Motivated Attention to Social and Nonsocial Reward Images: Examining Relations with Externalizing Risk in Children

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Motivated Attention to Social and Nonsocial Reward Images: Examining Relations with Externalizing Risk in Children

A Dissertation Presented

by

ADAEZE C. EGWUATU

Submitted to the Graduate School of the University of Massachusetts Amherst in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

MAY 2022

Neuroscience and Behavior
Motivated Attention to Social and Nonsocial Reward Images: Examining Relations with Externalizing Risk in Children

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Neuroscience and Behavior Program
DEDICATION

To all my loved ones, in this dimension and the next. You all have contributed to making me the woman I am today, and for that, I thank you.
ACKNOWLEDGMENTS

I would like to thank my advisor, Jennifer M. McDermott, for her many years of guidance and support. I would also like to extend my gratitude to the other members of my committee, Kirby Deater-Deckard, Adam Grabell, and Koraly Edgar-Perez, for their helpful comments and suggestions on all stages of this project. I am also extremely thankful to all the undergraduate researchers who helped me prepare, run and process these studies. In particular, thank you to Kirsten Keller, Hannah Wisniewski, Yonah Joffee, and Jessica Yee for helping me do all the frustrating, but necessary, tasks of recruiting, entering, and processing (and reprocessing again) the data of over 100 participants I could not have completed this scale of a dissertation without you. I also wish to express my appreciation to all the children and their families who participated in this project. A special thank you to everyone who supported me and helped me stay focused during this process. I would like to thank my lab-mates and dearest friends, Chaia Flegenheimer and Sarah Jo Torgismson, for keeping me grounded and smiling throughout the highs and lows of my graduate program. I would also like to thank my former roommates- Steele H. Valenzuela, Deborah Denzel, William G. Rodriguez, Jessica Caballero-Feliciano, Christina Chisholm, and John Swenson, for being supportive comrades as we all walked through the fire. To my fellow BLACKademics, especially Mélise Edwards, Wayne Barnaby, Azaria Anderson, Michael Seifu, and Gorana Gonzalez (our honorary NSBer!)- thank you for always reminding me of who I am and what I am capable of, even when I have forgotten myself. Finally, I would like to thank my MVP, Joseph Dwyer. Thanks for being everything a person could wish for in a life partner. I love you with all my heart.
ABSTRACT

MOTIVATED ATTENTION TO SOCIAL AND NONSOCIAL REWARD IMAGES: EXAMINING RELATIONS WITH EXTERNALIZING RISK IN CHILDREN

MAY 2022

ADAEZE C. EGWUATU, B.S., UNIVERSITY OF FLORIDA
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Directed by: Professor Jennifer M. McDermott

Children that exhibit issues with externalizing behaviors often experience maladaptive outcomes in later life. Externalizing problems during middle childhood (e.g., 6-10 years old) are linked to issues with emotion regulation, which are, in turn, caused by disrupted attention and emotion reactivity to reward. Externalizing problems during this period have also been linked diminished processing of social reward stimuli, suggesting externalizing risk in children may be reflected in contrasting patterns in processing of non-social and social rewards. However, research comparing how differences in affective processing of specific reward content (i.e. social versus non-social) patterns relate to externalizing behavior within normative development is scarce. The following three studies aim to examine neural correlates of affective processing to social and non-social reward stimuli and their relation to externalizing problems in children using a novel, developmentally appropriate image set.

The first study (Chapter 2) explores neural processing of different reward categories using event-related potentials (ERPs) in children aged 6-10 years old. Larger ERP responses were associated with early salience processing to object-based (non-social) and intrapersonal reward (social) stimuli. However, larger responses in ERPs
associated with sustained processing to these same stimuli categories were associated with greater self-regulation deficits. Gender differences in processing emerged, such that boys showed greater sustained processing to object-based rewards (non-social) than girls.

The second study (Chapter 3) examined whether relations children’s ERP responses differed by gender. Greater externalizing problems in boys were associated with greater, indiscriminate processing of stimuli during early stages in neural processing. In contrast, greater externalizing problems in girls were associated with greater sustained processing of both object-based reward and neutral stimuli.

The final study (Chapter 4) sought to determine whether ERP responses to distinct forms of social and non-social reward stimuli moderated relations between temperamental traits associated with heightened positive/reward sensitivity (i.e., surgency) and externalizing problems in children. High surgency traits (e.g., impulsivity) in children were associated with greater parent-report of externalizing problems. High Surgency was also associated with greater sustained processing of object reward stimuli (non-social) and interpersonal reward stimuli (social). However, these sustained processing patterns did not moderate the relationship between temperament and externalizing problems. Instead, greater externalizing problems were related to greater processing of intrapersonal (social) compared to object-based reward stimuli in high surgency children during early stages in neural processing. Collectively, these results suggest an outsized role for stimulus identity and temporal organization in evaluating early markers for externalizing behavior problems in middle childhood.
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CHAPTER 1
BACKGROUND AND SIGNIFICANCE

1.1 Externalizing Behavior Problems in Childhood

The phrase “externalizing behaviors” describes a constellation of problematic behaviors that manifest externally and are directed toward an individual’s environment (Frick & Viding, 2009). These behaviors encompass a diverse array of issues such as aggression, rule-breaking, noncompliance, hyperactivity, and impulsivity. Externalizing issues can emerge at various points in time during development. However, externalizing behavior problems during childhood are especially significant because difficulties emerging during this period have been linked to maladjustment across several areas later in life.

For example, children with high levels of externalizing issues are more likely to experience limited academic success, poor social adjustment and increased interpersonal conflict, all of which can negatively impact the development of other major life skills (I. Bongers et al., 2007; Fergusson et al., 2005; Korhonen et al., 2018). Children showing high levels of externalizing behavior are more likely to develop clinical behavioral disorders, such as attention-deficit and hyperactivity disorder (ADHD), oppositional defiant disorder (ODD), and conduct disorder (CD; Frick & Thornton, 2017). Collectively, these disorders are amongst the most frequently diagnosed behavior disorders in children aged 7-18 years of age (Danielson et al., 2018; Ghandour et al., 2019).

Individuals whose externalizing difficulties emerge as children show more frequent and severe behavior problems than individuals who start exhibiting problem
behavior later in development (e.g., adolescence, Hinshaw, 2002; Moffitt et al., 2001). Early-onset individuals are more likely to develop risky, antisocial behaviors such as verbal/physical violence, lying, stealing, and vandalism (Jenson et al., 2011; Moffitt, 2006). In contrast, individuals with later-onset have issues that tend to be limited to adolescence as their problematic behaviors taper off in frequency and severity as they approach adulthood. The persistent pattern of problematic behaviors seen among early-onset individuals places them at significantly higher risk for a wide range of adverse outcomes and an overall poorer quality of life. Significant externalizing behavior issues in childhood have been linked to higher rates of drug and alcohol dependence, arrests and convictions, incarcerations, and greater need for social welfare services among adults (Foster & Jones, 2005; Galán et al., 2020).

Taken together, these reports highlight childhood externalizing behavior as a major risk factor, and a probable developmental precursor, for later antisocial behavior (Beech et al., 2018; J. Liu, 2004). Unfettered externalizing behavior negatively impacts children’s development, leading to social and behavioral problems that place significant burdens on the affected individual, their family, and society (Christenson et al., 2016). From this perspective, childhood externalizing behavior should be viewed as a major public health issue and highlights the need to identify children at high-risk for future problems (Stormont, 2000; Wakschlag et al., 2018).

Thus, a major approach of childhood externalizing research is to explore developmental processes that contribute to externalizing behavior problems during childhood. Recognizing these processes will help early awareness of features that best identify children at highest risk of developing behavioral issues. Tracking specific makers
of externalizing risk can give us greater insight into how underlying processes unfold over time, as well as help in determining sensitive periods and particular contexts in which behavioral difficulties are most likely to arise (Beauchaine & McNulty, 2013; Wakschlag et al., 2018). Therefore, the best way to unpack the relations between childhood externalizing behaviors and their related developmental outcomes is to explore underlying mechanisms that contribute to its etiology.

1.2. Middle Childhood as a Sensitive Period for Developing Externalizing Risk

From a psychopathological perspective, middle childhood also presents a critical point in emotional development where children are at heightened risk for externalizing problems. Children with externalizing difficulties are known to struggle with emotional dysregulation. Emotion dysregulation refers to a pattern in emotional response that impedes appropriate goal-directed behavior (Thompson, 1994a). Notably, these problematic emotional states persist despite an individual’s efforts to make the necessary adaptations to change their state and/or behavior (Beauchaine, 2015; Jazaieri et al., 2020). The strong link between emotional dysregulation and externalizing behavior in childhood suggests that early disruptions in emotional development may underlie emerging externalizing psychopathology.

Emotion dysregulation is a normal part of childhood development. In early childhood (e.g., infancy to 5 years), children are still learning how to manage their emotions and heavily rely on their adult caregivers to navigate them through emotional situations. Children are more likely to exhibit regular bouts of emotion dysregulation and engage in externalizing behavior; therefore, making it difficult to distinguish between
typical and atypical patterns of externalizing behavior during this period (Cole et al., 1994; Thompson, 1994b).

However, children show rapid shift in their emotion regulation abilities as they enter middle childhood (e.g., 6-10 years; Briggs-Gowan et al., 2006). As children approach school age (e.g., 5-6 years), they are met with increased behavioral and social expectations from their caregivers and peers (Wakschlag et al., 2005). This period also coincides with extensive neural development; children show rapid brain maturation and more efficient functional connectivity between brain areas involved in regulating emotions (Giedd et al., 2012; Kaczkurkin, Park, et al., 2019). Children begin to process and interpret their surroundings more effectively, giving them greater ability to manage and monitor their emotions to respond appropriately to situations (Mah & Ford-Jones, 2012). As a result, children become better at regulating interactions within their environment.

In typically developing children, middle childhood is marked with a decrease in externalizing behavior (Petersen et al., 2015). However, children with life-long externalizing difficulties show steady increases in the frequency and severity of externalizing behavior during this period (I. L. Bongers et al., 2004). Furthermore, increased externalizing problems during school age strongly predict externalizing problems during pre-adolescence (e.g., 11-12 years), which is a period marked with stabilizing externalizing symptoms and emerging psychopathology (Mesman et al., 2001; Moilanen et al., 2010a). Major shifts in externalizing behavior are linked to developmental changes across several brain areas involved in processing emotion (Lewis et al., 2008; Shader & Beauchaine, 2020; Whittle et al., 2020), which begin in early
middle childhood and peak during preadolescence (Giedd et al., 2012). These data suggest that altered neural patterns during emotion processing and regulation may presage externalizing problems in children.

Overall, this evidence suggests that emotional dysregulation in middle childhood is a major developmental factor that predicts lifelong externalizing risk. Altered development in brain regions related to emotion underscore emotion dysregulation during this period. Therefore, it is important to investigate developmental patterns in children’s processing of emotions and, more importantly, how variations in these patterns relate to externalizing risk in children (D. Schultz et al., 2004a).

1.3 Affective Processing as a Measure of Externalizing Risk in Children

Affective processing refers to the systematic processing of emotion-related information (Walla, 2018; Walla & Panksepp, 2013). Emotions\(^1\) are complex mental states that signal the presence of important information within our environment. These states also provide clues that shape how we act on that information (Campos et al., 2015; Damasio et al., 1994; LeDoux, 1995). Infinite, highly variable situations can elicit specific emotions, which makes understanding a single emotion, on its own, difficult. In addition, the same situation can also elicit very different emotions, depending on the situation in which it occurs. Therefore, affective processing plays a critical role in both managing and monitoring emotions by shaping evaluative judgments about incoming

\(^1\) The exact definition of an emotion is still contentiously debated. However, for the sake of this review, *emotions* can be described as mental states elicited spontaneously by external events that are accompanied by physiological, cognitive, and behavioral changes that occur throughout the body (Cabanac, 2002)
emotional signals and translating those inputs into useful information that can be used to produce flexible behavior.

1.3.1 Emotion-Cognition Interactions in Affective Processing

To effectively process emotions, a large amount of incoming sensory information must be parsed to make sense of the ongoing situation and the emotion(s) it elicits. Cognition is heavily involved in performing this affective processing; however, individuals, children especially, have limited cognitive resources to efficiently parse through this immense amount of information. Instead of trying to process all stimuli at once, we use our attention to effectively filter through competing stimuli by focusing on information that is most relevant to the current situation.

Emotional stimuli are prioritized during attention due to their inherent motivational salience (M. Bradley et al., 2003; Lang & Bradley, 2013; Suri & Gross, 2015). Motivational salience refers to a stimulus’ ability to command attention in relation to its motivational value (W. Schultz, 2015). The motivational value of an emotional stimulus is designated by valence associations between a stimulus and a certain outcome (Rolls, 2000). For example, positive emotions are elicited by stimuli associated with positive outcomes (positive value) and negative emotions are elicited by stimuli associated with negative outcomes (negative value). The amount of attention deployed toward an emotional stimulus depends on how valuable it is. Emotion stimuli with greater value will attract more attention than stimuli with lesser value. These enhancements in attention help us focus in on stimuli that are relevant to our goals. For example, rewards attract attention through their associations with positive outcomes; these stimuli elicit positive emotions that motivate actions towards them. In contrast, punishments attract
attention through their relations with negative outcomes; these stimuli evoke negative emotions, which motivate behavior away from them.

Although concepts of affective processing and affective experience are related to each other, it is worthy to note that these processes are functionally distinct. Affective experience\(^2\) relates more to the physiological reactions and behavioral expressions in response to emotion-inducing stimuli. Affective processing relates more to the evaluation of emotion-inducing stimuli and in relation to contingences surrounding ones’ goal (Walla, 2018; Wyer et al., 1999). In this sense, affective experience corresponds to the question “*how does this emotion make me feel?*”, while affective processing asks, “*what does this emotion mean in relation to my goals?*”.

### 1.3.2 Temporal Dynamics underlying Affective Processing

Another major component integral to affective processing is time. Emotions are states in constant flux and are distinguished by their ebb and flow. Emotions differ across several features, such as their time of onset (threshold), rise time, intensity, duration, persistence, and frequency (Ryo et al., 2019; Waugh et al., 2015b). Due to the great variability in the temporal dynamics of emotions, time is a central parameter that must be considered when operationalizing affective processing in children.

One emotion model that accounts for temporal dynamics in affective processing is the Process Model of Emotion Regulation (PMER) proposed by Gross and colleagues (Gross, 1998a, 1998b; Gross & Thompson, 2007; Jazaieri et al., 2020). The PMER takes

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\(^2\) The exact definition of an emotion is still contentiously debated. However, for the sake of this review, *emotions* can be described as mental states elicited spontaneously by external events that are accompanied by physiological, cognitive, and behavioral changes that occur throughout the body (Cabanac, 2002)
a cognitive science approach to describe temporal interactions occurring between emotion and cognition and how these interactions work to both generate and regulate emotions. According to this model, affective processing unfolds across two distinct stages: emotion generation and emotional regulation. Affective processing that occurs during the emotion generation stage serves to produce a meaningful emotion response whereas processing during the emotion regulation state is focused on modulating emotional responses.

Affective processing during emotion generation comprises four distinct phases. (Gross, 1998b). First, affective processing is initiated by an emotionally inducing stimulus; exposure to this event marks the situation phase. Attentional resources are directed toward the situation leading to the attention phase. Subsequently, during the appraisal phase, one must evaluate the situation to assess the meaning of the situation and its motivational relevance. The evaluation gives way to the response phase, where a response emerges in the form of a physiological and/or behavioral reaction. Appraisal gives way to the response phase, where an emotional response emerges in the form of a physiological and/or behavioral reaction. This emotional response involves visceral changes throughout the whole body. This whole-body experience is interchangeably referred to as emotional reactivity or affective reactivity in the literature.

The temporal phases involved in generating emotion highlight critical points where active affective processing can be employed to regulate and modulate emotional responses (Gross, 1998a). For instance, emotions can be regulated before an emotional response occurs. Attention and appraisal phases can be modulated by selectively refocusing attention somewhere else or by cognitively reframing the initial appraisal of
the situation (Gross, 1998b; Gross & Jazaieri, 2014). Additionally, emotion can be modulated during or after an emotional response. For example, suppressing an emotion or engaging behaviors to alter your affective response (e.g., watching a happy movie when you are sad) are instances where affective processes can be modulated after a response has transpired.

Overall, the PMER model emphasizes the dynamic nature of affective processing. Although affective processing comprises several, functionally-distinct stages that each unfold on their own time scale (Waugh et al., 2015c), modulations during each stage can significantly impact the temporal course and pattern of other stages in processing. For example, the initial attention and appraisal phases of the emotion generation stage of affective processing can occur automatically and unfold very quickly (e.g., milliseconds). However, particularly motivationally salient stimuli may elicit strong emotion responses that engage further expenditure of attentional and evaluative resources in order to modulate qualitative features of emotions (e.g., intensity, duration, frequency) that support adaptive responses (Kuppens & Verduyn, 2017). This elaborated processing is more conscious and emerges later over longer periods of time (e.g., seconds, minutes, hours).

These affective processing stages also unfold in a cyclical, non-linear fashion. Processes involved in producing emotion (e.g., attention and appraisal) inform processes responsible for regulation of that emotion (e.g., redirecting attention, reappraisal). Likewise, affective information gathered after an emotional response (or after attempting to regulate that response) will influence how future emotions are elicited and, in turn, how future emotions are regulated. Thus, affective processing can generally be seen as a
feedback process, where each feedback loop enables us to gather information learned from prior experiences and to use this information to maximize the capacity to regulate affective states (McRae & Zarolia, 2020; Riedel et al., 2018). In all, the PMER provides an excellent framework detailing how emotional, cognitive, and motivational aspects of affective processing interact to drive emotion regulation and support adaptive behavior.

Although the PMER conceptualizes how emotion regulation occurs in adults, this model can be helpful in framing how affective processing supports the development of children’s emotion regulation abilities (or lack thereof). Emotion regulation requires children to both assess the relative value of a situation (e.g., is it positive or negative) and monitor if the emotion that situation elicits sufficiently aligns with their goals (Lazarus, 1991). Subsequently, they need to learn from the information gained from emotional experiences needs be held to steer future responses (Baumeister et al., 2007; Clore & Huntsinger, 2007). To do this, children must be able to sufficiently track and organize salient information across environmental contexts. Therefore, children’s ability to regulate their emotions is linked to their capacity to engage cognitive process, like attention.

Young children do not have the neural capacity to effectively support complex cognitive processes needed to efficiently process and regulate emotions. However, as children approach early school age (e.g., around 5-6 years), their cognitive capabilities improve rapidly due to extensive brain development throughout middle childhood (Campbell, 2011). With these improvements in cognitive function, children can begin to engage in more sophisticated strategies to control their emotions during this period, that become less effortful and more automatic over time (Calkins & Marcovitch, 2010).
### 1.3.3 Affective Processing and Maladaptive functioning during Childhood

The PMER framework highlights critical points in time where disruptions in affective processing could lead to maladapted functioning. Vulnerabilities during early steps in processing can cause downstream effects that negatively impact other affective components, in turn compromising the entire affective processing system. Disordered processing during the attention and appraisal phases of emotion generation could distort representations of emotional information associated with an eliciting event. These widespread deficits would impede a person’s ability to extract meaningful information from their affective experiences, making them ill-equipped to interpret their emotions with its relevant. Disrupted processing during these stages could also led to unstable shifts in temporal dynamics (e.g., intensity, duration, frequency, rise time), resulting maladaptive emotional responses. Indeed, perturbed emotional reactivity has long been linked to emerging psychopathology in children (Davidson, 1998; Thompson, 1994a).

Moreover, affective processing deficits during emotion generation can feed into problems during emotion regulation. Successful emotion regulation requires that an individual *identify* when emotions need to be regulated, appropriately *select* and *implement* actions to regulate these experiences, and *monitor* whether these actions lead to emotional impulses consistent with one’s goals (Gross & Jazaieri, 2014). These steps are facilitated by the successful integration of emotional and cognitive information, as well as feedback, gathered during affective processing (McRae & Zarolia, 2020; Riedel et al., 2018). However, disruptions occurring early in affective processing (e.g., attention and appraisal) could inhibit children’s ability to form and draw on associations made during current and past experiences, thus leading to poor emotional regulation and
increased externalizing behavioral problems later in life (Izard et al., 2015). In fact, issues with detecting and evaluating emotions are prominent features among children exhibiting chronic emotional dysregulation (Bjureberg et al., 2016). Thus, from a developmental perspective, investigating patterns unfolding during the earliest stages of affective processing (i.e., attention) may be helpful in differentiating between typical and atypical variations in emotional development. Such signatures would provide researchers with great predictive utility in identity children most at-risk for externalizing problems.

