory, Research, and Treatment, 9*(6), 497-509. https://doi.org.10.1037/per0000308

Mutlu, A.K., Schneider, M., Debbané, M., Badoud, D., Eliez, S., & Schaer, M. (2013). Sex differences in thickness, and folding developments throughout the cortex. *NeuroImage, 82*, 200-207. https://doi.org/10/1016/j.neuroimage.2013.05.076

Newland, R.P. & Crnic, K.A. (2011). Mother-child affect and emotion socialization processes across the late preschool period: Predictions of emerging behavior problems. *Infant and Child Development, 20*(6), 371-388. https://doi.org/10.1002/icd.729

Nieuwenhuis, S., Holroyd, C.B., Mol, N., & Coles, M.G. (2004). Reinforcement-related brain potentials from medial frontal cortex: Origins and functional significance. *Neuroscience & Biobehavioral Reviews, 28*(4), 441-448. https://doi.org/10.1016/j.neubiorev.2004.05.003

Northoff, G. & Tumati, S. (2019). "Average is good, extremes are bad" – Non-linear U-shaped relationship between neural mechanisms and functionality of mental features. *Neuroscience & Biobehavioral Reviews, 104*, 11-25. https://doi.org/10.1016/j.neubiorev.2019.06.030

Nylund, K.L., Asparouhov, T., & Muthén, B.O. (2007). Deciding on the number of classes in latent class analysis and growth mixture modeling: A Monte Carlo simulation study. *Structural Equation Modeling, 14*(4), 535-569. https://doi.org/10.1080/10705510701575396

Oberski, D. (2016). Mixture models: Latent profile and latent class analysis. In Robertson, J. & Kaptein, M. (Eds.), *Modern statistical methods for human-computer interactions* (pp. 275-287). Springer International Publishing. https://doi.org/10.1007/978-3-319-26633-6_12

Olvet, D.M. & Hajcak, G. (2009). The stability of error-related brain activity with increasing trials. *Psychophysiology, 46*(5), 957-961. https://doi.org/10.1111/j.1469-8986.2009.00848.x

Pasion, R. & Barbosa, F. (2019). ERN as a transdiagnostic marker of the internalizing-externalizing spectrum: A dissociable meta-analytic effect. *Neuroscience & Biobehavioral Reviews, 103*, 133-149. https://doi.org/10.1016/j.neubiorev.2019.06.013

Patterson, G.R., DeBaryshe, B.D., & Ramsey, E. (1989). A developmental perspective on antisocial behavior. *American Psychologist, 44*(2), 329-335. https://doi.org/10.1037/0003-066x.44.2.329

Paus, T. (2001). Primate anterior cingulate cortex: Where motor control, drive, and cognition interface. *Nature Reviews Neuroscience, 2*(6), 417-424. https://doi.org/10.1038/35077500

Pearl, A.M., French, B.F., Dumas, J.E., Moreland, A.D., & Prinz, R. (2014). Bidirectional effects of parenting quality and child externalizing behavior in predominantly single parent, under-resourced African American families. *Journal of Child and Family Studies, 23*(2), 177-188. https://doi.org/10.1007/s10826-012-9692-z

Pek, J. & Flora, D.B. (2018). Reporting effect sizes in original psychological research: A discussion and tutorial. *Psychological Methods, 23*(2), 208-225. https://doi.org/10.1037/met0000126

Pfabigan, D.M., Alexopoulos, J., Bauer, H., Lamm, C., & Sailer, U. (2011). All about the money? External performance monitoring is affected by monetary, but not by socially conveyed feedback cues in more antisocial individuals. *Frontiers in Human Neuroscience, 5*, 100. https://doi.org/10.3389/fnhum.2011.00100

Pinquart, M. (2017). Associations of parenting dimensions and styles with externalizing problems of children and adolescents: An updated meta-analysis. *Developmental Psychology 53*(5), 873-932. https://doi.org/10.1037/dev0000295

Portengen, C.M., Sprooten, E., Zwiers, M.P., Hoekstra, P.J., Dietrich, A., Holz, N.E., Aggensteiner, P.M., Banaschewski, T., Schulze, U.M.E., Saam, M.C., Craig, M.C., Sethi, A., Santosh, P., Ouriaghli, I.S., Castro-Fornieles, J., Rosa, M., Arango, C., Penzol, M.J., Werhahn, J.E., … & Naaijen, J. (2021). Reward and punishment sensitivity are associated with cross-disorders traits. *Psychiatry Research, 298*, 113795. https://doi.org/10.1016/j.psychres.2021.113795

Premachandran, H., Zhao, M., & Arruda-Carvalho, M. (2020). Sex differences in the development of the rodent corticolimbic system. *Frontiers in Neuroscience, 14*, 583477. https://doi.org/10.3389.fnins.2020.583477