Many developmental researchers have embraced the concepts described in Gross’s PMER model. This framework is commonly used to explain the link between emotion dysregulation and externalizing etiology (Halligan et al., 2013; Röll et al., 2012). For instance, many studies fail to fully implement several key principles of the PMER model in their research designs. Most researchers aim to understand how affective processes lead to problems regulating emotion in children and how those problems relate to externalizing difficulties. This approach has led to increased research emphasis on disrupted emotion reactivity as a possible marker of externalizing risk.

However, narrowing research focus on emotion reactivity and emotion dysregulation in relation to externalizing risk can be limiting because this approach does not account for evidence pointing to equifinality in externalizing behavior trajectories. Equifinality is the concept that a particular outcome (e.g., externalizing behavior) can occur through multiple paths (Nolen-Hoeksema & Watkins, 2011). Several contrasting emotion reactivity patterns have been reported in children with externalizing behavior problems. For example, externalizing difficulties have been linked to both elevated negative reactivity (Gatzke-Kopp et al., 2015; Kalvin et al., 2016), and diminished
negative reactivity (Kimonis et al., 2006; Masi et al., 2014), as well as heightened positive reactivity (Foell et al., 2016; Scott et al., 2020) or diminished positive reactivity (Conzelmann et al., 2009; Fortunato et al., 2013). Some study findings have also reported associations with externalizing behavior and diminished emotion reactivity independent of valence (Musser et al., 2013; Sharp et al., 2008). These diverse study results indicate that externalizing behavior is associated with emotion reactivity patterns that transcend across the affective spectrum. More so, these findings highlight individual differences in emotion reactivity, specifically along dimensions relating to core affect\(^3\) (e.g., valence and arousal). These differences need to be accounted for when investigating the link between affective processing and development of externalizing behavior in children.

Many studies that exclusively focus on emotion reactivity in children also neglected other key components involved in affective processing, such as attention and perception. These processes are time-sensitive and unfold over a temporal sequence that culminates in affective response (i.e., emotion reactivity). In this view, when researchers examine emotion reactivity in children, they are observing the output (i.e., emotion generation). Thus, centering study measures on emotion reactivity provides a limited perspective regarding the underlying mechanisms related to externalizing risk in children. In doing so, researchers fail to address the critical impact that prior cognitive-emotion interactions have in shaping these affective processes.

\(^3\) The exact definition of an emotion is still contentiously debated. However, for the sake of this review, *emotions* can be described as mental states elicited spontaneously by external events that are accompanied by physiological, cognitive, and behavioral changes that occur throughout the body (Cabanac, 2002)
Converging research shows that children with externalizing problems demonstrate marked cognitive deficits during affective processing tasks. Poor emotion recognition and slower processing of emotional stimuli has been associated with externalizing difficulties in children (Chronaki, 2016; Rehder et al., 2017; Wells et al., 2020). These relations are more pronounced in children who have been clinically diagnosed with externalizing behavior disorders (e.g., ADHD, ODD, CD; (B. Corbett & Glidden, 2000; Hartmann & Schwenck, 2020; Vandewouw et al., 2020). Successful emotion recognition relies on children’s ability to attend to and encode relevant information (Hartmann & Schwenck, 2020; Schwenck et al., 2013). Thus, deficits in emotion recognition imply that children with externalizing problems may have trouble extracting critical information in their environment due to impaired attention. Externalizing problems have also been linked with perturbed emotional perception. Emotion perception biases and perception errors have previously been linked to elevated externalizing symptoms in at-risk children (S. E. Martin et al., 2009; D. Schultz et al., 2004b). Poor emotional perception has also been linked to dysregulated emotion reactivity and externalizing behavior in children (Factor et al., 2016; Göbel et al., 2016).

Moreover, externalizing children appear to show cognitive biases to emotion that are valence specific. Namely, these biases are characterized by heightened attention and emotional reactivity to positive rewarding stimuli. Attention biases to positive stimuli, but not negative stimuli, have been linked to both coinciding (Cremone et al., 2018; Morales et al., 2016; Susa Erdogan et al., 2017) and future externalizing problems in preschool children (He et al., 2017a; Morales et al., 2019). The patterns seen in attention studies is consistent with work showing heightened reward sensitivity in children with
externalizing behavior (Fortunato et al., 2013; Gatzke-Kopp et al., 2009; Kohls et al., 2009; Tenenbaum et al., 2018). Biased attention to positive information reflects increased motivational salience and suggests heightened reward sensitivity in children with externalizing behaviors (Beauchaine & McNulty, 2013; Kleberg et al., 2021). Therefore, heightened attention and emotional reactivity toward positive, rewarding stimuli may be a prominent feature of externalizing risk.

However, a potential limitation exists within the research linking reward biases in attention with externalizing problems in children. Prior studies are inconsistent with the types of reward stimuli used during task-paradigms. For example, studies have used socially-oriented reward stimuli (e.g., faces; Cremone et al., 2018; Morales et al., 2016, 2019; Susa Erdogan et al., 2017), non-social reward stimuli (He et al., 2017b), or a mix of social/non-social reward (Broeren & Lester, 2013; Herpers et al., 2019a). Converging evidence suggest that social and non-social rewards recruit overlapping, but functionally distinct, processes (Izuma et al., 2008; Matyjek et al., 2020; Norris et al., 2004). Therefore, attentional patterns to reward stimuli, and their relations to externalizing risk in children, may depend on the type of reward stimuli used (e.g., social vs non-social). To our knowledge, very little work has compared the effects of social and non-social reward on attention in a normative child sample. Thus, research examining affective processing differences between social and non-social reward stimuli is needed to ascertain attention patters associated with typical and atypical development.

In summary, aberrations in emotional attention and perception present as possible etiological factors underlying externalizing behavior in children. Specifically, these aberrations may impair the ability to make accurate interpretations about affective
experiences and situational context surrounding that experience (Locke et al., 2015; Locke & Lang, 2016). These findings speak to the major role that cognitive and motivational processes have in appraising and amassing information relevant to emotion processing. Thus, externalizing behavior problems in children do not only stem from perturbed emotion reactivity and/or emotion dysregulation. Instead, externalizing issues may also arise from altered cognitive-emotion interactions that disrupt the information processing of emotion, specifically emotional valence (e.g., reward).

1.2.1 Social Affective Processing

Affective processing is also impacted by social development as emotions are very experience dependent. One of the most profound experiences that humans’ encounter are interactions with other people. Children learn to share and regulate their emotions through early social interactions with their caregivers, family, and peers (Shuman, 2013). From these interactions, children become skilled at modulating both their emotions and behavior by anticipating the emotional states and needs of other people; skills that are especially useful as social interactions become more varied and complex with increasing age (Junge et al., 2020). Therefore, it is important to explore the influence of social information in affective processing to understand its contribution to adaptive and maladaptive outcomes in children (Marinetti et al., 2011; van Kleef et al., 2016).

One theoretical perspective that explores these associations is the Social Information Processing (SIP) model. This social cognitive framework examines how children process and interpret information when engaging in a social situation, and how that information influence pathways toward typical and atypical social behavior (Crick & Dodge, 1994). According to this model, children’s processing of social interactions
unfolds over six steps. It begins with the encoding of cues (step 1). Encoding generally encompasses selectively attending to cues, external or internal, that are most relevant. Next, children interpret these cues (step 2). During this step, children attribute causes to the event and make inferences about the intentions of other people involved in the interaction. After the child interprets the situation, they must clarify the desired outcome (step 3). For example, a child may be motivated to socially engage to acquire or maintain a friendship with another child. Once a goal is established, children formulate possible responses to the situation (step 4) and evaluate the anticipated outcomes and consequences of these responses that are most compatible with their goal (step 5). Finally, children act on the behavioral response (step 6). These steps are initiated again when children evaluate feedback from the resulting behavioral outcome.

Moreover, the SIP model posits that these processing steps occur in a non-linear, cyclical fashion. Each step unfolds rapidly and works in parallel with each other. This level of parallel processing creates a series of feedback loops which provide ongoing sources of information about the proceeding interaction at every step (Crick & Dodge, 1994). The monitoring of such information is useful in reinforcing the enactment of adaptive behavior. Also, feedback from these steps allow for the construction of meaningful representations of social situations. These representations form a cognitive repository of acquired social rules, schemas, and knowledge that children can pull on for future use. It is important to note that perturbations at any step in this model can result in maladaptive behavior. As children develop, social information processing becomes increasingly influenced by past events and social experiences.
One acknowledged limitation of the SIP model is that it does not account for emotion within this framework. Social interactions are inherently arousing events and would elicit emotions in children. Thus, emotions are sources of information that would impact social processing. Lemerise and Arsenio (2000) built upon the SIP theory by integrating emotion and cognitive processes into the model. They proposed that emotion impacts social processing at the beginning stage. As the social encounter is an emotion-eliciting event, children must encode and interpret these emotional cues. Vice versa, the encoding and interpretation of emotion cues can lead to resulting changes in children’s emotional states (Crick & Ladd, 1993). Thus, a major factor driving social information processing is the intensity of the child’s emotional experience as well as their capacity to regulate their emotions (Lemerise & Arsenio, 2000).

Another major factor in this sequence is that children must also encode and interpret the emotional cues displayed by the person(s) they are interacting with. In other words, the ability to examine other’s emotional states in relation to one’s own, and select an appropriate response, are determining factors in effective social processing and social engagement. Collectively, these associations influence how children consider and value information when making decisions about behavior within a social context (Niven, 2017; Van Kleef, 2009).

Principles from the SIP model has guided research aimed at better understanding the processes that underlie externalizing problems in children. Researchers believe that externalizing behavior problems originated from deficits in several stages of social processing (Lansford et al., 2006; Van Rest et al., 2020). Externalizing issues have been linked problems occurring early in social information processing. (e.g., step 1 and 2).
Children with externalizing problems are more likely to focus on fewer cues and encode cues less accurately than those typically developing children (Martel, 2019). For example, several studies show that children with externalizing problems have problems recognizing and identifying the cues of others (Horsley et al., 2010; Hunnikin et al., 2020). Specifically, extensive research has demonstrated that externalizing children are more likely perceive ambiguous interactions as hostile and attribute negative intentions toward peers, leading to more negative peer relations (Choe et al., 2013; Hartmann & Schwenck, 2020). These early social processing deficits can lead to downstream deficits during later stages of social processing (Harper et al., 2010; Lansford et al., 2006). For example, children who display issues encoding and interpreting social cues are more likely to choose goals that are more compatible with externalizing behavior (i.e., step 3- clarifying goals), limit their potential behavioral responses to externalizing ones (i.e., step 4- response formulation), and place increased value on externalizing anticipate rewarding outcomes from externalizing outcomes and place increased value on externalizing behavior (step 5-response evaluation and decision). Together, these aberrant patterns increase children’s chances of displaying externalizing behavior (step 6- behavior enactment). Thus, social information processing deficits start a “vicious cycle” that reinforces and maintains externalizing behavior in children and stunts their social development (Crick & Dodge, 1994).

When applying an affective lens, it is possible that pervasive social processing deficits associated with externalizing issues in children are linked to issues processing and responding to emotional information. Children experiencing intense emotions are likely to limit their focus on social cues and inaccurately encode and misinterpret social
information (Van Rest et al., 2020). These elevated emotions may also inhibit attempts to regulate emotions; motivating to select impulsive, maladaptive responses while ignoring adaptive behavioral alternatives (Lemerise & Arsenio, 2000). Likewise, failure to attend and react emotionally to others emotional cues is a SIP pattern thought to equally encourage externalizing behavior (Choe et al., 2013). Children with externalizing problems may be less likely to pay attention to prosocial cues from others or perceive these cues as positive or important. Furthermore, they may be less likely to react emotionally to depictions of social cues, or value positive social interactions and favor prosocial behavior (Hartmann & Schwenck, 2020). This evidence implies that that inability to attend and react to social cues is a major childhood risk factor for emerging externalizing problems.

In sum, evidence suggest that childhood externalizing problems may stem from problems encoding and interpreting the social and emotional cues of others in social interactions. These early social-emotional processing deficits negatively impact children’s decision-making and reinforce externalizing behavior. Each stage in the SIP model is dependent on early encoding of social cues as well as the emotional stages of others’ and their own. Thus, encoding can be considered the most critical stage in both social and affective processing.

Encoding processes are greatly facilitated by attention. Attention gates social information by placing selective focus on the most relevant information (Capozzi & Ristic, 2018). Attention also shapes behavior as individuals are more likely to frame their decisions and actions to information that most engage and maintain their attention. Attentional preferences to social cues emerge very early in development. Extensive
research has established that children display significant attention biases to social cues (e.g., faces) than to non-social cues (e.g., objects) as early as infancy (Bhat et al., 2010; Leppänen & Nelson, 2009; Maylott et al., 2020). Furthermore, these patterns are more sustained if these social cues are emotional rather than non-emotional in nature (LoBue & DeLoache, 2010; Peltola et al., 2008; Stahl et al., 2010). Both social and emotional biases in attention are further shaped by the experiences that individuals encounter, and these patterns become more solidified over development (LoBue, 2009; Salley & Colombo, 2016). Thus, attentional patterns to social and emotional cues are an important marker to study, especially when examining developmental problems rooted in social and emotional processing and regulation difficulties in children, such as externalizing disorders.

Research on social cognition development provide further evidence towards how aberrant social attention can serve as a developmental precursor of externalizing problems in children. Social attention plays a major role in scaffolding social cognitive processes, such as empathy (Bons et al., 2013; Wellman et al., 2004). Empathy is a fundamental component in social information processing that promotes positive socio-emotional functioning and social behavior (Findlay et al., 2006; Junge et al., 2020; Lemerise & Arsenio, 2000). Reduced empathy has been cited as a common feature present in children at high-risk for externalizing problems (Moul et al., 2018; Shirtcliff et al., 2009; van Langen et al., 2014). Specifically, externalizing problems are associated with impaired affective empathy, which refers the ability to share and respond to emotions and feelings of other people (Paz et al., 2021; Schipper & Petermann, 2013). In contrast, social attention is associated with higher levels of affective empathy (Dadds et
al., 2006; Herpers et al., 2019b; Noten et al., 2019; von Polier et al., 2020). Together, these works demonstrate how social and emotional attention both serve to promote socioemotional development and reduce externalizing risk.

Research specifically examining the role of social and emotional attention in relation to emerging externalizing difficulties is limited. However, converging evidence from several studies highlight associations between perturbed social attention and externalizing problems in children. For example, several studies have linked reduced attention to social stimuli to externalizing behavior in children (Bedford et al., 2015; Dadds et al., 2011; Dadds & Frick, 2019; Hoyniak et al., 2019; Waller, Corbett, et al., 2020). Similar deficits in social attention have been reported in adults displaying severe externalizing and antisocial behaviors (Jusyte & Schönenberg, 2017; Kimonis et al., 2020; Marsh & Blair, 2008; Waller et al., 2021a). These findings suggest that emerging externalizing issues in childhood could possibly stem from early problems attending to social cues. Persistent issues with encoding social information may exacerbate externalizing behavior leading to problems that endure throughout development.

It must be noted that the majority of work examining links between social attention and externalizing tend to focus on negative emotions, like anger and threat (Chronaki, 2016). In turn, relations between social attention to positive stimuli (e.g., happy faces, social reward) and externalizing problems in children has received lesser attention. Limited work with older children and adolescents have reported links with externalizing problems reduced attention bias and reactivity to positive social stimuli (Demurie et al., 2011; Herpers et al., 2019b; Jenness et al., 2021; Perino et al., 2019). These results contrast with research in younger children reporting links between
heightened attention bias to social reward and externalizing problems (He et al., 2017c; Morales et al., 2020). On the surface, these inconsistent findings point to age-related variation in cognitive-emotion interactions among externalizing individuals (Grisanzio et al., 2021; Jenness et al., 2021; Lindstrom et al., 2009). However, children who show persistent and more severe problem behaviors as they age tend to present worse outcomes. Thus, these age-related discrepancies may highlight developmental changes in social affective processing in high-risk children (Jenness et al., 2021).

Combined, this evidence suggests cognitive-emotion patterns associated with externalizing behavior may not only depend on valence, but also on context (i.e., social versus nonsocial). It is possible reduced attention to positive social stimuli and increased attention to non-social reward stimuli may influence the onset and maintenance of externalizing problems among children. However, few studies make clear distinctions between social and non-social stimuli content when examining externalizing behavior in children. Thus, more research exploring relations between social and nonsocial distinctions in affective processing and externalizing risk is needed.

1.3 Neural Correlates of Affective Processing & Externalizing Risk

Over the years, research implementing neurobiological measures have gained increased popularity. Emotions are functional states. They guide and drive our behavior and these states are constructed within the brain (Adolph et al., 2017; Barrett, 2017). To understand how deficits in affective processing impact externalizing behavior, one must examine underlying mechanisms influencing affective processing within typical populations. Unpacking questions of where and how affect is typically processed in the brain can help direct research focus on specific neural mechanisms contributing to
externalizing problems. Moreover, assessing neurobiological measures gives information about mechanisms and etiological factors that cannot be understood via self-report or observation approaches. Neural correlates are also great for examining developmental changes within the brain and body associated with significant shifts in behavior. Determining biological vulnerability can help identify which individuals are at more risk for problems and thus help untangle heterogeneity seen in behavioral and self-report formats.

A significant body of research has been dedicated to identifying both the structural and functional neuroanatomy involved in mediating affect. Although the functional neural circuitry has not been fully delineated, advances in human neuroimaging (e.g., fMRI) have provided extensive insights into the major neural regions involved in generating, detecting, and regulating affect. An overview of these key brain structures is discussed below.

1.3.1 Neural Networks Implicated in Affective Processing

Undoubtedly, neuroanatomical studies have expanded our knowledge of the specific regions involved in affect. However, in recent years, neuroanatomical models of affect have shifted away from the notion that specific affective processes are linked to select regions. Instead, proponents of more contemporary models endorse that affective processes reflect wide-scale information processing through the engagement of large brain circuits (Chang et al., 2015; Pessoa, 2018). A multitude of evidence shows that the key affective regions highlighted above are extensively connected and these connections allow for heavy communication between regions (Pessoa, 2017; Vuilleumier, 2005). For example, subcortical structures involved in emotional generation (e.g., amygdala, ventral
striatum) communicate directly with frontal cortical regions involved in emotional regulation (e.g., OFC, vmPFC, insula, ACC) via neural projections to these sites (Pessoa, 2017). Equally, these cortical regions direct inputs back to subcortical regions, thus modulating affective processing. These neural circuits allow for multiple levels of affective processing as cortical-subcortical circuits permit the brain to process information from multiple brain regions simultaneously. Reversely, a single region can impact several processes it receives information from (as well as sends information to) across several other regions from across the brain. Brain regions linked to affect have also been shown to be involved in several processes, such as motor, somatosensory, motivation, and perceptual processing (Adolphs, 2003). Thus, affect processing should not be viewed as a set of discrete processes influenced by a group of isolated regions. Instead, affective processing can be conceptualized as an iterative process that intertwines information across regions involved in multiple processes (e.g., emotion, motivation, motor, perception) in order to enable flexible and complex behavior.

Since affective processing requires concurrent activation of several regions, a network approach allow us to attribute specific affective processing deficits seen in externalizing populations to disrupted functional patterns within dissociable neural systems (Spunt & Lieberman, 2012). There are three major neural networks implicated in general emotional processing: the amygdala network, salience network, and executive control network.

*The amygdala network* is associated with emotional evaluation and emotional regulation (Kennedy & Adolphs, 2012; Zald, 2003). The amygdala network is rooted in the amygdala (hence the name) and comprises functional connections with the OFC and
vmPFC (Bickart et al., 2014; Kennedy & Adolphs, 2012). Evidence also indicates that the amygdala network includes fronto-stratial pathways, which modulate affective valuation of reward and are shown to play a significant role in emotional regulation and motivated behavior (Etkin et al., 2015; Ochsner et al., 2012; Tekin & Cummings, 2002; Waraczynski, 2006). The salience network plays a crucial role in orienting attention toward biologically and cognitively relevant events (Eckert et al., 2009; Menon & Uddin, 2010). This network is also involved in monitoring changes in external events and linking these events with internal body-related signals to adaptively guide attention. The anterior insula (AI) and the ACC are the major nodes of this network (Bressler & Menon, 2010).