Rappaport, B.I. & Barch, D.M. (2020). Brain responses to social feedback in internalizing disorders: A comprehensive review. *Neuroscience & Biobehavioral Reviews, 118,* 784-808. https://doi.org/10.1016/j.neubiorev.2020.09.012

R Core Team. (2022). *R: A language and environment for statistical computing.* Retrieved from http://www.r-project.org/

Richman, S.B. & Mandara, J. (2013). Do socialization goals explain differences in parental control between Black and White parents? *Family Relations, 62*(4), 625-636. https://doi.org/10.1111/fare.12022

Rodrigues, J., Liesner, M., Reutter, M., Mussel, P., & Hewig, J. (2020). It's costly punishment, not altruistic: Low midfrontal theta and state anger predict punishment. *Psychophysiology, 57*(8), e13557. https://doi.org/10.1111/psyp.13557

Roos, L.E., Pears, K., Bruce, J., Kim, H.K., & Fisher, P.A. (2015). Impulsivity and the association between the feedback-related negativity and performance on an inhibitory control task in young at-risk children. *Psychophysiology, 52*(5), 704-713. https://doi.org/10.1111/psyp.12389

Rosenberg, J., Beymer, P., Anderson, D., van Lissa, C. J., & Schmidt, J. (2018). tidyLPA: An R package to easily carry out latent profile analysis (LPA) using open-source or commercial software. *Journal of Open-Source Software*, *3*(30), 978. https://doi.org/10.21105/joss.00978

Sagvolden, T., Johansen, E.B., Aase, H., & Russell, V.A. (2005). A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes. *Behavioral and Brain Sciences, 28*(3), 397-418. https://doi.org/10.1017/s0140525x05000075

San Martín, S.R. (2012). Event-related potential studies of outcome processing and feedback-guided learning. *Frontiers in Human Neuroscience, 6*, 304. https://doi.org/10.3389/fnhum.2012.00304

Santesso, D.L., Dzyundzyak, A., & Segalowitz, S.J. (2011). Age, sex, and individual differences in punishment sensitivity: Factors influencing the feedback-related negativity. *Psychophysiology, 48*(11), 1481-1489. https://doi.org/10.1111/j.1469-8986.2011.01229.x

Schad, D.J., Vasishth, S., Hohenstein, S., & Kliegl, R. (2020). How to capitalize on a priori contrasts in linear (mixed) models: A tutorial. *Journal of Memory and Language, 110*, 104038. https://doi.org/10.1016/j.jml.2019.104038

Schwenck, C., Ciaramidaro, A., Selivanova, M., Tournay, J., Freitag, C.M., & Siniatchkin, M. (2017). Neural correlates of affective empathy and reinforcement learning in boys with conduct problems: fMRI evidence from a gambling task. *Behavioural Brain Research, 320*, 75-84. https://doi.org/10.1016/j.bbr.2016.11.037

Shannon, K.E., Sauder, C., Beauchaine, T.P., & Gatzke-Kopp, L.M. (2009). Disrupted effective connectivity between medial frontal cortex and the caudate in adolescent boys with externalizing behavior disorders. *Criminal Justice and Behavior, 36*(11), 1141-1157. https://doi.org/10.1177/0093854809342856

Shaw, D.S., & Bell, R.Q. (1993). Developmental theories of parental contributors to antisocial behavior. *Journal of Abnormal Child Psychology, 21*(5), 493-518. https://doi.org/10.1007/bf00916316

Sheffield, J.G., Crowley, M.J., Bel-Bahar, T., Desatnik, A., Nolte, T., Fonagy, P., & Fearon, R.P. (2015). Reward-related neural activity and adolescent antisocial behavior in a community sample. *Developmental Neuropsychology, 40*(6), 363-378. https://doi.org/10.1080.87565641.2015.1101466

Shephard, E., Jackson, G.M., & Groom, M.J. (2014). Learning and altering behaviors by reinforcement: Neurocognitive differences between children and adults. *Developmental Cognitive Neuroscience, 7*, 94-105. https://doi.org/10.1016/j.dcn.2013.12.001

Sonkusare, S., Breakspear, M., & Guo, C. (2019). Naturalistic stimuli in neuroscience: Critically acclaimed. *Trends in Cognitive Sciences, 23*(8), 699-714. https://doi.org/10.1016/j.tics.2019.05.004

Spurk, D., Hirschi, A., Wang, M., Valero, D., & Kauffeld, S. (2020). Latent profile analysis: A review and "how to" guide of its application within vocational behavior research. *Journal of Vocational Behavior*, *120*, 103445. https://doi.org/10.1016/j.jvb.2020.103445

Stekhoven, D. J., & Bühlmann, P. (2012). MissForest- non-parametric missing value imputation for mixed-type data. *Bioinformatics*, *28*(1), 112–118. https://doi.org/10.1093/bioinformatics/btr597

Stieben, J., Lewis, M.D., Granic, I., Zelazo, P.D., Segalowitz, S., & Pepler, D. (2007). Neurophysiological mechanisms of emotion regulation for subtypes of externalizing children. *Development and Psychopathology, 19*(2), 455-480. https://doi.org/10.1017/s0954579407070228

Tan, P.Z., Oppenheimer, C.W., Ladouceur, C.D., Butterfield, R.D., & Silk, J.S. (2020). A review of associations between parental emotion socialization behaviors and the neural substrates of emotional reactivity and regulation in youth. *Developmental Psychology, 56*(3), 516-527. https://doi.org/10.1037/dev0000893

Tarver, J., Daley, D., Lockwood, J., & Sayal, K. (2014). Are self-directed parenting interventions sufficient for externalizing behaviour problems in childhood? A systematic review and meta-analysis. *European Child & Adolescent Psychiatry, 23*(12), 1123-1137. https://doi.org/10.1007/s00787-014-0556-5

Tobias, M.R. & Ito, T.A. (2021). Anxiety increases sensitivity to errors and negative feedback over time. *Biological Psychology, 162*, 108092. https://doi.org/10.1016/j.biopsycho.2021.108092

Tully, L.A. & Hunt, C. (2015). Brief parenting interventions for children at risk of externalizing behavior problems: A systematic review. *Journal of Child and Family Studies, 25*(3), 705-719. https://doi.org/10.1007/s10826-015-0284-6

Ullsperger, M., Danielmeier, C. & Jocham, G. (2014). Neurophysiology of performance monitoring and adaptive behavior. *Physiological Reviews, 94*(1), 35-79. https://doi.org/10.1152/physrev.00041.2012

van Buuren, S., & Groothuis-Oudshoorn, K. (2011). mice: Multivariate imputation by chained equations in R. *Journal of Statistical Software, 45*(3), 1-67. https://doi.org/10.18637/jss.v045.i03

van Meel, C.S., Oosterlaan, J., Heslenfeld, D.J., & Sergeant, J.A. (2005). Telling good from bad news: ADHD differentially affects processing of positive and negative feedback during guessing. *Neuropsychologica, 43*(13), 1946-1954. https://doi.org/10.1016/j.neuropsychologia.2005.03.018

Velanova, K., Wheeler, M.E., & Luna, B. (2008). Maturational changes in anterior cingulate and frontoparietal recruitment support the development of error processing and inhibitory control. *Cerebral Cortex, 18*(11), 2505-2522. https://doi.org/10.1093/cercor/bhn012

Verhoeven, M., Junger, M., van Aken, C., Deković, M., & van Aken, M.A. (2010). Parenting and children's externalizing behavior: Bidirectionality during toddlerhood. *Journal of Applied Developmental Psychology, 31*(1), 93-105. https://doi.org/10.1016/j.appdev.2009.09.002

Werthamer-Larsson, L., Kellam, S., & Wheeler, L. (1991). Effect of first-grade classroom environment on shy behavior, aggressive behavior, and concentration problems. *American Journal of Community Psychology, 19*, 585-602. https://doi.org/10.1007/bf00937993

Wickham, H., Chang, W., Henry, L., Pederson, T.L., Takahashi, K., Wilke, C., Woo, K., Yutani, H., & Dunnington, D. (2016). *ggplot2: Elegant graphics for data analysis.* Retrieved from https://cran.r-project.org/package=ggplot2

Wiersema, J.R., van der Meere, J.J., & Roeyers, H. (2007). Developmental changes in error monitoring: An event-related potential study. *Neuropsychologia, 45*(8), 1649-1657. https://doi.org/10.1016/j.neuropsychologia.2007.01.004

Williams, G.A. & Kibowski, F. (2016). Latent class analysis and latent profile analysis. In Jason, L.A. & Glenwick, D.S. (Eds.), *Handbook of methodological approaches to community-based research: Qualitative, quantitative, and mixed methods* (pp. 143-151). Oxford University Press. https://doi.org/10.1093/med:psych/9780190243654.003.0015

Yan, N., Ansari, A., & Peng, P. (2020). Reconsidering the relation between parental functioning and child externalizing behavior: A meta-analysis on child-driven effects. *Journal of Family Psychology, 35*(2), 225-235. https://doi.org/10.1037/fam0000805

Yi, F., Chen, H., Wang, X., Shi, H., Yi, J., Zhu, X. & Yao, S. (2012). Amplitude and latency of feedback-related negativity. *NeuroReport, 23*(16), 963-969. https://doi.org/10.1097/wnr.0b013e328359d1c4

Yordanova, J. & Kolev, V. (2007). Event-related brain oscillations in normal development. In Schmidt, L.A. & Segalowitz, S.J. (Eds.), *Developmental psychophysiology: Theory,*

systems, and method (pp. 15-68). Cambridge University Press.
https://doi.org/10.1017/cbo9780511499791.004