The salience network also includes three key subcortical structure involved emotion and reward processing- the amygdala, ventral striatum, ventral tegmental area, and thalamus (Pessoa & McMenamin, 2017). Last, the executive control network is involved in higher-order cognition (e.g., controlled attention, goal-oriented processing, working memory) and is crucial in supporting executive functions and impulse control (Bressler & Menon, 2010; Seeley et al., 2007). The major nodes of this network consist of functional connections between frontal and parietal regions, such as the dorsolateral prefrontal cortex (dlPFC), dorsal ACC (dAcc), frontal eye fields, and posterior parietal cortex (Comte et al., 2016).

Regarding socioemotional processing, these key networks have been highlighted as networks that subserve social processes and behavior. The amygdala network plays a primary role in socioemotional processing (Happé & Frith, 2014). Prior research suggest that the amygdala network supports social perception and affiliative motivation- the motivation to value and seek social bonds with others. The functional anatomy of the
The amygdala network within social context involves the same regions in general affective processing, with the inclusion of a few extended regions. The extended regions included structures located in the temporal regions, such as the superior temporal sulcus (STS), fusiform gyrus, temporo-parietal junction (TPJ), and hippocampus.

The empathy network is crucial to detecting and responding to other’s emotion. The insula and amygdala are major nodes in this system; other relevant nodes include the ventral striatum, ACC, medial prefrontal cortex (mPFC), and the medial OFC (Decety, 2010; Weisz & Zaki, 2018). Finally, the mentalizing network is involved in the automatic attribution of mental states, as well as self-referential processing and perspective taking (Cerniglia et al., 2019; Frith & Frith, 2003). This network is anchored in the dorsal medial prefrontal cortex (dmPFC) and includes functional connections with the temporal regions like the TPJ, temporal pole, and precuneus (Weisz & Zaki, 2018).

Overall, these networks share multiple overlapping regions that work in concert to mediate several aspects of affective processing.

1.3.1.1 Developmental trajectories of Neural Networks Implicated in Affective Processing

Work examining the development of affective processing and its extended networks provide a preliminary sketch of how these systems support emotional and social functioning over time. In an extensive literature review by Happé & Frith (2014), the authors thoroughly detail the developmental chronology of major emotional and social milestones during typical development and their associated neural networks. The literature shows that these networks, although underdeveloped, are functional from birth, (see also Decety, 2010; Socta-Icza et al., 2015).
During early childhood (e.g., 1 year to 5 years), a period of extensive emotional and social development starts to unfold; this period is marked by increased emotional recognition, emerging morality and prosocial, emerging self-awareness, and social learning capabilities (Happe & Frith, 2014). This surge in skill development is thought to reflect extended development of regions within amygdala, empathy, and mentalizing networks (Happe & Frith, 2014). Middle childhood (e.g., 6-12 years) is marked by the substantial gains in self-regulation capabilities, such as emotion regulation and executive functioning. These gains are mediated by development of structures within the executive control network, starts to come online strongly during this period (Engelhardt et al., 2019; Etkin et al., 2015; Hartung et al., 2020). Concurrently, this period is also marked by increasing maturation of the prefrontal cortical structures (e.g., mPFC, OFC, ACC) across all networks as well as increased strengthen connectivity between subcortical structures (e.g., amygdala, striatum) and cortical structures, resulting increased top-down control of emotion. Combined, the gains in emotional and social capabilities attributed to this stage of maturation in prefrontal brain circuitry are prominently seen during middle childhood.

1.3.2 Structural and Functional Neural Networks Related to Externalizing Problems

Significant neuroimaging evidence demonstrate a link between externalizing behaviors and distinct structural and functional alterations in affect-related structures. For example, decreased gray matter volume in the amygdala, frontal (OFC, insula, cingulate) and temporal regions have been linked to externalizing difficulties in children (Ameis et al., 2014; Fahim et al., 2011; Thijssen et al., 2015). Smaller brain volume in dorsal lateral PFC and partial regions has also been linked to atypical neurocognitive development in children within this population (Fairchild et al., 2013; Thijssen et al., 2015). Among
studies examining brain morphology in boys and girls with limited prosocial emotion, externalizing problems were linked to decreased volume in amygdala, anterior insula, and ventral striatum (De Brito et al., 2009; Fairchild et al., 2013; Raschle et al., 2018) and this pattern has also been reported in adolescents (Waller, Hawes, et al., 2020). Structural abnormalities in the OFC, ACC, and temporal lobes have also been documented in children (De Brito et al., 2009; Fairchild et al., 2013) and incarcerated adolescents (B. M. Caldwell et al., 2019) with socioemotional deficits. Externalizing behavior in childhood has also been linked to structural abnormalities in these regions during adolescence (Caldwell et al., 2015), providing further evidence that childhood externalizing problems are rooted in aberrations in brain development.

In addition to brain morphology, altered structural connectivity between neural regions has been linked to externalizing behavior. White matter (WM) connects brain regions together and facilitates integration of information via coordinated cross talk between neural regions. Thus, developing strong WM connections is foundational to maintaining efficient neural networks. Specifically, structural connectivity research as focused on the inferior longitudinal fasciculus, inferior fronto-occipital fasciculus, cingulum, and uncinate fasciculus as these tracts physically connect key regions involved in several networks implicated in general affective processing (amygdala, salience, executive control) and social affective processing (e.g., amygdala, empathy, mentalizing).

Decreased integrity in these white matter (WM) tracts has been linked to aggressive behavior and conduct problems in children (Bolhuis et al., 2019; Burley et al., 2020; Grazioplene et al., 2020), and adolescents (Sarkar et al., 2012). This work is consistent with several findings supporting links between altered WM structure and
antisocial behavior in adults (see Waller et al., 2017). Similar WM patterns have also emerged in studies examining individuals exhibiting limited emotional and prosocial behavior. Several studies have linked decreased WM integrity with higher levels of conduct problems in children and adolescents (e.g., Breeden et al., 2015), as well as typically developing adults (e.g., Dotterer et al., 2020) and adult criminal offenders (Motzkin et al., 2011). Thus, these findings highlight distinct structural differences, as well as extensive disruptions in connectivity across several neural networks, among externalizing populations across development. These works also provide evidence linking disrupted neural networks with deficient social and affective processing and emerging externalizing issues.

Functional neuroimaging research (i.e., functional MRI) has further built upon structural neuroimaging findings. Resting-state fMRI research has revealed distinct patterns in intrinsic activity among individuals with significant socio-affective and externalizing difficulties. For example, one study found that adolescent offenders with externalizing problems (i.e., conduct disorder) show decreased resting functional connectivity within the amygdala and frontal regions (e.g., vmPFC and OFC); these circuits are involved in generating and regulating emotion, and associative learning, suggesting deficient affective processing among externalizing youth (Aghajani et al., 2017). This finding is corroborated by prior work in clinically referred children (Finger et al., 2012) and adult offenders (Motzkin et al., 2011), that reveal similar links between externalizing behavior and reduced functional coupling between these areas.

In contrast, externalizing adolescent offenders showed increased resting connectivity in the amygdala with striatal and frontoparietal regions (e.g., associative
areas, ACC); these circuits are known to mediate reward processing, attention, and perception (Aghajani et al., 2017, 2021). Notably, these functional patterns only emerged in externalizing adolescents with significant socio-affective deficits (Aghajani et al., 2017). Functional activity in externalizing adolescents without socio-affective deficits exhibited activity like typical developing adolescents, suggesting individuals exhibiting both externalizing and socio-affective difficulties show a neural profile distinct from other externalizing groups. Additional work found that these functional connectivity patterns were linked to distinct social, affective, and behavioral dimensions. For example, Aghajani et al. (2016) found that exaggerated functional connectivity in circuits mediating reward processing and social cognition were associated with antisocial tendencies. Furthermore, weak functional connectivity in circuits serving salience processing and emotion reactivity were associated with diminished affective responding among adolescent offenders. Interestingly, behavioral deficits (e.g., impulsivity, recklessness) among this group were distinctly related to altered connectivity in circuits implicated in executive control (Aghajani et al., 2016).

Task related fMRI research further complements findings from structural brain and resting-state activity studies by providing insights about neural mechanism that are process-specific. Externalizing problems have consistently been linked to diminished amygdala functional activity during affective processing in children and adolescents (Alegria et al., 2016; Noordermeer et al., 2016). In addition to diminished amygdala functioning, research shows that externalizing youths also exhibit disrupted functional connectivity with several prefrontal and temporal regions when processing affective stimuli. Implicated regions include vmPFC, OFC, insula, ACC, hippocampus, and
temporal sulcus (Finger et al., 2012; Hwang et al., 2016; Passamonti et al., 2010; Stadler et al., 2007; Sterzer et al., 2005). These deficits correspond with adult studies reporting similar neural aberrations (Kiehl et al., 2001; Motzkin et al., 2011). Furthermore, in studies examining functional activity in early versus adolescent-onset externalizing populations, disruption in these circuits are more pronounced in early-onset externalizers (Fairchild et al., 2013; Passamonti et al., 2010), suggesting that neural dysfunction leads to the emergence (and maintenance) of externalizing issues in at-risk children (Matthys et al., 2013a; Sterzer et al., 2005; Tyler et al., 2019).

In all, these findings indicate impaired information processing systems in groups high in externalizing. More specifically, these studies show that externalizing individuals show abnormal communication within circuits implicated in emotion and cognition. These abnormalities signify aberrant emotion-cognition interactions, as well as elevated reward sensitivity, which may lead to impaired processing of affective information in this population. Moreover, these neural patterns only emerged in externalizing populations with significant deficits in social and affective domains, thus externalizing problems may emerge through different neurodevelopmental pathways.

1.3.3 Neurophysiological Measures of Affective Processing

Neuroimaging studies provide useful information linking alterations in structural and functional brain circuitry to specific forms of externalizing vulnerability in children. However, one major limitation of these techniques is that they cannot precisely capture fluctuations in neural activity over time. For example, techniques such as fMRI use indirect measures (e.g., blood flow) to assess neural activity on the timescale of seconds (Logothetis, 2002). However, neurons can process various forms of information in the
matter of milliseconds (Nemenman et al., 2008; Stanford et al., 2010). The brain can complete several processes within a second timescale (i.e., 1,000 milliseconds), thus timing of the fMRI signal makes it difficult to pinpoint distinct neural processes in time. As previously mentioned, affective processing reflects a series of subprocesses that occur cyclically and interchangeably, depending on the situational context (see Gross, 2015). Given the low temporal resolution of the fMRI signal, this limitation makes it difficult to untangle the temporal dynamics occurring in neural activity during distinct stages in affective processing, and further, distinguish distinct patterns in neural activation that predict deficits in affective processing.

Electrophysiological techniques, such as electroencephalography (EEG), present as more suitable methods for capturing the rapid changes in neural activity, especially during multi-faceted processes such as affect. EEG uses electrodes to record electrical brain activity at the scalp. The neural signals collected at the scalp reflect the summation of postsynaptic potentials resulting from synchronous firing of cortical neurons, thus making EEG a direct measure of neural activity (Banaschewski & Brandeis, 2007). This precise capture of neural responding contributes to the high temporal resolution of EEG, as researchers can record neural activity on the scale of milliseconds. A further benefit of the EEG technique is that distinct stages in neural processing can be characterized by linking neural activity to specific events. These event-locked segments of EEG activity are referred to as event-related potentials (ERPs) and are useful in illustrating the fluctuations in neural activity across time (see Hajcak et al., 2010; Ibanez et al., 2012). ERPs consists of sequential shifts in voltage that can be used to index distinct temporal stages in neural processing. For example, with ERPs, researchers can more easily
compare changes in neural activity during early and later stages of affective processing (i.e., implicit, and explicit processing). This temporal preciseness is especially useful when investigating at-risk populations as researchers can use ERPs to identify aberrant patterns of neural activity at specific levels of processing.

1.3.3.1 The Late Positive Potential (LPP)

The LPP is a positive, slow wave ERP component that appears around 300ms after stimuli onset (for review see: Hajcak et al., 2012; Olofsson et al., 2008). This component is typically found over central and parietal sites on the scalp, however the LPP has been shown to shift to more anterior regions over time (Foti et al., 2009; Hua et al., 2014; Macnamara et al., 2009). The LPP is thought to reflect sustained attention to affective content, such as pictures (Hajack, MacNamara, & Olvet, 2010, Olofsson et al., 2008). Studies have consistently demonstrated that the LPP is enhanced for affective stimuli (e.g., both positive and negative) compared to neutral stimuli (Cuthbert et al., 2000; Schupp, Cuthbert, et al., 2004; Schupp, Junghöfer, et al., 2004), and for more arousing pictures compared to less arousing pictures (Cuthbert et al., 2000; Schupp et al., 2006; Schupp, Junghöfer, et al., 2004). It has also been shown that the LPP can be downregulated (i.e., attenuated amplitudes) when participants are given explicit instructions when reappraising affective content (DeCicco et al., 2014; Van Cauwenberge et al., 2017). Together, these findings indicate that the LPP can serve as a neural index of both emotional reactivity/arousal and emotional regulation.

Research collecting EEG and fMRI data simultaneously have linked the LPP to functional activity in several brain regions; these regions include the visual cortex, temporal cortex, partial cortex, amygdala, ventral striatum, ACC, OFC, mPFC and insula
(M. M. Bradley et al., 2003; Y. Liu, Huang, Mcginnis-Deweese, et al., 2012a; Peyk et al., 2008; Sabatinelli, Bradley, et al., 2007; Sabatinelli et al., 2012). These findings imply that the LPP reflects engagement of a wide scale of neural networks over time as several of these brain areas have been shown to overlap in several processes such as attention, perception, motivation, emotion, and cognition. This flexible engagement of neural networks may also explain the dynamic spatiotemporal pattern in the LPP demonstrated across several studies (e.g., shift of maximal amplitudes from partial to anterior sites) and further suggest that the LPP may reflect the unfolding of several distinct processes over time (Foti et al., 2009).

Some evidence suggests that active neural networks reflected by the LPP are specific to the stimuli category. For example, Liu et al. (2012), found that the LPP elicited by each affective category (i.e., positive and negative) was associated with a different set of regions. Specifically, for positive stimuli, the LPP was distinctly associated with activity in the mPFC and nucleus accumbens (i.e., ventral striatum); this pattern was also coupled with activation in the superior partial lobe (involved in perceptual processing) and variability in amygdala activity (Liu et al., 2012). These areas are involved with emotional salience/perception and reward processing. In contrast, the LPP to unpleasant pictures were associated with areas involved in both emotional perception and motor control. This finding is consistent with theories suggesting that emotional valence is driven by the activation of two separate motivational circuits (Roseman, 2008; Simpson & Balsam, 2016). These theories claim that positive stimuli activate a reward circuit that motivates an individual to approach stimuli (i.e., approach motivation), whereas as negative valanced stimuli activate a separate circuit that
motivates individuals to avoid stimuli (i.e., avoidance motivation). This result, combined with the observed relations between the LPP and regions involved in attention and perceptual processing (frontal and parietal regions), further complement prior work purporting that enhanced LPP activity reflects the increased allocation of attentional resources toward motivationally-relevant stimuli (Moratti et al., 2004; Schupp, Cuthbert, et al., 2004).

The LPP also presents a promising neural index of emerging emotional development in children as it is developmentally robust and is strongly elicited in children as young as 5 years old (Dennis & Hajcak, 2009; Hajcak & Dennis, 2009). Several studies have demonstrated that the LPP can be reliably measured several years later and that activity patterns remain stable across individual children over time (Babkirk et al., 2015; Pegg et al., 2019). Thus, this work suggests that the LPP is ideal for assessing real-time affective processing in children.

Considerable research also suggests that altered LPP patterns may be a predictor of emerging psychopathology in children. Several studies have linked aberrant LPP activity to clinical disorders, such as anxiety and depression (for review, see Chronaki, 2016). However, work examining relations between the LPP and emerging externalizing problems in children is scarce. Furthermore, out of the few studies that have examined the LPP in the context of externalizing symptomatology, the majority of these studies focus on negative valence only (Cheng et al., 2012; Ellis et al., 2017). However, select studies provide some evidence that the LPP may be sensitive to altered affective processing in externalizing youths. In a study by Pincham, Bryce, & Fearon (2015), researchers found that increased antisocial behavior was associated with attenuated LPPs.
to both positive and negative pictures in juvenile offenders. These findings consistent with other studies citing hypo-responsivity to emotional information as a predictor of externalizing problems (Pincham et al., 2015). In a follow-up using the same sample, participants showed enhanced processing of emotional images (i.e., larger LPPs) following a psychosocial intervention (Pincham et al., 2016). However, this trend in the LPP was only significant for negative-valanced images. The authors noted that the lack of change in the LPPs to positive content may have been due to limitations in stimuli material, most notably the lack of highly arousing and developmentally-appropriate positive imagery within available standardized stimuli sets. In another study by Bunford et al. (2017), smaller LPPs to positive, social stimuli was associated increased externalizing problems (e.g., conduct issues) and social problems in a mixed group of clinically referred children and adolescents. This finding is consistent with prior work indicating a link between decreased affective reactivity to social stimuli, externalizing symptomology, and social skills (Gossen et al., 2014). Moreover, findings from Bunford et al. (2017) complement work showing increased affective reactivity and attention to social versus non-social affective content in typical adults across multiple levels of analysis (Kosonogov et al., 2018, 2020; Rubo & Gamer, 2018; Schacht & Vrtička, 2018).

Taken together, research indicates that the LPP is a useful measure for indexing affective processing and emotional development in typical and atypical populations. However, more work is needed in order deduce LPP patterns that indicate altered affective processing among externalizing child populations. Specifically, future work should examine the relation between externalizing problems in children and LPP reactivity to positive stimuli, as well as how the LPP compares across social and non-
social emotional categories, as research in these areas have been largely unexplored within the literature.

1.3.3.2 The fN400

The fN400 is another ERP component that may be relevant to affective processing mechanisms. The fN400 is a negative deflecting ERP component that presents around 300-500ms after visual presentation and appears across fronto-central regions of the scalp (Curran, 2000). The fN400 is elicited by a wide array of sensory stimuli (e.g., words, pictures, sounds, odors) providing evidence that this component reflects a multimodal system for processing sensory information (Ganis et al., 1996; Kutas & Federmeier, 2011). It is also commonly examined in the context of working memory (Voss & Paller, 2008; R. West et al., 2006). Within this context, reduced fN400 amplitudes (i.e., less negative) indicates better encoding of information associated with greater memory retrieval. In contrast, enhanced fN400s indicate weaker encoding of information and are correlated with poorer memory retrieval. In other words, attenuated fN400s may reflect the effective detection and capture of relevant information (for review, see Whittlesea & Williams, 2001).

There has been much contentious debate among scholars over what processes the fN400 functionally represents in the brain. Some scholars propose that the fN400 tracks perceptual information and thus modulations in the fN400 represent familiarity and the discrimination between old information (attenuated fN400 amplitudes) and new information (enhanced fN400 amplitudes) (Curran, 2000; Schaefer et al., 2011; Xu et al., 2015). In contrast, others argue that the fN400 tracks conceptual information such that
fN400 amplitude differences only occur if the information presented by stimuli are meaningful (Voss & Federmeier, 2011; Voss & Paller, 2007).

However, converging evidence suggests the fN400 actually reflects evaluative processing of contextual information and fN400 differences may represent context monitoring that occurs in response to shifts in outcome expectations (Amoruso et al., 2013; P. A. Leynes et al., 2017; P. A. Leynes & Crawford, 2018). Incoming information is constantly being compared to past experiences, which inform our interpretations of different situations. To make appropriate decisions, the brain must be able to evaluate which information is most relevant to the situation. Thus, modulations in the fN400 may reflect maintenance of stimuli meaning by integrating current contextual information with perceptual and semantic information from past experiences (Amoruso et al., 2013; Shehzad & McCarthy, 2019). In other words, stimuli that share perceptual and semantic features with stimuli associated with more meaningful/relevant contexts will be easier to encode and require less processing effort to construct meaning (Voss, Lucas, Paller 2010; Leynes et al., 2019).

The idea of the fN400 as an index of contextual processing is supported by research examining the neural generators of the fN400. Several studies report that fN400 activity originates from coordinated activity of the temporal and frontal areas of the brain (Halgren et al., 2002; Voss & Paller, 2007). These research findings show that the fN400 is highly associated with distributed processing in brain areas involved in various functions, such as scene processing and recognition (e.g., parahippocampal cortex, PHC), language processing and social perception (e.g., superior and middle temporal gyri, STG, MTG; inferior frontal gyrus, IFG), attention and cognitive control (e.g., superior frontal...
gyrus, SFG; dorsolateral PFC, dIPFC), and decision making (e.g., orbital frontal cortex, OFC; frontal polar cortices). These brain areas have been consistently cited in work examining the neural underpinnings of implicit memory and contextual processing (Bar & Aminoff, 2003; Bayen et al., 2000; Epstein, 2014). Furthermore, when comparing across similar paradigms, reduced activity in these areas is associated with attenuated fN400s to meaningful information and enhanced fN400s to non-meaningful or ambiguous information (Halgreen et al., 2002; Voss et al., 2008). Thus, stimuli elicit larger fN400s when stimuli are not context-relevant and/or when it takes more effort to extract meaningful information.

Regarding affective processing, the fN400 component is highly sensitive to affective content. Study findings have consistently demonstrated that neutral stimuli elicits larger fN400s (weaker encoding) than emotional stimuli during memory tasks (Hagemann et al., 2016; Schaefer et al., 2011; Xu et al., 2015). Furthermore, neutral stimuli can elicit similar fN400 amplitudes as emotional stimuli, but only if it is associated with an emotional context (Ventura-Bort et al., 2019). This evidence implies that affective responding can help place emphasis on pertinent information during a processing stream. Affective valence and arousal have been shown to have distinct impacts on fN400 amplitudes as well. For example, better memory retrieval has been associated with reduced fN400s to positive versus negative content and this effect was positively associated with increasing arousal (Kissler & Hauswald, 2008; Schaefer, Pottage, & Rickart, 2011; Van Strien et al., 2008; Xu, Zhang, Li, & Guo, 2015). These findings fall in line with work suggesting that affective content enhances working
memory capabilities by directing attention towards goal-relevant stimuli (Hur, Iordan, Dolcos, & Berenbaum, 2017; Lindstrom & Bohlin, 2010; Yiend, 2010).

The fN400 has also been shown to be particularly sensitive to social information. In a recent study by Kourtis et al. (2020), the authors collected ERPs as adult participants viewed pictures depicting an interactive sequence between two people. Results showed that participants exhibited reduced fN400s during action sequences only when explicit communicative cues were exchanged between the individuals in the preceding scene (e.g., mutual eye contact and hand gestures), suggesting that social information (i.e., communicative cues) facilitates interpretation during scene processing. Katsumi et al. (2020) found that fN400s were more attenuated to scenes depicting social encounters compared to scenes with no social encounter in typical adults. Furthermore, reduced fN400 amplitudes were associated with increased LPPs amplitudes to social encounters that implied a positive social interaction, suggesting that participants found positive social stimuli particularly more meaningful and motivationally relevant. Associations between fN400 and LPP have also been linked to empathic abilities. Specifically, Manfredi et al. (2020) reported that modulations of fN400 and LPP toward humorous scene depictions reflected increased ability to derive meaning (e.g., humor) through the broader context of the story (i.e., semantic coherence). Moreover, fN400-LPP associations were associated with increased subjective report of amusement and arousal; these results (both fN400-LPP and subjective ratings) were also associated with higher empathy scores.

Together, these works indicate that the fN400 reflects a distributed, multimodal neural system responsible for context processing of stimuli. The fN400 specifically
reflects contextual meaning processing and is especially sensitive to affective content that is 1) highly arousing, 2) positively valanced, and 3) socially oriented. Research also suggests that fN400 patterns are associated with LPP patterns, indicating that contextual processing significantly impacts later stages of affective processing. In all, these results highlight the role of context in affective processing and the fN400 as a possible neural index of context monitoring (e.g., what does this emotion mean in relation to this context).

Currently, work examining the development of the fN400 in children is very limited. The few studies done on the fN400 in child populations focus exclusively on the context of memory (Boucher et al., 2016; Corbett et al., 2016). Child research examining the fN400 as an index of affective processing or socio-affective processing outside the realm of memory is non-existent in the literature. Additionally, to date, no research has examined the fN400 in relation to emerging externalize problems in children. Prior work with adolescent offenders has linked contextual processing differences (as indexed by the fN400) with affective processing and empathy deficits in adolescent offenders (Gonzalez-Gadea et al., 2014). Specifically, these contextual and affective processing deficits were linked to increased difficulty in allocating attention toward to complex scenes, suggesting that these deficits are mediated by attention control deficits. These results are consistent with work suggesting that inappropriate attention to context is a major factor seen among offenders exhibiting the most severe behavior (Baskin-Sommers et al., 2015b). Further work found that these contextual, affective, and attentional deficits were associated with executive dysfunction and disruptive behaviors in adolescent offenders (Santamaría-García et al., 2019, 2020). Overall, converging evidence highlights the need to examine
the role of contextual processing (via the fN400) in relation to externalizing behavior in children.

1.4 Developmental Influences in Externalizing Risk in Children

Children differ from each other in the way process their emotions. When examining risk in children, researchers must consider factors that influence individuals’ differences as developmental trajectories will vary from child to child. Two factors that are most linked to individual differences in emotion and heightened risk for externalizing are gender and temperament. We review these factors in greater depth below.

1.4.1 Gender

Externalizing behaviors and related disorders are far more prevalent in males than females. Compared to females, males engage in significantly higher rates of aggression, misconduct, hyperactivity, and antisocial behaviors (Golding & Fitzgerald, 2019; Hicks et al., 2007a; Martel, 2013). Furthermore, individuals who exhibit life-course persistent externalizing behavior, and thus are prone to developing the most pervasive and severe forms of externalizing problems, consist nearly exclusively of males (Moffitt, 2006, 2018). Research estimates also suggest that males are 10 to 15 times more likely to develop life-course persistent externalizing behavior than females (Fairchild et al., 2013; Moffitt et al., 2001). Combined, these findings underscore gender as a significant factor influencing externalizing outcomes in children, and specifically highlight that externalizing risk is elevated in children who are male.

The robust gender gap seen in the prevalence of externalizing problems has led to increased research investigating factors that cause these patterns to emerge. Consensus
within the literature is that males possess some type of predisposition for externalizing symptoms that females do not, and that differential susceptibility seen across gender may be attributed to biological differences underlying gender development (Habersaat et al., 2018; Hicks et al., 2007a). However, the developmental mechanisms through which gender differences in vulnerability to externalizing problems arise are still poorly understood.

One emerging theory is that gender differences in externalizing viability may stem from developmental differences in affective processing between boys and girls (Brody, 1985; Maguire et al., 2015; Valentino et al., 2012). A considerable body of research has reported robust valence distinctions between males and females when processing affective stimuli. Specifically, extensive research shows that males attend and react most strongly to positive stimuli, whereas girls are more responsive to negative stimuli than positive stimuli (M. M. Bradley et al., 2001; Kret & De Gelder, 2012; Stevens & Hamann, 2012; Whittle et al., 2017b).

Functional magnetic imaging (fMRI) research suggest that these valence-specific patterns are rooted in gender-related differences in neural function. For example, several studies have demonstrated that males exhibit greater amygdala activation in response to positive stimuli (Fine et al., 2009; Hamann & Ely, 2002; Wrase et al., 2003). In contrast, negative stimuli recruits greater amygdala activity in females (Domes et al., 2010; McClure et al., 2004; Wehrum et al., 2013). Evidence of gender-related differences in amygdala function is very relevant to affective processing as it plays a central role in facilitating attention toward salient cues as well as generating emotional responses (Baxter & Croxson, 2012; Davis & Whalen, 2001; Vuilleumier & Huang, 2009)
Regarding externalizing susceptibility, these studies point to a neurobiological basis of elevated externalizing risk in males versus females. Males are more reactive to positive stimuli than females. Emotional reactivity to positive stimuli is purported to reflect the engagement of reward-processing systems in the brain (Berridge & Kringelbach, 2015; Kujawa et al., 2020; X. Liu et al., 2011). Thus, enhanced processing of positive emotional information in males suggests that males are prone to be more reward sensitive than females. This idea is further corroborated by study findings that show males display a greater bias to reward than females (Greimel et al., 2018a; Lighthall et al., 2012; Warthen et al., 2020a).

Notably, exaggerated reward responsiveness is a feature highly associated with externalizing problems (Bjork et al., 2010; Hawes et al., 2020; Rodriguez-Thompson et al., 2020). Neurodevelopmental models of externalizing postulate that heightened reward sensitivity seen in externalizing individuals reflects dysfunction of dopamine - a key neurotransmitter involved in modulating emotion and motivation (Arnsten & Rubia, 2012; Beauchaine & McNulty, 2013). Compared to females, males are more likely to express genes associated with aberrant dopamine functioning and externalizing behavior, as well as exhibit excess brain activity in dopamine-rich areas related to emotion and motivation (Diekhof et al., 2021; Loke et al., 2015; Peterson et al., 2017).

Males also appear to show slower development of neural connections between subcortical regions in involved in generating emotion (i.e., amygdala) and prefrontal regions involved in regulating emotion compared to females. Specifically, males exhibit a lower prefrontal to amygdala activation ratio to emotional stimuli as a function of age (Killgore et al., 2001). Increased prefrontal-amygdala connectivity is thought to reflect
on-going maturation of neural networks that support and modulate affective processing (Tottenham & Gabard-Durnam, 2017) and are linked to developmental gains in emotion regulation and behavioral control (Gee et al., 2013; Qin et al., 2012). In contrast, reduced prefrontal-amygdala connectivity is associated with attention problems, emotion dysregulation, poor self-control, and elevated externalizing behavior in children (Bertocci et al., 2014; Gaffrey et al., 2021; Park et al., 2018). Furthermore, deficiencies with dopamine function and prefrontal-amygdala connectivity have been associated with has been associated with increasing more severe and intractable externalizing behavior as children age (Beauchaine & Gatzke-Kopp, 2012; Beauchaine & McNulty, 2013). Thus, males may be doubly vulnerable to externalizing problems due to greater developmental propensity to express deficiencies in both reward-related and regulatory systems.

Knowledge gained from neuroimaging work is immense and helps describe possible neurobiological pathways in which gender differences in externalizing problems emerge. Techniques such as fMRI give great information about where gender-related differences in affective processing appear in the brain but, due to its slower temporal resolution, fMRI does not give clear and precise insights about when these processing differences arise. Affective processing consists of several dynamic components that each unfold on their own timescale (Waugh et al., 2015a). Thus, higher temporal resolution is needed to identify developmental variations occurring during specific facets of affective processing (e.g., attention, evaluation, response). Therefore, research using temporally sensitive measures is important for understanding and tracking developmental pathways for externalizing risk in male and female children.
Neuropsychological measures, such as event-related potentials (ERPs), have high
temporal resolution that captures neural processing with millisecond precision. ERPs can
also be easily assessed across different age groups, making them well suited for
developmental studies. Additionally, ERPs reliably capture gender differences in
affective processing and several ERP studies have shown gender distinctions in
emotional reactivity patterns to valence that are consistent with findings in fMRI research
(Kemp et al., 2004; Lithari et al., 2010; Orozco & Ehlers, 1998). Several studies also
highlight the ability of ERPs to discriminate genders differences occurring during early
stages versus later stages of affective processing, illustrating the usefulness of ERPs in
distinguishing between temporally sensitive processes (e.g., Gardener et al., 2013; Kim et
al., 2013).

One ERP component particularly ideal for examining gender differences in
affective processing is the late positive potential (LPP). The LPP is a sustained, positive
ERP component that indexes volitionary attention toward salient information (e.g.,
evocative emotional stimuli; (Hajcak et al., 2009). This component is thought to reflect
dynamic activation of a wide neural network that encompasses subcortical and cortical
regions like the amygdala, striatum, and prefrontal cortex - brain areas known to show
distinct functional differences in males and females when processing emotional
information (Frank & Sabatinelli, 2019; Y. Liu, Huang, Mcginnis-Dewese, et al., 2012b;
Sabatinelli et al., 2013). Studies examining the LPP in children and adolescents reveal
valence-specific gender differences in the LPP, with boys exhibiting enhanced LPPs to
positive stimuli and girls exhibiting enhanced LPPs to negative stimuli (Solomon et al.,
2012; Zhang et al., 2017). Nearly identical patterns in the LPP have been reported in
studies of adults (Bianchin & Angrilli, 2012; Groen et al., 2013; Kato & Takeda, 2017; Syrjänen & Wiens, 2013). Not only are these findings in line with neuroimaging work showing gender-related differences in affective processing, but they also show that these gender differences emerge early and are sustained throughout development.

The LPP also appears to be sensitive to gender differences in processing social information. Several studies show that females exhibit larger LPPs to emotional images depicting social scenes compared to males (Groen et al., 2013; Proverbio, 2017; Proverbio et al., 2008a, 2009). These studies are consistent with fMRI research showing that females engage regions involved in social information processing more strongly than males. Although research examining gender differences to social information processing is more limited, the current literature suggest that males are less perceptive and less reactive to social information than females. Taken together, these findings highlight that gender differences in both social and affective processing are important to consider when exploring neural mechanisms that may contribute to the difference in externalizing susceptibility evident between males and females.

1.4.2 Temperament

Another development factor affecting vulnerability to externalizing problems is temperament. Temperament broadly refers emotional and behavioral tendencies that manifest early in development (Ross et al., 1999; M. K. Rothbart & Bates, 2006). Temperamental traits are biologically based and remain relatively stable over time. However, how these traits are expressed is also heavily shaped by environmental interactions leading to individual differences in developmental outcomes associated with
various temperamental traits (Gartstein et al., 2012a; Martel, 2019; M. K. Rothbart, 2007; M. K. Rothbart et al., 1994).

Several developmental models exist that propose different ways to define and measure temperamental traits. The most widely recognized model in the developmental literature is the perspective proposed by Rothbart and colleagues (Derryberry & Rothbart, 1988). According to this Rothbart model, temperament encompasses individual differences across two main components: reactivity and regulation (Derryberry & Rothbart, 1997). Reactivity refers to an individual’s initial response to an environmental stimulus and regulation refers to processes that modulate reactivity.

A temperament dimension significant to relations in emotional reactivity to positive valence and externalizing problems in children is surgency. Surgency reflects the tendency to experience positive emotions, approach and seek-out situations related to reward, and be hyperactive. High levels in surgency are also associated with increased risk for externalizing. Specifically, externalizing risk has been linked to surgency in terms of high approach motivation (Oldehinkel, Hartman, De Winter, et al., 2004; Putnam & Stifter, 2005; Rydell et al., 2003). Approach motivation is defined as the motivation to approach stimuli that signal potential reward and is thought to reflect activation in neurobiological systems involved in reward processing and motivated behavior (Depue & Collins, 1999; Gray, 1987; Martel, 2013). Children displaying high levels approach motivation tend to show higher motor activity and engage in behavior before considering potential consequences (DeYoung, 2010; Martel, 2013; Tackett, 2010). This tendency to engage in impulsive behavior is strongly linked to emerging externalizing problems in children and related neurobiological models suggest that trait impulsivity places children
at even higher risk for developing more severe externalizing behaviors over time (Beauchaine & McNulty, 2013; Scheper & Majdandzic, 2017; Venables et al., 2018).

In contrast, some studies have linked surgency to positive outcomes in children. For example, in a study conducted by Salley and colleagues, temperamental surgency was positively related to increased social responsiveness and engagement in children (Salley et al., 2013a). This finding is consistent longitudinal research linking surgency traits in preschoolers with greater social abilities in adolescence and adulthood (Berdan et al., 2008; Caspi et al., 2003; Caspi & Silva, 1995; Grazlano & Ward, 1992). Notably, research associating surgency in children with positive outcomes tend to focus more on positive emotionality aspects of surgency than aspects related to approach motivation and reward sensitivity (Denham et al., 1990; N. N. Eisenberg et al., 1998; Schaffer, 1966). Indeed, positive emotionality has been associated with increased sociability in both infants and children (Fox et al., 2001; Hane et al., 2008). Positive emotionality has also been linked to increased wellbeing during adulthood (Naragon-Gainey & Watson, 2021). In contrast, low positive emotionality and approach in social situations has been associated with later problem behavior (Durbin et al., 2005). These findings suggest that affiliative aspects associated with surgency may serve as protective factor in children at risk for externalizing problems.

Overall, these works indicate surgency as a temperamental risk factor for externalizing problems in children. Most research has focused relations with appetitive aspects of surgency (i.e., approach motivation, impulsivity) as predictors of externalizing risk. However, research also shows that temperamental surgency is also related to increased social responsiveness and sociability in children. Positive social engagement
and behavior has been negatively associated with externalizing problems in children (Dobbelaar et al., 2021; Hukkelberg et al., 2019; Padilla-Walker et al., 2015; Toseeb et al., 2020), adolescents (Dvorsky et al., 2018; Racz et al., 2017), and adults (Memmott-Elison et al., 2020). Conversely, low positive emotion and low reactivity in social situations has been linked to severe externalizing problems in children (Castagna et al., 2021; Hawes et al., 2020; Kohls et al., 2020). Therefore, when examining relations between temperamental surgency and externalizing risk, it may be important to differentiate individual differences in reactivity to social and nonsocial stimuli. Patterns of reactivity to social and nonsocial stimuli and/or situations among children high in surgency may reflect separate pathways to developmental outcomes, where patterns of heightened reactivity to nonsocial stimuli confer externalizing risk and patterns of reactivity to social stimuli protect against externalizing risk.

ERP measures, such as the LPP, are great tools for capturing individual differences in emotional reactivity in children. For example, patterns of LPP modulation have been linked to differences in personality in adults (Alperin et al., 2017; Speed et al., 2015). Furthermore, enhanced LPP reactivity to positive stimuli has been associated with approach motivation and attention bias to rewards in adults, suggesting that the LPP is related to surgency (Bamford et al., 2015; Gable & Harmon-Jones, 2010). Remarkably, very little research has assessed, on a neurophysiological level, how neural markers of affective processing relate to temperamental traits like surgency and associated externalizing risk in children. This gap is problematic because understanding these relations in children can help researchers better identify risk markers before problematic behaviors begin. Given that work exploring differences in LPP reactivity patterns to
social and nonsocial stimuli is even more scarce, it is crucial for research to unpack these reactivity and gender interactions in children.

1.5 Summary and Aims of the Present Dissertation

In all, research suggest that externalizing behavior in children is associated with early disruptions in affective processing, particularly attention. Furthermore, these disruptions seem to be dependent on the contextual domain that processing occurs. Specifically, research indicates that externalizing problems are associated with increased attention and emotional reactivity to positive/reward stimuli. In contrast, externalizing problems appear to be associated with decreased attention and emotional reactivity to social stimuli. Thus, differences in affective processing to social and non-social reward stimuli may provide unique predictors of externalizing risk in children.

Affective images are an advantageous tool for measuring individual differences in affective processing and reward sensitivity. Research in adults using affective images has demonstrated that changes in core affect (i.e., valence and arousal) reliably measured using behavioral and neurophysiological measures such as the LPP (Bradley et al., 2001). Indeed, enhanced LPPs to positive images linked to neural activity in the nucleus accumbens (NAcc) and medial prefrontal cortex (mPFC), two neural areas associated with affective and reward processing in adults (Costa et al., 2010; Sabatinelli et al., 2007). These findings correspond to affective models suggesting that the LPP to positive images reflect activation of underlying neural systems that mediate motivation and motivated behavior (Bradley & Lang, 2013). Thus, passive viewing of affective images provides a useful approach to assess neural measures of affective processing.
Currently, little work has compared affective processing of social and non-social stimuli and externalizing risk in children (Demurie et al., 2011; Stavropoulos & Carver, 2014). One major limitation to this research is that a standardized image set of this nature has not been validated in children. Although a few studies have attempted to compare child ratings using a ‘child-appropriate’ sample of images from the International Affective Picture System (IAPS), children report lower valence (and even lower arousal) ratings of the images as compared to adults, as well as weaker correlations between the dimensions (Hajack & Dennis, 2009; McManis et al., 2001). These patterns are problematic and suggest that selective content in current image sets is not motivationally relevant to children. Moreover, studies have not used affective images to distinguish affective processing of social and nonsocial reward stimuli in children, thus the proposed study will be the first to use affective images in this context. There is also long-standing research highlighting differences in processing of affective and social information based on gender and temperamental traits (Behrendt et al., 2020; Fischer et al., 2018; Stadler et al., 2007; Whittle et al., 2017a). Yet, no studies to date have looked at the neural underpinnings of this risk process in conjunction with these factors in children.

Therefore, the overarching goal of this dissertation project was examined neural correlates of affective processing to social and non-social reward using a developmentally appropriate image set with a focus on the frontal N400 (fN400) and Late Positive Potential (LPP) components and track the association with risk for externalizing problems in children. Special focus was given to incorporating gender and temperament factors (i.e., surgency) as these factors have long-standing connections to heightened risk for externalizing. As such, the aims of this dissertation project are three-fold. First, this
project investigated neural differences in social and nonsocial affective processing using a developmentally appropriate stimuli set and explore relations to externalizing risk. Second, potential interactions between gender and neural markers of affective processing to social and non-social reward were gender differences in patterns of social and nonsocial affective processing were examined in relation to externalizing. Third, individual differences in temperamental reactivity (i.e., surgency) were explored in relation to patterns of social and nonsocial affective processing and externalizing risk in children.

In this research, we center our focus on middle childhood. Middle childhood is a transitional period in development marked by rapid brain maturation in emotion and cognitive areas and is associated with significant gains in affective processing abilities and emotion regulation (Mah & Ford-Jones, 2012). Middle childhood also marks a turning point in development were trajectories of externalizing and internalizing start to stabilize (Ladd, 2006; Nivard et al., 2017; Whittle et al., 2020). Thus, middle childhood is an ideal period to examine affective processing patterns and its relation to externalizing symptomology.

Furthermore, we conducted this work with a normative, community sample. As stated in this review chapter, externalizing behavior is a normal part of childhood development. There is wide variation in externalizing behaviors seen in typical development and this variability can make it challenging to differentiate between typical and atypical behavior during development. Therefore, it is important establish the bounds in neural patterns that characterize normative development in order to more accurately identify neural markers associated with atypical development (Drabick &
Kendall, 2010; Mittal & Wakschlag, 2017). Overall, the findings from this dissertation will provide richer understanding of the neural mechanisms and interactive processes involved in risk for externalizing problems in middle childhood.
CHAPTER 2
MORE THAN A FACE: NEURAL MARKERS OF MOTIVATED ATTENTION TOWARD SOCIAL AND NON-SOCIAL REWARD-RELATED IMAGES IN CHILDREN

The aim of this study was to investigate neural differences in social and nonsocial affective processing using a developmentally appropriate stimuli set and explore relations to externalizing risk. To examine this, we recorded EEG activity from typically developing children while they completed a passive-viewing picture task. Study findings were published in Biology Psychology (https://doi.org/10.1016/j.biopsycho.2018.08.012) and the accepted manuscript is provided below.
More than a face: Neural markers of motivated attention toward social and non-social reward-related images in children

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Keywords: LPP, social, reward, children, ERP, self-regulation

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2.1 Abstract

Affective images engage motivational systems that shape emotional experience and cognitive processes. However, relatively little work has examined motivated attention toward distinct categories of approach motivation, particularly social motivation, in children. In the current study, event-related potentials (ERPs) were collected while children (n=43; 22 females; $M_{age} = 8.49$ years) completed a picture-viewing task using a novel stimulus set of child relevant images representing social and non-social categories of reward-related images. Results showed that the frontal N400 (fN400) was more prominent for intrapersonal images that showed individuals playing alone or achieving rewards (e.g. medals). For the LPP, males showed the greatest reactivity to non-social object-based reward images. In contrast, females showed a larger LPP response for interpersonal images that showed scenes of social interaction between individuals. Overall, LPP reactivity to intrapersonal images was correlated with greater behavior regulation problems. Collectively, these results highlight unique patterns of neural prioritization to distinct categories of social and non-social reward-related stimuli that may serve as important markers in tracking connections between approach motivation and the development of self-regulation in children.
2.2 Introduction

Attending to salient cues impacts how children process their environment and make decisions about engaging in adaptive interpersonal behavior. Recent work suggests that children exhibit increased behavioral performance in the face of socially rewarding cues (Demurie et al. 2011) as well as heightened neural activity to anticipation of social rewards (Stavropoulos & Carver, 2014). Although limited work has assessed differences in physiological measures to social and monetary reward outcomes in children and adolescents (Ethridge et al., 2017; Kohls, Herpertz-Dahlmann & Konrad, 2009a; Kohls, Herpertz-Dahlmann & Konrad, 2009b), no studies to date have assessed affective processing of a broad range of socially salient and non-social reward-related cues in typical children.

Although reward processing is important in shaping adaptive behavior, growing evidence shows that not all forms of reward-related cues are processed equally. For instance, a large body of literature has highlighted that enhanced sensitivity to non-social rewards (i.e., objects and money) and diminished sensitivity to social rewards (i.e., faces; Cox et al., 2015, Sasson & Touchstone, 2014; Septa et al., 2012; Stavropoulos & Carver, 2014) is related to social-emotional and behavioral deficits in children with autism spectrum disorders (Delmote et al., 2012; Lin, Adolphs, & Rangel, 2012; Mundy, 1995; Zeeland et al., 2010). Furthermore, high sensitivity to non-social rewards has been noted to promote poor inhibitory control that can result in inappropriate responses (e.g., aggression, delinquency, and hyperactivity), which hinder goal-directed behavior and can lead to maladaptive outcomes (Newman & Wallace, 1993; Nigg, 2000). In contrast, enhanced sensitivity to socially rewarding cues has been associated with better
engagement of cognitive control in clinical populations (i.e., ADHD) and lower impulsivity in typically developing adolescents (Kohls, Herpertz-Dahlmann & Konrad, 2009; Telzer, Fuligni, Lieberman & Galvan, 2013). Although no work to date has linked processing of social reward cues in typical children to behavioral outcomes, difficulty with processing social cues in childhood has previously been noted as a predictor of aggression and antisocial behavior in adolescents high in externalizing symptoms (Dodge et al., 2013; Lansford et al., 2016) as well as adolescents at risk for anxiety and depression (Kujawa, Arfer, Klien, & Proudfit, 2014). Thus, investigating connections between social and non-social reward processing early in development is especially important, as childhood is a pivotal time in shaping trajectories of growth for social and regulatory skills.

Functional magnetic resonance imagining (fMRI) has provided a wealth of knowledge regarding the neural areas involved in social and non-social reward processing due to the excellent spatial resolution of this methodology. Work using fMRI to investigate the biological substrates of reward processing in adults indicates that social rewards recruit similar neural networks as non-social rewards such as the nucleus accumbens (NAcc) and the medial prefrontal cortex (mPFC; Izuma, Saito & Sadato, 2008; Radke et al., 2016), which is also implicated in regulating goal-oriented behavior (Hare et al., 2009). However, neuroimaging methodology is limited in its capability to track differences in the affective properties underlying of social and non-social reward processing due to its poor temporal resolution. Another way to assess physiological markers of reward-related processes is with event-related potentials (ERPs), which reflect neural activity time-locked to specific stimuli or responses. Given their excellent
temporal resolution, ERPs are well suited to unpacking rapidly occurring emotion-related processes that may be difficult to ascertain via neuroimaging or observation and self-report (Kujawa et al., 2012; Santerre & Allen, 2007). ERPs are also easily assessed in both children and adults (Nelson & McCleery, 2008), thus making it an ideal measure for unpacking real-time reactivity to social and non-social reward cues across development.

One ERP component, the late positive potential (LPP), is a sustained positive component has been established as a reliable measure of affective saliency and motivation (Hajack, Weinberg, MacNamara & Foti, 2012). The LPP begins to emerge early as 300-400ms post-stimulus presentation and is sustained throughout the duration of stimulus presentation (Moran, Jendrusina & Moser, 2013). Increasing motivation and emotion intensity modulates the LPP, such that larger LPPs are elicited by high arousing affective images compared to neutral images and affective images of lower intensity (Schupp, Cuthbert, Bradley, Cacioppo, Ito & Lang, 2000).

Positive affective images (as well as positive imagined scenes) have been noted to strongly activate the NAcc, mPFC, and amygdala- brain areas underlying reward processing and emotion (Costa, Lang, Sabatinelli, Versace, & Bradley, 2010; Sabatinelli, Bradley, Lang, Costa, Versace, 2007). Furthermore, neuroimaging studies examining the neural substrates underlying the LPP have found that the LPP elicited by positive images is related to activation of brain structures involved in reward processing (i.e., NAcc, mPFC, orbital frontal cortex [OFC]), emotional arousal (i.e., amygdala, insula), and stimulus-reward association learning (i.e., inferior temporal visual cortex; Spiegler & Mishkin, 1981, Liu, Huang, McGinnis-Deweese, Keil, & Ding, 2012; Sabatinelli, Lang, Keil, & Bradley, 2007) Therefore, the LPP to positive, arousing images is thought to
reflect motivated attention and the allocation of processing resources to potentially rewarding stimuli (Lang & Bradley, 2010).

The LPP is developmentally robust with good stability across middle childhood (Kujawa et al., 2013) and reliable assessment across the later preschool and early childhood years (Decicco, Solomon & Dennis, 2012; Hajack & Dennis, 2009; Hua, Han, Chen, Yang, Zhou & Hu, 2014). Studies employing stimuli associated with social reward assess the LPP in children are limited and has, thus far, demonstrated that attenuated LPPs to positive emotional stimuli (i.e. happy faces) is associated with higher levels of social problems and rule-breaking behavior (Bunford, Kujawa, Swain, Fitzgerald, Monk & Phan, 2017). To date, no study has yet examined a range of salient social reward cues (beyond faces) and compared them with non-social reward in young children, nor whether reward related LPP amplitudes correspond to patterns of self-regulation.

In addition to the LPP, additional components related to affective image processing are the early posterior negativity (EPN) and the N400. The EPN is a negative going deflection (approximately 200-300ms post stimulus presentation) that is often maximal over parietal and occipital sites. This component thought to reflect enhanced perceptual processing of emotional aspects of stimuli and may be sensitive to modulation by pleasant stimuli or the reference configuration used (see Hajcak, Weinberg, MacNamara & Foti, 2012 for a review). In contrast, the N400 is enhanced in frontal regions, particularly in the presence of affective stimuli. Indeed, a number of these studies describe the component as an fN400 and in addition to semantic priming, the N400/fN400 has been shown to index orienting to emotional cues (Ganis, Kutas & Sereno, 1996; Kanske, Plitschka & Kotz, 2011). Although the psychological processes
reflected in the N400/fN400 appear varied and are still under debate, the broader collection of work suggests that the fN400 component may reflect meaning processing more broadly when stimuli include scenes, objects, actions, faces, and gestures (Kutas & Federmeier, 2011; Leynes, Bruett, Krisan & Veloso, 2017).

Although affective images are an advantageous tool for measuring motivated attention to rewarding stimuli, there has not yet been a standardized image set representing a broad range of socially rewarding and non-socially rewarding cues for use in research with children. Furthermore, current image sets (i.e. International Affective Picture System; IAPS, Lang, Bradley & Cuthbert, 1999), contain a high degree of content that are inappropriate for children. A handful of studies have compared child ratings using a child-appropriate sub-sample of IAPS images; however, children report lower valence (and even lower arousal) ratings of those images as compared to adults (Hajack & Dennis, 2009; McManis et al., 2001). Thus, the current research suggests that the content of available image sets is less motivationally relevant to children.

Given that most studies in children have not yet used affective images beyond face stimuli to assess processing of social and non-social reward images, the current project uses a novel and diverse set of motivationally relevant affective images that span a range of social motivation and social engagement cues (i.e. peers and parent-child interaction). Currently, little is known about the development of the biological substrates of processing social versus non-social reward cues in children (Stavropoulos & Carver, 2014). As such, the goals of the current study were two-fold. First, we sought to directly compare neural reactivity to a diverse range of motivationally salient social and non-social stimuli in children using ERPs that distinguish fast automatic processing of stimuli.
from more sustained voluntary processing. Second, we aimed to explore associations between affective processing of social and non-social reward and parent report of children’s regulation skills. It was hypothesized that non-social reward images would receive early preferential processing as evidenced by larger EPN or N400 responses and that this form of enhanced processing would correspond to poorer self-control. We further hypothesized that social reward images would receive preferential processing in the form of larger LPP responses and that enhanced affective processing of social reward stimuli compared to non-social reward stimuli would be associated with more adaptive behavioral and emotional outcomes.

2.3 Materials and methods

2.3.1 Participants

Seventy-three children (38 female, $M_{age} = 8.30$ years) participated in the current study. Twenty-five participants were excluded due to low number of trials (i.e., less than 8 trials per image category; Moran et al., 2013), three participants were excluded as outliers (ERP amplitudes greater than 3 SDs for each image category), and two participants were excluded due to technical difficulties in electrophysiological recording. Thus, the final sample included 43 participants (22 female, $M_{age} = 8.49$ years). Parents were compensated $20 for participation and children received a small prize. Informed consent from the child’s guardian and child assent was obtained prior to beginning study procedures.
2.3.2 Stimuli and measures

The Child Affective Picture Set-Rewards (CAPS-R) consists of one hundred and fifty pictures (both illustrations and photographs) collected from children’s storybooks and open-sourced image databases. The themes for the current stimuli set were inspired by subscales from the Behavioral Inhibition/ Behavioral Activation Scale (BIS/BAS), a questionnaire used to examine individual differences in approach-motivation (Blair, 2003; Carver & White, 1994). Images were collected and rated by 160 undergraduate students (80 females) and the current stimuli is comprised of the top 25% of images based on undergraduate valence and arousal ratings from an unpublished study. Pictures were divided into four categories. The interpersonal reward category was comprised of 54 images that depicted social interactions (e.g., parent/peer contact and joint attention). The intrapersonal reward category consisted of 40 images depicting happy people with no social interaction (e.g., people with medals/trophies, children playing by themselves). The object reward category consisted of 16 images depicting object-based rewards relevant to children (e.g., presents, toys, cupcakes). Additionally, a neutral category consisting of 40 neutral scenes (e.g., clocks, shoes, trees) was incorporated.

2.3.3 Picture viewing task.

For the picture-viewing task, participants were instructed to view and rate each image. At the beginning of each trial, a fixation cue was presented for 200 milliseconds (ms) to signal that an image was about to appear, followed by a blank screen for 200 ms. A snowflake was used for fixation, rather than a traditional cross, to remind child participants to remain still during the task in order to minimize movement artifact.
Following fixation, participants were presented with a picture for 3000 ms, then another blank screen for 200ms (see Figure 1).

Next, participants rated pictures using pictorial valence and arousal scales. The valence scale ranged from 1 to 5 and depicted five emotion faces ranging from unhappy to happy (i.e., very unhappy emoticon corresponded to ‘1’, neutral emoticon corresponded to ‘3’, and very happy emoticon corresponded to ‘5’). The arousal scale also ranged from 1 to 5 and depicted five thermometers, which ranged from empty to full (i.e., empty thermometer = ‘1’, half-full thermometer = ‘3’, and full thermometer = ‘5’). For valence, a yellow circle appeared on screen and participants were instructed to “fill in the yellow circle” by pointing to the face that best matched the emotion experienced while viewing the picture. For arousal, an empty thermometer appeared, and participants pointed to thermometer that matched the intensity of emotion experienced (i.e., empty thermometer = no intensity vs. full thermometer = high intensity). Participants were given unlimited time to rate pictures. Participants completed a practice block of 5 trials (one of each picture type). The main task consisted of 4 blocks with 42 trials per block. Each picture was presented once and in pseudo-random order. The task was presented using STIM 2.0 software (Compumedics, Inc.).

2.3.4 EEG acquisition, reduction, and analysis

Electroencephalographic (EEG) activity was recorded using a 64 Ag/AgCl electrode Neurocan Quick-cap (Compumedics Neuroscan, Charlotte, NC). EEG activity was referenced to a midline reference electrode located posterior to Cz and a midline electrode anterior to Fz served as the ground electrode. Electroculogram (EOG) activity was recorded by placing two external electrodes above and below the left outer orbit of
the eye. Continuous raw EEG data was collected and digitized using SCAN 4.5 software (Compumedics Neuroscan). All impedances were kept below 10 kΩ. Eye blinks were regressed, data was re-referenced off-line to the average mastoids, and then filtered using a 30 Hz zero phase shift filter (24 dB/octave, low-pass cutoff). Data for each trial was segmented beginning at 200 ms prior to picture onset till 2500 ms post picture onset. For each epoch, the 200 ms period prior to picture presentation was used for baseline correction. Trials containing artifact exceeding +/- 150 microvolts were removed, and usable epochs were averaged for each participant. In accordance with prior studies assessing fN400 and LPP responses to affective images (e.g. Dennis & Hajcak, 2009; Pincham, Bryce & Pasco, 2015; Solomon, DeCicco & Dennis, 2012) and work demonstrating that the LPP shifts to a more anterior presentation when using a mastoid reference and late time window (see Hajcak et al., 2012), the mean activity for each component was analyzed at 3 electrode regions: Frontal (F1, Fz, F2), Central (C1, Cz, C2), and Parietal (P1, Pz, P2). The fN400 was scored between 250-500ms post picture onset and the scoring window for the LPP was 1000 to 2500 ms after picture onset.

2.3.5 Parent report of executive functioning (EF)

Parents completed the Behavioral Rating Inventory of Executive Functioning questionnaire (BRIEF, Gioia et al., 2000). Parents responded to 86 items that assessed children’s behaviors related to executive functioning (EF) skills. Parents rated each behavior as “never” (1), “sometimes” (2), or “often” (3). Scores were calculated by summing items associated with eight EF subscales: inhibition, set shifting, emotional control, task initiation, working memory, planning and organization, and self-monitoring. Two composite scores were also created to assess global aspects of EF: the Behavioral
Regulation Index (BRI; sum of Inhibit, Shift, and Emotional Control subscales) and the Metacognition Index (MI; sum of Initiate, Working Memory, Plan/Organize, Organization of Material, and Monitor subscales). Higher scores on EF composite scores are associated with increased problems in these areas.

2.4 Results

2.4.1 Statistical Approach

Behavioral ratings and ERP data (i.e., fN400, LPP) were analyzed using mixed, repeated measure ANOVAs (mixed RM-ANOVAs) controlling for gender and age.

For behavioral analyses, differences in valence and arousal ratings were examined in separate 2 (Gender) x 2 (Age) x 4 (image category) RM-ANOVAs, with image category entered as a within-subject factor. ERP amplitudes of interest (i.e., N400 & LPP) were analyzed using a 2 (Gender) x 3(Region) x 4 (Image Category) RM-ANOVA, with region and image category entered as within-subject factors.

Difference scores were also created in order to compare neural activity to social and non-social reward images more directly, as well as to account for individual differences in children’s baseline reactivity to images. The difference scores were created by subtracting the ERP component elicited by neutral images from those elicited by interpersonal, intrapersonal and object-based reward images, thus, controlling for neutral baseline activity. A 2 (Gender) x x 3 (Region) x 3 (Image Category) RM-ANOVA was conducted for each ERP component of interest, with region and image category entered as within-subject factors. Greenhouse-Gessier corrections were applied to all analyses that violated sphericity assumptions.
To examine relations between specific ERP components and behavior, fN400 and LPP amplitudes for each image category were correlated with parent report of child executive functioning while controlling for age and gender.

### 2.4.2 Behavioral Results

Valence ratings significantly differed by image category \( F(3, 120)= 55.545, p < .001, \eta_p^2 = .581; \) see Figure 2a). Follow-up analyses showed that neutral images were rated the lowest of all the image categories \( M= 3.35, SD = .551; t's \geq -2.260, p's < .001 \). Additionally, interpersonal images \( M= 4.020; SD = .479) \) were rated lower than the intrapersonal \( M= 4.120, SD = .477) \) and object-based reward images \( M= 4.206, SD = .695; t's \geq 8.92, p's < .029 \). Ratings did not differ between intrapersonal and object-based reward images \( t(42)= -1.249, p=.219 \). There were no main or interactive effects for gender for valence ratings.

Arousal ratings also differed by image category \( F(3,120)= 31.386, p < .001, \eta_p^2 = .440; \) see Figure 2b) in a similar pattern. Specifically, the neutral images were rated the lowest in arousal compared to all other categories \( M= 3.107, SD = .922; t's \geq 5.759, p's < .001 \) and interpersonal images \( M= 3.606, SD = .858 \) were rated lower on arousal than both intrapersonal \( M= 3.752, SD = .848 \) and object-based reward images \( M= 3.921, SD = .932; t's \geq -4.056, p's < .001 \). Unique to the arousal rates, object-based reward images were rated higher than all the other image categories \( t's \geq -2.066, p's < .045 \). No main or interactive effects emerged for gender.
2.4.3 Electrophysiological Components

2.4.3.1 fN400

Main effects emerged for category ($F(3,120)=3.286$, $p=.029$, $\eta^2=.076$) and region ($F(2,80)=148.340$, $p<.001$, $\eta^2=.788$) that were qualified by a category x region interaction ($F(6,240)=2.625$, $p=.046$, $\eta^2=.062$; see Figure 3). Follow-up analyses showed that at the frontal region both intrapersonal ($M=-14.185$, $SD=5.567$) and object-based reward images ($M=-14.332$, $SD=7.878$) elicited larger fN400 responses compared to interpersonal reward images ($M=-12.481$, $SD=6.363$; $t's \geq 2.284$, $p's < .027$). This pattern was also present at the central region ($t's \geq 2.736$, $p's < .009$), with larger fN400 responses to intrapersonal ($M=-8.839$, $SD=4.503$) and object-based reward images ($M=-9.265$, $SD=6.182$) compared to interpersonal reward images ($M=-7.121$, $SD=5.542$). In parietal regions, neutral images ($M=-1.764$, $SD=4.603$) also elicited a larger fN400 compared to interpersonal reward images ($M=-.088$, $SD=5.634$; $t(42)=2.580$, $p=.013$), as did object-based reward images ($M=-2.333$, $SD=6.655$; $t(42)=2.580$, $p=.013$). An interaction emerged between region and gender ($F(2,80)= 5.461$, $p=.016$, $\eta^2=.120$) that was driven by girls exhibiting a larger parietal fN400 compared to boys ($t(41)= 2.653$, $p=.011$). Additionally, a main effect of age emerged ($F(1,40)= 4.100$, $p=.050$, $\eta^2=.093$) that showed a positive relation between age and amplitude of the fN400 response ($r(41)=.308$, $p=.045$) such that younger children had larger (more negative) fN400 responses overall.
2.4.3.2 Late Positive Potential (LPP)

A two-way interaction between category and gender ($F(3, 120)=3.421, p=.030, \eta^2=.079$; Figure 3). Follow-up tests revealed that males had a larger LPP response to object-based reward images compared to females ($t(41)=2.011, p=.051$). A main effect of region ($F(2, 80)=15.897, p<.001, \eta^2=.284$) emerged that was qualified by a two-way interaction between region and gender ($F(2, 80)=4.582, p=.017, \eta^2=.103$) showing that males had larger LPP responses in the frontal region ($M=1.529, SD=5.214$) compared to both the central ($M=1.688, SD=4.231$) and parietal regions ($M=-1.242, SD=3.874$; $t's \geq 3.805, p's < .011$). In contrast, females showed a larger LPP in the central region ($M=-.025, SD=5.221$) compared to the parietal region ($M=-.805, SD=4.812$; $t(21)=2.192, p=.040$). There was also an interaction between region and age ($F(2, 80)=6.200, p=.005, \eta^2=.134$) such that younger children showed larger LPP responses in the frontal region ($r(41)=-.313, p=.041$).

2.4.4 ERP Difference Scores

When comparing fN400 difference scores, main effects emerged for category ($F(2,80) = 4.442, p<.019, \eta^2=.100$) and region ($F(2,80) = 5.094, p<.008, \eta^2=.113$). Follow-up analyses revealed that N400 difference score amplitudes were larger at both frontal ($M=-.459, SD =3.737$) and central ($M=-.243, SD =3.384$) regions compared to the parietal region ($M=.563, SD =3.199; t's \geq -2.281, p's < .028$) and were larger (i.e., more negative) for both intrapersonal ($M=-.356, SD =3.827$) and object-based ($M=-.931, SD=4.469$) reward images as compared to interpersonal images ($M=1.149, SD =4.211; t's \geq 2.652, p's < .011$). There was also an interaction between region and age ($F(2,80)=$
such that younger children exhibited a larger fN400 in the frontal region as compared to the parietal region ($r(41)=.319$, $p=.037$).

For the LPP difference score, a two-way interaction emerged between image category and gender ($F(2, 80)=3.571$, $p=.037$, $\eta^2=.082$). Follow-up comparisons indicate that males ($M=2.764$, $SD=6.973$) have a larger LPP difference score to object-based rewards than females ($M=-2.341$ $SD=6.761$; $t(41)=-2.437$, $p=.019$). Comparing the amplitudes between each image LPP difference score, females show a more positive LPP response to interpersonal versus intrapersonal images ($M=.897$, $SD=6.534$) than males ($M=-4.519$, $SD=8.974$; $t(41)=-2.270$, $p=.029$).

2.4.5 Associations between ERPs and Self-Regulation

ERP components were correlated with parent report of child executive function (EF) skills and self-regulation on the global scales of the BRIEF: the Behavioral Regulation (BRI) Scale ($M=43.82$, $SD=11.07$) and the Metacognition (MI) Scale ($M=67.10$, $SD=15.25$).

No significant associations emerged between the fN400 and MI, nor the LPP and MI. For the BRI, greater regulation difficulties were associated with larger LPPs to intrapersonal reward images ($r(38)=.476$, $p=.002$) and object reward images ($r(38)=.335$ $p=.034$). When controlling for reactivity to neutral images, only larger LPP scores to intrapersonal reward images were positively correlated with greater behavioral regulation problems ($r(38)=.407$ $p=.009$). No significant association emerged between the fN400 and BRI.
2.5 Discussion

The current study assessed neural markers of motivated attention toward a variety of reward-related cues in children using a novel image set designed with developmentally relevant stimuli. By assessing ERPs to images that reflected a broad range of social and non-social reward-related stimuli, we sought to understand how attentional engagement to salient cues in the environment unfolds during early development and relates to adaptive and maladaptive patterns of self-regulation in childhood. Several key findings emerged highlighting unique patterns in self-report as well as neural processing that vary by distinct categories of reward-related cues.

Child ratings of image confirmed that both types of reward images were rated more strongly on valence and arousal than neutral images. Moreover, intrapersonal and object-based reward images were also rated as more positive and arousing as compared to interpersonal images. Prior work in children using adult image sets has shown differential patterns of image ratings among children, suggesting that these images may be less relevant and less effective at capturing attention in children (Hajcak & Dennis, 2009). In contrast, image ratings in this study indicate that the current set of reward images is developmentally appropriate and effective at engaging motivated attention in children.

Comparison of neural reactivity to each image category revealed distinct patterns of temporal processing. Object-based reward cues and intrapersonal images were preferentially processed at earlier stages as reflected in the fN400 response. Sustained processing of reward-related images via the LPP differed by gender. Namely, males had larger LPP responses to object-based reward cues whereas females had larger LPP responses to interpersonal versus intrapersonal images. These patterns also emerged
when assessing ERP differences scores controlling for reactivity to neutral images. Both object-based and intrapersonal reward categories elicited heightened neural reactivity in the frontal region. This pattern may correspond to the nature of the underlying structures involved in reward-related processing as prior work highlights significant roles for various areas of the frontal cortex (e.g. Liu et al., 2007). An additional factor contributing to the prominent anterior topography may relate to the nature of the task used in this study. Specifically, during the picture rating part of the task children were asked how the image made them feel. As prior work suggests that the prefrontal cortex is particularly involved in mentalizing about the oneself (Mitchell, Banaji & Macrae, 2005), the task instructions may have also contributed to the heightened processing evident in the frontal region. This mentalizing process may have also been employed differentially in younger and older children, as the fN400 to object and intrapersonal reward images was larger among younger children in the frontal region. Thus, younger children may have been using more frontal resources in order to reflect on the images whereas as older children may have been more successful at automatic reflection on this category of stimuli. Alternatively, younger children may have found these stimuli more salient. To better understand potential age differences in processing reward-related stimuli, future studies should examine reactivity to these reward categories in a passive paradigm that doesn’t have explicit self-reflection demands.

A gender distinction also emerged for the fN400, such that girls processed all categories of images more strongly in the parietal region than boys. One possibility is that girls could be utilizing a different strategy, one of more automatic processing, to process these stimuli. Alternatively, boys may have had a stronger reaction to the stimuli set that
manifested in a larger ERP response in anterior regions. Such an explanation corresponds to behavioral and fMRI work in adults showing differences in processing distinct forms of reward cues in males and females (Spreckelmeyer et al., 2009). However, when assessing fN400 difference scores that control for processing of neutral stimuli, no gender differences emerged. Larger fN400s to object-based and intrapersonal reward images were present in the standard and difference score versions of the fN400, suggesting that these categories are particularly salient to children. Both the object-based and intrapersonal images reflect specific reward items and/or achievement accomplishments, thus enhanced early processing of these two categories of may reflect greater efficiency in neural networks underlying processing of this type of reward-related imagery that allows for greater allocation of attentional resources to process additional contextual cues or task demands. It will be important to confirm whether these patterns of processing correspond to more efficient attentional engagement and behavioral performance when these forms of stimuli are embedded within other tasks. Confirmation of such patterns would serve as a foundation for subsequent work exploring how training impacts processing of social and non-social reward cues and ways in which these cues might be used to support self-regulation in children.

For the LPP, younger children exhibited greater sustained attention at the frontal region. Males also showed the largest LPP response in the frontal region and females showed the strongest LPP in the central region. Inspection of the grand means confirmed that LPP processing of the stimuli were concentrated in the anterior portion of the scalp and decreased moving posteriorly across the midline. These findings correspond to prior work using pleasant and unpleasant image categories that have found the LPP effect to be
a ‘topographically dynamic response’ when examining a wider window encompassing picture viewing time (Hua et al., 2014; Solomon, 2012). A similar pattern has also emerged in studies employing a mastoid configuration (Hajcak & Dennis, 2009) and it has been postulated that these regional patterns may reflect the development of connections between visual processing and frontally based attention networks (Kujawa et al., 2013; Moratti, Saugar & Strange, 2011).

Previous work assessing a more general category of pleasant images has shown enhanced LPP reactivity in a middle range time window within the central region among preschool aged children (Hua et al., 2014). To date, little work has focused on nuances within the broad category of positive stimuli that can influence children’s motivated attention to various forms of social and non-social reward-related cues. The current study suggests that the content of positive images, beyond the presence or absence of a face, is processed in distinct ways in males and females. Future work should examine activation patterns of specific neural structures that respond to a wide range of reward-related images, beyond traditionally assessed facial and monetary cues, and in a variety of tasks that tap individual differences in approach motivation.

Interestingly, females showed a larger LPP to interpersonal versus intrapersonal images. In the current study, the interpersonal stimuli included images that demonstrated relationships status (friends, parents and child) or group interaction (children playing) whereas the intrapersonal stimuli included faces of individuals with or receiving rewarding objects (i.e. medals). Thus, for girls, the interactive nature of the interpersonal images activated more sustained processing and captivated motivated attention more effectively than viewing an individual obtaining a reward. This pattern may indicate
heightened processing of social interaction in females and/or a more rapidly emerging developmental efficiency in processing individual face stimuli with age. For instance, other work using face stimuli to assess social reward show a reduced LPP to faces, particularly happy faces, among adolescents and adults (MacNamara et al., 2016; Smith, Weinberg, Moran & Hajcak, 2013). In contrast, males showed a larger LPP to object-based reward images than females. Thus, males showed both rapid (fN400) and sustained (LPP) reactivity to object-based rewards. These findings support and extend prior findings in adults that used fMRI to demonstrate differences in neural processing of reward between males and females (e.g. Spreckelmeyer et al., 2009). Combined, these gender differences in LPP responses to distinct forms of social and non-social categories of reward-related images provide unique insight into the neural processing of a more expansive range of salient cues that capture motivated attention in children.

A growing body of literature also demonstrates the utility of ERPs to characterize patterns of attentional capture denoting normative and maladaptive patterns of emotional processing related to behavior in children (e.g., Babkirk, Rios & Dennis, 2015; Solomon, et al., 2012). It has been proposed that attenuated reactivity to positively valanced stimuli may be a mechanism contributing to risk-taking and anti-social behavior (Gatzke-Kopp & Beauchaine, 2007). Indeed, neural evidence in the form of reduced LPP responsivity to positive stimuli has been associated with greater social problems in children and adolescents (Bunford et al., 2017). In the current study, children with amplified LPPs to intrapersonal reward-related images showed higher rates of behavior regulation problems, suggesting sustained processing of these images is related to impairments in children’s ability to engage in effective self-control.
The current study is the first to directly compare neural processing of motivated attention in children to a range of developmentally relevant, reward-related stimuli. However, there are several areas limitations to note. First, the present study only assessed neural markers of motivated attention toward these stimuli and future work should incorporate these images into tasks where children earn reward. Second, this study did not find a clear EPN response. The literature suggests that this component is not always present in young children, is highly dependent on stimulus selection and is affected by the use of a 64-channel montage (Bradley, Hamby, Low & Lang, 2007; De Cesarei & Codispoti, 2006; Hajcak & Dennis, 2009). Expanding the ages studied while using a different channel confirmation may shed light on whether the EPN is relevant for reward-based work that does not utilize face stimuli. Third, longitudinal work will be important to track child responsivity to this broad set of social and non-social reward stimuli to explore the potential for a later appearing EPN responses as well as track the stability in the fN400 and LPP components. Last, it will be important to link these neural markers to behavioral assessments of reward responsivity and social functioning with parents and peers.

In sum, these results expand our understanding of attentional processing of reward-related images in children and underscore the advantage of using neural measures to track the development of approach motivation. Importantly, this research contributes to a small but growing literature identifying ways to track the multi-faceted nature of social and non-social reward-related cues (Demurie et al., 2011; Stavropoulos & Carver, 2014) by establishing a child-friendly stimulus set consisting of a wide range of developmentally relevant images. Given that both reward and social signals significantly
impact child learning and can activate intrinsic motivation (Stavropoulos & Carver, 2014), neural markers of social and non-social reward processing responses can be valuable tools in tracking and intervention effects aimed at promoting adaptive outcomes among children, particularly those at risk of socio-emotional difficulties.
References


Figure 1: Picture viewing task
Figure 2: Ratings of (a) valence and (b) arousal by picture category
Figure 3: ERP components (fN400 & LPP) by region and image category
CHAPTER 3

MOTIVATED ATTENTION TO SOCIAL AND NON-SOCIAL REWARD STIMULI: EXPLORING GENDER-RELATED RISK OF EXTERNALIZING PROBLEMS IN CHILDREN

3.1 Aims and Hypotheses

As reviewed in Chapter 1, male children are at an elevated risk for developing externalizing problem behaviors compared to females. Converging evidence suggests that gender differences in externalizing risk are attributed to differences in the way that males and females process emotions (Eme, 2016; Maguire et al., 2015). However, very little work has used ERP measures to examine whether gender differences in affective processing relate to different externalizing patterns between males and females. Given the evidence presented in Chapter 2, that highlights gender differences in the LPP (i.e., greater processing of non-social reward in boys compared to girls), and relations between the LPP and behavioral issues associated with externalizing behavior (i.e., larger LPPs to object and intrapersonal reward stimuli related greater self-regulation problems), the current aim of this study is to expand on those findings by assessing links between gender, neural markers of affective processing, and externalizing risk using clinical assessments of externalizing outcomes (e.g., aggression, conduct disorder, hyperactivity) within a larger sample of children compared to Study 2.

We predict that boys and girls will exhibit LPP patterns consistent with results in Chapter 2 (McDermott & Egwuatu, 2018). Specifically, we expect boys to show enhanced LPPs to object-based images compared to girls. Based on past literature documenting attention biases to social information in girls, we also predict that girls will
show enhanced LPPs to social images (interpersonal and intrapersonal) compared to boys (Groen et al., 2013; Kato & Takeda, 2017; Proverbio et al., 2008b, 2009).

When examining gender differences in externalizing problems, we predict a main effect of gender, such that higher levels of externalizing problems will be found in boys versus girls. Moreover, we expect that externalizing problems will be predicted by an interaction between gender and image type. Specifically, boys who exhibit larger LPPs to non-social (object-based) images compared to social images are predicted to have higher levels of externalizing. In contrast, boys displaying larger LPPs to social images compared non-social (object-based) images are predicted to have lower rates of externalizing. We do not expect to see significant statistical interactions between LPP magnitude and image type for girls.

As discussed previously, the fN400 is thought to index attentional processing of semantic information; it has been shown to sensitive to affective information, especially positive social stimuli (Amoruso et al., 2013; Shehzad & McCarthy, 2019; Wu et al., 2014). Based on limited research reporting positive, non-social bias in males and social bias in girls (Greimel et al., 2018b; Pintzinger et al., 2016; Spreckelmeyer et al., 2009), we expect to find gender differences in the fN400 such that boys will show larger fN400s to non-social reward stimuli (i.e., object images) and girls will show larger fN400s to social reward stimuli (i.e., interpersonal images). Although these hypotheses are somewhat exploratory given the limited work examining this component in the context of affective stimuli among children, this work may provide insightful information about potential gender differences unfolding in earlier stages of processing and indicate
whether these early temporal patterns underscore gender differences in externalizing difficulties in children.

3.2 Methods

3.2.1 Participants

One hundred and sixteen children between the ages of 6 and 10 years old participated in the current study (60 male, M<sub>age</sub>= 8.38 years). Participants and their families were recruited at University of Massachusetts Amherst via email advertisements and paper flyers. This initial sample also included the 73 participants previously reported on in Chapter 2 (see Section 2.1). Of the 116 children recruited, thirty participants (25.6 %) were excluded due to low number of ERP trials (i.e., less than 8 trial per image category; Moran et al., 2013), five participants (4.3%) to technical difficulties in recording and processing their EEG, two participants (1.7%) failed to complete the task, and one participant (.9%) was greater than 3.29 standard deviation from the mean on key variables (see Tabachnick et al., 2019). In all, the final sample included 78 children (40 male, M<sub>age</sub>= 8.51 years). Excluded participants did not significantly differ from those included in the final analysis on child age (p=.071), child gender distribution (p=.342), caregiver’s age (p=.420), and caregiver education (p=.235). Participant and caregiver demographic information are summarized in Table 1.

3.2.2 Procedure

Study procedures were identical to those described in Chapter 2 (section 2.2.1). Upon arrival, signed guardian consent and written/verbal child assent was obtained. After obtaining guardian consent and child’s assent, child participants were fitted with an EEG
cap to record EEG/ERP activity and completed study task. During EEG data collection, the parental guardian completed questionnaires regarding their child’s emotional and behavioral development. At the conclusion of the study, all families were given monetary compensation for participation ($20) and children chose two small age-appropriate prizes to take home.

3.2.2.1 Task Stimuli

Stimuli was taken from the Child Affective Picture Set- Reward (CAPS-R; McDermott & Egwuatu, 2018). The CAPS-R set consisted of 150 pictures consisting of both illustrations and photographs. Pictures were divided into two social reward categories (i.e., interpersonal, and intrapersonal), a non-social reward category (objects), and neutral category for comparison. A detailed description of the CAPS-R picture set, its stimuli categories, and how these categories were formulated can be found in Chapter 2 (see Section 2.2.)

3.2.2.3 Affective Picture Viewing Task.

Participants completed a picture viewing task where they viewed and rated each picture for perceived valence and arousal using a rating scale. Stimuli were presented across 4 blocks in pseudo randomized order. Total task time lasted between 40-60 mins for each participant. A detailed description of the task procedure can be found in Chapter 2 (see section 2.2.1).
3.2.2.4 EEG acquisition and ERP measures

Continuous EEG activity acquisition and ERP processing procedures remained the same as described in Chapter 2 (section 2.3). Mean amplitudes for the fN400 and LPP were calculated at 3 electrode regions: Frontal (F1, Fz, F2), Central (C1, Cz, C2), and Parietal (P1, Pz, P2) to control for topographical changes in ERPs amplitudes over time (Foti et al, 2009). For the fN400, the scoring window was extended from 250-500ms to 250-600ms post picture onset based on visual inspection of participants’ individual grand mean components. The scoring window for the LPP remained from 1000-2500 ms.

3.2.3 Measures

3.2.3.1 Child Externalizing Behavior

Caregivers completed the parent-report version of the Behavioral Assessment System for Children- Second Edition (BASC-2-PRS-C), which contains 160 items designed to assess risk of psychopathology in children aged 6-11 (Kamphaus, 2015). Caregivers rated the frequency of child behavior problems within the last 6 months using a 4-point Likert scale. Responses ranged from “never” (0) to “almost always” (3). To examine children’s levels of externalizing symptomology, the current study focused its analysis on items related to the Externalizing Problems (EXT) composite score. The EXT composite was calculated by summing the T scores of the Hyperactivity (HYP), Aggression (AGG), and Conduct Problems (CND) clinical subscales. Overall, the BASC-2 is a highly reliable measure (e.g., α’s = .84 for children 6-7 years old; α = .86 for children 8-11 years old; Kamphaus, 2015) and has excellent reliability for the EXT composite scale (α= .92 for 6-7 years; α= .94 for 8-11 years ) and its associated subscales.
in school-aged samples (e.g., HYP: $\alpha = .85$ for 6-7 years, $\alpha = .86$ for 8-11 years; AGG: $\alpha = .85$ for 6-7 years, $\alpha = .87$ for 8-11 years, and CND: $\alpha = .83$ for 6-7 years, $\alpha = .88$ for 8-11 years; Kamphaus, 2015).

### 3.2.4 Statistical Approach

The first aim of the current study was to confirm whether the self-report and ERP patterns described in Chapter 2 (see Section 2.4) held with a larger sample size.

To examine differences in perceived valence and arousal to pictures, mixed repeated measures analysis of covariance (ANCOVAs) was conducted with gender (male, female) as between-subject factors and picture categories as within-subject factors (interpersonal, intrapersonal, object, and neutral). Participant age was entered as a continuous covariate to control for potential developmental differences in perceived valence and arousal. Analyses for self-report ratings were performed separately for valence and arousal. Greenhouse-Gessier corrections were applied to all analyses that violated the sphericity assumption.

Modulations in ERP amplitudes were assessed through a series of mixed repeated measures ANCOVAs. Gender (male, female) was entered as a between-subjects factor. Electrode region (frontal, central, and parietal) and picture categories (interpersonal, intrapersonal, object, and neutral) were entered as within-subject factors. Child age was controlled for to account for any potential developmental differences in ERP activity. Greenhouse-Geisser corrections were applied to all analyses that violated the sphericity assumption. Separate analyses were performed for the fN400 and LPP. Exploratory post-hoc comparisons (i.e., t-tests) were also conducted to examine gender level differences for each picture category at regions where ERP amplitudes were maximal as determined
by statistical analyses. The significance level for post-hoc tests for significant main effects and interactions, and for exploratory comparisons, were all adjusted (alpha = .01) to correct for multiple comparisons.

Regarding our second aim, we conducted moderation analyses to investigate whether ERP amplitudes (i.e., fN400 and LPP) moderated the relation between gender and externalizing symptomatology in children. ERP measures were entered as a predictor, gender was entered as a moderator, and the BASC-2 Externalizing (EXT) raw composite score was entered as an outcome variable. Participant age was entered as a covariate to control for the possible effects of developmental differences on ERP amplitudes. Analyses were run separately for each picture category (interpersonal, intrapersonal, object, neural). Each set of regression analyses were run separately for the fN400 and LPP. To limit the number of tests performed, regressions analyses were only conducted at electrode regions where ERP amplitudes were maximal. Simple slope analyses were conducted to probe any significant or trending interactions ($p < .05$ and $p < .10$, respectively).

To directly investigate processing differences between social and non-social stimuli, we calculated ERP difference scores between social and nonsocial categories (i.e., interpersonal-object, intrapersonal-object) and ran moderation analyses with ERP difference scores as moderating variables. The LPP and fN400 difference scores were examined separately. As with prior analyses, the significance threshold was adjusted (alpha = .01) for regression models, to minimize potential Type 1 error due to multiple comparisons.
Based on previous reports suggesting neutral stimuli may elicit heightened responses in certain individuals (see, Schneider et al., 2016; van den Heuvel et al., 2018) and visual inspection of the neutral ERP grand means in the current study, which similarly showed elevated amplitudes, we decided not to include neutral difference scores (e.g., affective - neutral) in our main analysis. As ERP activity to neutral pictures could also potentially reveal unique effects with regard to gender differences and externalizing outcomes, we chose not to control for neutral as a baseline stimulus, as doing so would hinder our interpretation of the results.

3.3 Results

3.3.1 Self-Report Ratings

Descriptive statistics for valence and arousal self-report ratings are detailed in Table 2. A main effect of picture category emerged for valence ratings, $F(3, 225)=118.05, p<.001, \eta^2_p=.611$. Valence ratings showed a significant linear pattern among picture categories ($F(1,75)=98.71, p<.001, \eta^2_p=.568$), with children rating object pictures ($M=4.01$) highest on valence followed by intrapersonal pictures ($M=4.14$), interpersonal pictures ($M=4.02$), and neutral pictures ($M=3.36$). Post-hoc comparisons revealed that all reward picture categories (i.e., interpersonal, intrapersonal, object) received significantly higher valence ratings than neutral pictures (all p’s < .001). Children also rated object pictures significantly higher than intrapersonal ($p=.001$) and interpersonal ($p<.001$) categories on valence. Finally, intrapersonal pictures received higher ratings than interpersonal pictures ($p<.001$). No significant gender by picture category interaction emerged suggesting that males and females rated valence levels
similarly across picture categories, $F(3, 225)= .409, p=.674, \eta^2_p=.005$. For arousal ratings, a main effect of picture category emerged, $F(3, 225)=63.55, p<.001, \eta^2_p=.459$. Arousal ratings also showed a significant linear trend across picture categories, $F(1,75)= 30.65, p<.001, \eta^2_p=.290$; children’s self-report of arousal was highest for object pictures (M=4.06), followed by intrapersonal pictures (M=3.84), interpersonal pictures (M=3.69), and neutral (M=3.22). Post-hoc comparisons revealed that children reported significantly higher arousal for all reward picture categories than neutral (all p’s < .001). When comparing across reward picture categories, children also rated object pictures significantly higher than intrapersonal and interpersonal pictures in arousal (p’s <.001). Intrapersonal pictures were rated as more arousing than interpersonal pictures (p<.001). As with valence ratings, no significant gender by picture interaction emerged for arousal ratings, $F(3, 225)= .228, p=.789, \eta^2_p=.003$.

3.3.2 ERP Results

3.3.2.1 fN400

Descriptive statistics for the fN400 are summarized in Table 3. ERP waveforms for the fN400 at frontal, central, and parietal regions are presented in Figure 4.

A significant main effect of picture category emerged for the fN400, $F(3, 225)=4.39 p=.008, \eta^2_p=.055$. Intrapersonal pictures (M= -8.51 µV) elicited the largest (more negative) fN400 amplitudes, followed by object pictures (M= -8.27 µV), neutral pictures (M= -7.60 µV), and interpersonal pictures (M= -6.87 µV). Post-hoc comparisons revealed that interpersonal images elicited a significantly smaller (less negative) fN400 amplitudes compared to intrapersonal pictures (p<.001) and object images (p=.014). Post-
ho comparisons between interpersonal and neutral images were non-significant (p=.109).

A main effect of region, $F(2, 150)=150.31 \ p<.001, \ \eta_{p}^{2}=.667$, and a significant linear trend emerged for the fN400 across regions ($F(1, 75)=166.54 \ p<.001, \ \eta_{p}^{2}=.689$). Specifically, fN400 amplitudes were largest at the frontal region (M= -12.38 $\mu$V) followed by central (M= -8.42 $\mu$V) and parietal (M= -2.63 $\mu$V) regions. Post-hoc comparisons revealed that fN400 amplitudes at frontal regions were significantly larger than amplitudes at both central and parietal regions (p’s <.001). The fN400 at the central region was also significantly larger than amplitudes at the partial region (p<.001).

A significant interaction between picture category and electrode region also emerged, $F(6, 450)=2.79, \ p=.034, \ \eta_{p}^{2}=.036$. However, post-hoc comparisons confirmed main effect patterns. For each picture category, the fN400 was largest at frontal scalp regions. Likewise, for each electrode region the fN400 amplitudes were for intrapersonal pictures and smallest for interpersonal pictures.

A significant interaction also emerged between gender and region, $F(2, 150)=2.79, \ p=.034, \ \eta_{p}^{2}=.036$. However, post-hoc comparisons showed that the topographical distribution of fN400 amplitudes did not significantly differ between males and females (all p’s >.10) and fN400 amplitudes were most focused at frontal regions across gender (all p’s <.001). No interaction emerged between gender and picture category, $F(3, 225)=.834, \ p=.459, \ \eta_{p}^{2}=.011$. Exploratory post-hoc analyses were conducted at the frontal region to examine gender comparisons within each picture category at maximal sites. Analyses confirmed that males and females did not differ in frontal fN400 amplitudes for each picture category (all p’s > .300; see Figure 5 & 6).
3.3.2.2 LPP

Descriptive statistics for the LPP are summarized in Table 4. ERP waveforms for the LPP at frontal, central, and parietal regions are presented in Figure 4. No main effect of picture category emerged for the LPP, $F(3, 225)= 1.36, p=.258, \eta_p^2=.018$. However, there was a significant main effect for region, $F(2, 150)= 4.91, p=.017, \eta_p^2=.061$. Post-hoc comparisons revealed that LPP amplitudes at the parietal region ($M=-.660 \mu V$) were significantly smaller (i.e., less positive) than amplitudes at frontal ($M=.242 \mu V$) and central ($M=.258 \mu V$) regions (all $p$’s < .05). However, only post-hoc comparison between parietal and central regions remained significant when correcting for multiple comparisons (i.e., $\alpha=.01$). LPP amplitudes did not significantly differ between frontal and central regions ($p=.946$).

A marginal interaction emerged between gender and picture category, $F(3, 225)= 2.37, p=.081, \eta_p^2=.031$ (see Figure 5 & 6). Exploratory post-hoc analyses showed that males exhibited larger LPP amplitudes to object pictures compared to females ($M_{males}= 1.84 \mu V$ vs. $M_{females}= -1.27 \mu V$), however this effect did not reach significance ($p=.065$). We further explored gender comparisons at frontal and central regions, as the LPP was found to be maximal at these sites and amplitudes did not significantly differ between these two regions. Exploratory analyses revealed similar patterns between regions -, with males exhibiting larger LPP amplitudes to object pictures compared to females at both frontal and central regions (frontal: $M_{males}= 2.08 \mu V$ vs. $M_{females}= -1.03 \mu V$; central: $M_{males}= 2.25 \mu V$ vs. $M_{females}= -.999 \mu V$). However, these gender effects at frontal and central regions also did not reach significance ($p=.107$ and $p=.060$, respectively). No
differences emerged for the LPP to interpersonal and intrapersonal reward pictures ($p$’s > .05)

### 3.3.3 Externalizing Regression Results

Descriptive statistics for child externalizing behavior scales are summarized in Table 5 & 6. Bivariate correlations between major predictors and outcome variables are presented in Table 7. Male and female participants did not differ on externalizing, hyperactivity, aggression, and conduct problem scores on the BASC-2 (all $p$’s > .10). Larger LPP amplitudes to intrapersonal reward pictures were related to increased externalizing behaviors ($r=.230, p < .05$). Externalizing behavior was not related to LPP amplitudes to interpersonal and object reward categories nor to fN400 amplitudes elicited all image types.

Multiple regressions were performed to test the moderating role of ERP amplitudes (e.g., fn400, LPP) on the relation between gender and externalizing behavior. To avoid potential multicollinearity, continuous predictors (e.g., ERP measures) were mean centered and interactions variables (ERP by gender) were calculated as products of mean-centered predictors (Aiken & West, 1991). To untangle the unique effects of picture content on ERP patterns, regression models are reported separately for each picture category.

Study
3.3.3.1 fN400 and Externalizing Regression Results

Table 8 summarizes regression results with the fN400 as a predictor and in interaction with gender. All analyses were run with fN400 amplitudes at frontal regions as the fN400 was demonstrated to be maximal at this scalp region.

About main effects, significant associations between fN400 amplitudes and parent-report of externalizing symptoms emerged for regression models focusing on the interpersonal, object, and neutral picture categories. Within each category, larger fN400 amplitudes (more negative) were associated with higher externalizing scores

(interpersonal: \( b = -1.01, SE = .502, p = .047 \), object: \( b = -.931, SE = .448, p = .041 \), neutral: \( b = -2.35, SE = .787, p = .004 \)). No relations between age or gender with externalizing scores were observed for either category (p > .10).

With regard to gender as a moderator, significant interactions between gender and the fN400 predicting externalizing scores also emerged for interpersonal, object, and neutral picture categories (interpersonal: \( b = 1.87, SE = .813, p = .024 \), object: \( b = 1.52, SE = .694, p = .032 \), neutral: \( b = 2.72, SE = 1.03, p = .011 \)). Simple slope analyses were tested to follow up interaction effects, and they revealed a similar pattern across all three picture categories (see Figures 7a, 7c, & 7d). For boys, larger fN400 amplitudes were associated with significantly higher externalizing scores (interpersonal: \( b = -1.01, SE = .502, t = -2.01, p = .048 \), object: \( b = -.931, SE = .448, t = -2.08, p = .041 \), neutral: \( b = -2.35, SE = .787, t = -2.99, p = .004 \)). No significant relations between fN400 amplitudes and externalizing scores emerged for girls (interpersonal: \( b = .861, SE = .636, t = 1.35, p = .180 \), object: \( b = .589, SE = .530, t = 1.11, p = .270 \), neutral: \( b = .369, SE = .618, t = .598, p = .552 \)).
Table 9 summarizes the results of regression models with fN400 difference scores between social and non-social pictures entered as the moderating variable (i.e., interpersonal-object fN400, intrapersonal-object fN400). These analyses were conducted to compare potential processing differences between social and non-social stimuli more directly. Neither the predictors (i.e., age, gender, fN400 difference score) nor the two-way interaction between gender and fN400 was significant for either regression model (p > .10).

3.3.3.2 LPP and Externalizing Regression Results

Table 10 summarizes results for regression models with the LPP as a predictor the gender as moderator variable. Regression models were run with the LPP at the frontal region\(^4\) as amplitudes were maximal at this region.

Significant regression effects were observed only for the neutral category. Larger LPP amplitudes (more positive) to neutral pictures were marginally associated with lower externalizing scores, \(b = -1.02, SE = .559, p = .073\). No significant association emerged for age and gender (p > .10). A significant interaction between gender and LPP amplitudes to neutral pictures that positively predicted children’s externalizing scores, \(b = 2.25, SE = .746, p = .003\). Follow-up analyses revealed contrasting relations between LPP amplitudes to neutral pictures and externalizing symptomology for boys and girls (see Figure 8a). For girls, larger LPP amplitudes were associated with significantly higher externalizing scores, \(b = 1.24, SE = .498, t = 2.48, p = .015\) whereas larger LPP amplitudes were

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\(^4\) The LPP was found to be maximal at both frontal and central regions. Separate regressions were conducted at each region, results did not significantly differ between the two regions. Thus, only regression analyses for the frontal LPP are reported.
associated with marginally lower externalizing scores for boys, $b = -1.01, SE = .559, t = -1.81, p = .073$.

For the object category, a marginal interaction emerged between gender and LPP, $b = 1.18, SE = .710, p = .099$. Exploratory follow up analyses showed that, among girls, larger LPP amplitudes to object pictures were significantly associated with high parent-report of externalizing problems, $b = .899, SE = .447, t = 2.01, p = .048$ (See Figure 8b). No significant relations emerged between LPP amplitudes and externalizing symptomatology for boys ($p = .603$). No significant results emerged for regression models with LPP that were focused on interpersonal and interpersonal picture categories (all $p$’s > .10).

Table 9 summarizes the results of regression models with LPP difference scores between social and non-social pictures entered as the moderating variable (i.e., $\Delta$ interpersonal-object, $\Delta$ intrapersonal-object). No significant associations with predictors (i.e., age, gender, $\Delta$LPP score) nor significant interactions (i.e., gender by LPP) were observed for either regression model ($p > .10$).

3.4 Discussion

The goal of the current study was to build on findings from the pilot study reported in Chapter 2 detailing: (1) gender differences in affective processing (as measured by the fN400 and LPP) to distinct forms of social and non-social reward images and (2) distinct relations between ERP responses to social and non-social reward images and behavioral issues associated with externalizing risk. It is well documented that males are more likely to display higher rates of externalizing behavior than females (Chen, 2010; Mayes et al., 2020; Miner & Clarke-Stewart, 2008. In addition, considerable evidence suggests that males and females process emotions differently.
Specifically, males show biased processing of reward stimuli, whereas females show biased processing of social images (Greimel et al., 2018b; Spreckelmeyer et al., 2009). Thus, we examined whether relations between ERP responses to social and non-social reward images and externalizing behavior in children were impacted by gender. Overall, gender patterns were consistent with results reported in Chapter 2. Also, unique gender patterns emerged in the relation between ERPs and externalizing behavior. Namely, higher levels of externalizing behavior in boys were related to larger, more global, patterns in fN400 amplitudes. In contrast, externalizing behavior in girls related to larger LPP amplitudes to neutral and object images. These results suggest that gender differences in externalizing risk might be linked temporally- distinct patterns in affective processing between boys and girls.

Regarding the first goal, children’s self-report ratings of image categories were first analyzed to confirm whether valence and arousal patterns remined consistent with those reported in Chapter 2. In line with Chapter 2, children rated reward images as more positive and arousing than neutral images. Object reward images and intrapersonal reward images were rated as more positive and arousing than interpersonal reward images. Unique to the current study, we found that children rated object reward images significantly more positive and arousing than both social reward image categories (interpersonal and intrapersonal), highlighting a non-social/ social distinction in children’s emotional perception of reward contexts. Taken together, these results correspond with previous studies showing that children are especially responsive to positive valence/reward-related stimuli when processing emotions (Hajack & Dennis, 2009; McManis et al. 2001, Solomon et al., 2012) and show stronger emotional reactivity
and attention allocation in response to non-social reward than social reward (Wang et al., 2020).

These results provide further evidence demonstrating that the current image set effectively engages emotion processes in children and that images depict content that is motivationally relevant to children. Furthermore, our findings highlight differences in children’s emotional perception of distinct semantic categories of reward in children (i.e., social versus non-social reward, extrinsic versus intrinsic reward). Thus, future work should consider the impact of semantic content when selecting stimuli for affective processing research in children.

ERP responses to image categories were also consistent with patterns reported in Chapter 2. Findings showed the fN400 amplitudes were strongest at frontal regions. The spatial pattern found for the fN400 corresponds with previous work in adults reporting prominent frontal topography for this ERP component (Curran, 2000; Ganis et al., 1996). The LPP also was found to be strongest at frontal and central regions. As highlighted in Chapter 2, this finding is consistent with past studies in children reporting a dynamic spatiotemporal pattern in the LPP, with the LPP amplitudes showing a more anterior topographical distribution during later time windows (Hua et al., 2014; Solomon et al., 2012).

Object and intrapersonal reward images were also found to elicit larger fN400 amplitudes than interpersonal reward images. Notably, fN400 patterns also corresponded with patterns observed in children’s self-report ratings. Converging research suggests modulations in the fN400 component may reflect perceptual and semantic processing of meaningful information (Lenynes et al., 2017; Kutas & Federmier, 2011; Voss &
Federmeir, 2011; Voss & Paller, 2007). Therefore, the combination of self-report and fN400 patterns suggests that these specific reward categories (i.e., object and intrapersonal) are particularly more effective at facilitating attention processes than other reward types (i.e., interpersonal) within this age group.

As predicted, boys exhibited larger LPP amplitudes to object reward images than girls. However, this finding was marginally significant. It is not clear why the gender effect in this study was not as strong as the effect reported in the pilot study described in Chapter 2. One contributing factor could be the greater variability in LPP amplitudes to object images compared to other image categories across our participant sample (see Table 4). Therefore, it is possible that the correction we applied to address variance differences in ERP measures across image categories (i.e., Greenhouse-Gessier) may have been overly conservative and resulted in lower power (i.e., reduced degrees of freedom) and produced a weaker effect (Greenhouse & Geisser, 1959). Nonetheless, the observed pattern (larger object LPPs in boys than girls) was consistent with the finding reported in Chapter 2 and corresponds with previous work in adolescents and adults reporting heightened neural processing of positive valence/reward stimuli (Bianchin & Angrilli, 2012; Solomon et al., 2012; Zhang et al., 2017), as well as non-social reward (Althaus et al., 2014; Greimel et al., 2018a) in males compared to females.

Interestingly, boys and girls did not differ in ERP responses to social reward images (i.e., interpersonal, intrapersonal). This finding contradicted our hypothesis that girls would exhibit larger LPP amplitudes to social reward images than boys. One possible explanation for this unanticipated finding could be that the emotional stimuli used in this study focused on positive valence. As males have been shown to exhibit
processing biases to positive stimuli, that it is possible boys showed similar attention pattern to social reward stimuli to girls due to the positive orientation of the current stimuli.

The second goal of the current study was to examine whether gender moderated relations between ERP responses to social and non-social reward images and externalizing behavior. To do this we first conducted descriptive analyses to explore gender differences in externalizing behavior, as well as relations between the fN400, LPP, and externalizing behavior.

Contrary to our predictions, boys and girls did not differ in their externalizing behavior levels. This finding was inconsistent with findings from past literature reporting higher rates of externalizing behavior in boys compared to girls (Chen, 2010; Mayes et al., 2020; Miner & Clarke-Stewart, 2008). It is possible that this contrast with the literature emerged because we used a normative, community sample. This may have resulted in reduced variability in externalizing score than if we had oversampled for participants with subclinical levels of externalizing behavior. Moreover, developmental trajectories for externalizing behavior tend to begin stabilizing during preadolescence (Class et al., 2019; Hicks et al., 2007b; Moilanen et al., 2010b), therefore gender distinctions in externalizing levels may not have emerged due to the selected age range for the current sample (i.e., 6-10 years old).

Zero-order correlations between ERP responses and externalizing behavior measures revealed significant relations between LPPs to intrapersonal reward images and externalizing, such that larger LPPs to intrapersonal rewards (i.e., social images with no interaction) were associated with higher levels of externalizing behavior. This result
builds on previous findings from behavioral studies linking attention biases to socially-oriented reward cues (i.e., happy faces) with externalizing behavior in typically developing (Morales et al., 2020) and at-risk children (Cremone et al., 2018).

Furthermore, our results extend on these previous findings and suggest a relation between heightened attention to specific types of reward and externalizing behavior in children. Therefore, the current study suggests that the heightened LPP activity to social rewards, specifically those without an social interactive component, may uniquely reflect externalizing risk in children.

Externalizing behavior was associated larger fN400 patterns across all image categories (including neutral) in boys, suggesting that images elicited greater attentional engagement among boys irrespective of image context. Girls did not show any between the fN400 and externalizing problem. The fN400 is typically assessed using memory task paradigms in adults, therefore very little is known about the fN400 within the context of a passive-viewing paradigm in children. However, drawing on previous suggesting that the fN400 reflects contextual and semantic binding of information (Amoruso et al., 2013; P. Leynes & Mok, 2020; Voss & Paller, 2007), our results indicate that heightened externalizing risk in boys may be linked to early impairments in discriminating between contextual information. As mentioned in Chapter 1, externalizing problems in children has previously been linked to emotional perception issues, such as poor emotion recognition and emotional discrimination (Martin et al., 2009; Schultz et al., 2004a; Waddington et al., 2018). Moreover, males and females are known to show robust differences in their emotion perception abilities. For example, females tend to outperform males in both speed and accuracy during non-verbal emotion recognition and
discrimination tasks (Alaerts et al., 2011; Collignon et al., 2010; Hall et al., 2010; Hampson et al., 2006; Lawrence et al., 2015; McClure et al., 2004; Montagne et al., 2005; Wingenbach et al., 2018). These reports may provide explanation as to why relations between heightened fN400 responses and externalizing behavior emerged in boys but, not in girls.

Externalizing behavior was associated with larger LPP amplitudes to object and neutral images categories in girls. Regarding the object reward category, our findings for the object reward category contradicted our hypothesis that larger LPP amplitudes to objects would predict increased externalizing behavior in boys. Also, our findings contrast from a recent child study linking large attention biases to reward to externalizing behavior in boys, not girls (Morales et al., 2020). One possible reason why we did not observe a relation between LPP amplitude to object reward images and externalizing behavior in boys could be that the boys, in general, showed larger LPPs to object reward images than girls in our sample; therefore, there may not have been as much variation in LPP responses to object images compared girls. Also, our sample consisted of a normative sample, so limited variation in both the LPP and externalizing behavior scores may have contributed to our lack of finding in boys. As for girls, past research suggest that: (1) girls are less responsive to non-social reward than boys (Greimel et al., 2018b; Spreckelmeyer et al., 2009), (2) girls are more responsive to social versus non-social content than boys (Kato & Takeda, 2017; Proverbio, 2017; Proverbio et al., 2009), and (3) girls are less likely to develop externalizing problems than boys (Bennett et al., 2005; Caldwell et al., 2015; Chen, 2010; Hicks et al., 2007c; Zahn-Waxler et al., 2008).

However, emerging research also suggests that, among those who have longstanding
externalizing difficulties, males and females show similar affective processing patterns (Hodgins, 2020; Kohls et al., 2020). Therefore, it is possible that sustained attention (i.e., LPP) to non-social rewards is less normative in girls compared to boys but reflects a marker that relates to externalizing behavior more in girls than boys. In other words, if such a pattern is not typically seen in girls, sustained attentional processing of non-social reward would serve as a more sensitive marker in predicting externalizing risk in girls (as compared to boys).

We did not anticipate finding relations between LPP responses to neutral and externalizing behavior nor that these relations would predict increased externalizing behavior in girls. To our knowledge, no work has reported a relation between elevated neutral processing and externalizing problems in children. However, psychopathology research has linked heightened processing of neutral stimuli to greater internalizing symptoms, such as anxiety (Cooney et al., 2006; Kirschner et al., 2016; Li et al., 2020; Sharp et al., 2008; Wieser & Moscovitch, 2015). Therefore, it is possible greater sustained processing (indexed by the LPP) to neutral stimuli may signal increased risk for externalizing and internalizing problems in girls. Future work should further explore how LPP responses to distinct reward categories compare with other self-report and behavioral measures in capturing externalizing and internalizing risk processes in girls.

The current study did have some limitations that should be considered. First, our sample was representative of the local area, which consists mostly of well-educated, White families. As such, the homogeneity of our community sample should be

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5 Internalizing behaviors are problematic actions and/or states that are directed inward towards one’s self (J. Liu et al., 2011). Examples of internalizing symptoms are anxiety, depression, behavioral withdrawal, and somatic disturbances.
considered before generalizing findings to more socioeconomic and racial/ethnically diverse populations. Second, the current data are from a cross-sectional design, so caution should be taken before extrapolating these results. More longitudinal evidence exploring these patterns across time to make strong inference about gender-related trajectories in temporal processing of social and nonsocial reward in relation to externalizing risk.

The current study is one of the first to explore gender differences in affective processing of specific types of stimuli (e.g., social and non-social reward) in relation externalizing risk in a normative child sample. Our results reveal important patterns that indicate gender differences in externalizing risk might be reflected in temporally-distinct processes between boys and girls. Specifically, we found elevated externalizing risk was reflected during earlier stages in affective processing for boys and during later stages in affective processing in girls. The current work contributes to our understanding of possible neural mechanisms underlying gender differences in externalizing. Essentially, this research highlights the importance of considering the role of gender when examining externalizing risk patterns in children.
Table 1. Demographic Information of Total, Included, and Excluded Participants

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<th>Excluded (n=38)</th>
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<td>M (µV)</td>
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Table 4. Means (Standard Deviations) and Gender Comparisons for the LPP

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<th>Males (N=40) M (µV)</th>
<th>SD</th>
<th>Females (N=38) M (µV)</th>
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<td>Females (N=38)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>---------------------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
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<td>3.13</td>
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Table 6. Means and Standard Deviations for Externalizing Behavior Scales (T Scores)

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<th>Males (N=40)</th>
<th>Females (N=38)</th>
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<td>SD</td>
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<td>50.03</td>
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<td>Aggression</td>
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<tr>
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</tr>
<tr>
<td>2. Intrapersonal</td>
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<td>--</td>
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</tr>
<tr>
<td>3. Object</td>
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<td>.713**</td>
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<tr>
<td>4. Neutral</td>
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<td>∆ fN400 Score</td>
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<td>5. ∆ Inter-Obj</td>
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<td>8. Intrapersonal</td>
<td>-.089</td>
<td>.181</td>
<td>-.047</td>
</tr>
<tr>
<td>9. Object</td>
<td>.112</td>
<td>.198†</td>
<td>.325**</td>
</tr>
<tr>
<td>10. Neutral</td>
<td>-.040</td>
<td>.049</td>
<td>-.011</td>
</tr>
<tr>
<td>∆ LPP Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. ∆ Inter-Obj</td>
<td>.043</td>
<td>-.097</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

Table 7. Bivariate Correlations Among fN400, LPP, and Externalizing Behavior Scales (Raw Scores)
Table 7 (cont’d)

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. Δ Intra-Obj</td>
<td>-.188†</td>
<td>-.063</td>
<td>-</td>
<td>-</td>
<td>.343**</td>
<td>.471**</td>
<td>-.035</td>
<td>.338**</td>
<td>-</td>
<td>-.128</td>
<td>.714**</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.378**</td>
<td>.281**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.697**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Base-2 Scale**

| 13. Externalizing | -.041 | .016 | -.024 | -.166 | -.013 | .052 | .128 | .230* | .099 | .005 | -.017 | .080 | --   |      |      |      |
| 14. Hyperactivity | -.040 | -.004 | -.008 | -.127 | -.036 | .007 | .127 | .213† | .100 | .003 | -.029 | .055 | .868** | --   |      |      |
| 15. Aggression    | -.120 | -.081 | -.164 | -.239* | .102 | .102 | .105 | .115 | .027 | .001 | .043 | .064 | .888** | .662** | --   |      |
| 16. Conduct Problems | -.009 | .073 | .029 | -.128 | -.055 | -.055 | .116 | .294** | .119 | .028 | -.046 | .110 | .866** | .628** | .684** | --   |

*Note: Δ Inter-Obj = Interpersonal-Object ERP difference score; Δ Intra-Obj = Intrapersonal-Object ERP difference score.*

†\( p \leq .10; * p \leq .05; ** p \leq .01 \)
Table 8. Regression Analyses Per Image Category with Age, Gender, Fn400, and Gender by Fn400 Interaction Predicting Externalizing Behavior Problems

<table>
<thead>
<tr>
<th>Picture Category</th>
<th>Predictors</th>
<th>B (SE)</th>
<th>t</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpersonal</td>
<td>Age</td>
<td>.169 (2.97)</td>
<td>.057</td>
<td>.955</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-4.60 (5.59)</td>
<td>-.822</td>
<td>.414</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fn400</td>
<td>-1.01 (.502)</td>
<td>-2.01</td>
<td>.048*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender x fn400</td>
<td>1.87 (.813)</td>
<td>2.30</td>
<td>.024**</td>
<td></td>
</tr>
<tr>
<td>Intrapersonal</td>
<td>Age</td>
<td>.043 (2.99)</td>
<td>.014</td>
<td>.989</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-4.61 (5.61)</td>
<td>-.822</td>
<td>.414</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fn400</td>
<td>-1.05 (.906)</td>
<td>-1.16</td>
<td>.249</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender x fn400</td>
<td>1.84 (1.05)</td>
<td>1.76</td>
<td>.083†</td>
<td></td>
</tr>
<tr>
<td>Object</td>
<td>Age</td>
<td>-.089 (2.99)</td>
<td>-.030</td>
<td>.976</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-4.66 (5.60)</td>
<td>-.832</td>
<td>.408</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fn400</td>
<td>-2.35 (.448)</td>
<td>-2.08</td>
<td>.041*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender x fn400</td>
<td>1.52 (.694)</td>
<td>2.19</td>
<td>.032**</td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>Age</td>
<td>1.19 (2.83)</td>
<td>.419</td>
<td>.676</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-3.35 (5.49)</td>
<td>-.609</td>
<td>.544</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fn400</td>
<td>-2.35 (.787)</td>
<td>-2.99</td>
<td>.004**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender x fn400</td>
<td>2.72 (1.04)</td>
<td>2.62</td>
<td>.011**</td>
<td></td>
</tr>
</tbody>
</table>

Note: Gender is coded male= 0 and female= 1.

†p ≤ .10; *p ≤ .05; ** p ≤ .01; *** p ≤ .001. a No longer significant after correcting for multiple comparisons (α=.01).
Table 9. Regression Analyses Per Image Category with Age, Gender, fN400 Difference Score, and Gender by fN400 Predicting Externalizing Behavior Problems

<table>
<thead>
<tr>
<th>Picture Category</th>
<th>Predictors</th>
<th>B (SE)</th>
<th>t</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Δ Inter-Obj</td>
<td></td>
<td></td>
<td></td>
<td>.015</td>
</tr>
<tr>
<td>Age</td>
<td>-529 (.529)</td>
<td>-1.71</td>
<td>.865</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-4.63 (5.83)</td>
<td>-0.795</td>
<td>.429</td>
<td></td>
<td></td>
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<tr>
<td>Δ fN400</td>
<td>.277 (.728)</td>
<td>.380</td>
<td>.705</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender x Δ fN400</td>
<td>-668 (1.04)</td>
<td>-0.646</td>
<td>.520</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Δ Intra-Obj</td>
<td>.023</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-348 (3.10)</td>
<td>-0.112</td>
<td>.911</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-4.78 (5.73)</td>
<td>-0.833</td>
<td>.407</td>
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<tr>
<td>Δ fN400</td>
<td>.680 (.665)</td>
<td>1.02</td>
<td>.310</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender x Δ fN400</td>
<td>-923 (.912)</td>
<td>-1.01</td>
<td>.315</td>
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</tbody>
</table>

Note: Gender is coded male= 0 and female= 1. Δ Inter-Obj = Interpersonal-Object difference score; Δ Intra-Obj = Intrapersonal-Object difference score.

†p ≤ .10; *p ≤ .05; ** p ≤ .01; *** p ≤ .001.
<table>
<thead>
<tr>
<th>Picture Category</th>
<th>Predictors</th>
<th>B (SE)</th>
<th>t</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interpersonal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.026 (2.86)</td>
<td>.009</td>
<td>.993</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-4.37 (5.77)</td>
<td>-.758</td>
<td>.451</td>
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<tr>
<td>LPP</td>
<td>-.012 (.997)</td>
<td>-.013</td>
<td>.990</td>
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<td></td>
</tr>
<tr>
<td>Gender x LPP</td>
<td>1.24 (1.24)</td>
<td>1.00</td>
<td>.320</td>
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</tr>
<tr>
<td><strong>Intrapersonal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.111 (2.89)</td>
<td>.038</td>
<td>.970</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-4.61 (5.69)</td>
<td>-.810</td>
<td>.420</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPP</td>
<td>.273 (1.01)</td>
<td>.271</td>
<td>.787</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender x LPP</td>
<td>1.40 (1.50)</td>
<td>1.22</td>
<td>.227</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Object</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-.608 (2.91)</td>
<td>-.209</td>
<td>.835</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-3.73 (5.85)</td>
<td>-.638</td>
<td>.526</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPP</td>
<td>-.285 (.546)</td>
<td>-.522</td>
<td>.603</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender x LPP</td>
<td>1.18 (.710)</td>
<td>1.67</td>
<td>.099†</td>
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<td></td>
</tr>
<tr>
<td><strong>Neutral</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-.171 (2.82)</td>
<td>-.061</td>
<td>.952</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-4.76 (5.49)</td>
<td>-.852</td>
<td>.397</td>
<td></td>
<td></td>
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<tr>
<td>LPP</td>
<td>-1.02 (.559)</td>
<td>1.82</td>
<td>.073†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender x LPP</td>
<td>2.25 (.746)</td>
<td>3.02</td>
<td>.003**</td>
<td></td>
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</tr>
</tbody>
</table>

*Note: Gender is coded male= 0 and female= 1.
†p ≤ .10; *p ≤ .05; ** p ≤ .01; *** p ≤ .001.
### Table 11. Regression Analyses Per Image Category with Age, Gender, LPP Difference Scores, and Gender by LPP Difference Scores Interaction Predicting Externalizing Behavior Problems

<table>
<thead>
<tr>
<th>Picture Category</th>
<th>Predictors</th>
<th>B (SE)</th>
<th>t</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Inter-Obj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.024</td>
</tr>
<tr>
<td>Age</td>
<td>-.689 (3.03)</td>
<td>-.227</td>
<td>.821</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-4.35 (5.82)</td>
<td>-.747</td>
<td>.458</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ LPP</td>
<td>.259 (.475)</td>
<td>.546</td>
<td>.586</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender x Δ LPP</td>
<td>-.787 (.673)</td>
<td>-1.17</td>
<td>.246</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Δ Intra-Obj      |                | .022     |        |        |     |
| Age              | -.685 (2.96)   | -.232    | .817   |        |     |
| Gender           | -5.43 (5.66)   | -.960    | .340   |        |     |
| Δ LPP            | .388 (.597)    | .650     | .518   |        |     |
| Gender x Δ LPP   | -.289 (.745)   | -.388    | .699   |        |     |

*Note: Gender is coded male = 0 and female = 1.

Δ Inter-Obj = Interpersonal-Object difference score; Δ Intra-Obj = Intrapersonal-Object difference score.

†p ≤ .10; *p ≤ .05; ** p ≤ .01; *** p ≤ .001.
Figure 4: ERP components (fN400 & LPP) by region and image category for Chapter 3
Figure 5: ERP components (fN400 & LPP) for males (left) and females (right) by and image category at frontal region.
Figure 6: ERP components (fN400 & LPP) for males (blue line) and females (red line) for interpersonal (top left), intrapersonal (top right), object (bottom left), and neutral (bottom right) at frontal region.
Figure 7: Simple slopes with gender moderating the relation between the fN400 and externalizing behavior for (a) interpersonal, (b) intrapersonal, (c) object, and (d) neutral picture categories.
Figure 8: Simple slopes with gender moderating the relation between the LPP and externalizing behavior for (a) neutral and (b) object picture categories.
CHAPTER 4

MOTIVATED ATTENTION TO SOCIAL AND NON-SOCIAL REWARD STIMULI IN CHILDREN: ASSOCIATIONS WITH TEMPERAMENTAL SURGENCY AND EXTERNALIZING PROBLEM BEHAVIOR

4.1 Aims and Hypotheses

As reviewed in Chapter 1 (section 1.4), temperament is a key developmental factor influencing individual differences in emotion reactivity, as well as risk for externalizing problems in children. Specifically, temperamental surgency, a temperament profile characterized by high approach motivation, reward sensitivity, impulsivity, and positive emotionality, has been strongly linked to sustained externalizing difficulties in children (Putnam & Stifter, 2005). However, temperamental surgency has also been linked to positive social outcomes in children (e.g., social competence, affiliative behavior) suggesting that positive temperamental reactivity to social stimuli may possibly present as a developmental marker that protects against externalizing risk in children (Davis & Suveg, 2014; Endedijk et al., 2015; Sanson et al., 2004, 2009; VanSchyndel et al., 2017).

To our knowledge, no study has yet investigated if individual differences in surgency covary with how children attend to social versus non-social reward stimuli, nor how these patterns of covarying surgency and attention to reward stimuli might contribute to externalizing risk in children. Therefore, the aim of the current study was to assess surgency correlates with variations in fN400 and LPP to social and non-social reward images and explore how these patterns relate to externalizing risk in children.
Based on consistent findings from previous literature, we expected that higher surgency scores would statistically predict higher reported externalizing problems in children (Degnan et al., 2011; Dollar & Stifter, 2012; Marmorstein, 2013; Oldehinkel, Hartman, Winter, et al., 2004). We also expected that this positive association between surgency and externalizing problems would depend in part on differences in LPP activity to social and non-social images. Specifically, we predicted that higher surgency scores would be associated with higher parent-reported externalizing problems in children who exhibit attenuated LPPs to social images (e.g., interpersonal, intrapersonal) compared to non-social images (objects). In contrast, higher surgency scores were predicted to be associated with lower reported externalizing problems among children exhibiting enhanced LPPs to social images compared to non-social images.

No work to date has examined the fN400 in relation to temperament and externalizing risk in children, However, based on research highlighting the fN400 as a neural index of contextual processing of semantic information (Bar, 2004; Proverbio & Riva, 2009; West & Holcomb, 2002), we anticipate that the current research will provide insightful information about how individual differences in surgency relate to neural patterns emerging during earlier stages of affective processing (e.g., attention, appraisal) and whether variation in these neural signatures are associated with externalizing risk in children.
4.2 Methods

4.2.1 Participants

Participants were 78 children from the original sample of 116 participants described in Chapter 3, section 3.1 (40 males, \(M_{\text{age}}=8.51\) years). From this cohort, an additional two participants were excluded due to issues with questionnaire measurement (described below in section 4.2.3). Thus, the final sample for the current study consisted of 76 children with ages ranging from 7 to 10 years old (40 males, \(M_{\text{age}}=8.56\) years).

4.2.2 Procedure

Study procedures (i.e., consent and task procedure) were the same as those described in Chapter 2, section 2.2.1.

4.2.2.1 Task Stimuli

The stimuli used were the same as those described in Chapter 2, section 2.2.

4.2.2.2 Affective Picture Viewing Task

The affective picture viewing task was the same as described in Chapter 2, section 2.2.1.

4.2.2.3 EEG acquisition and ERP measures

Continuous EEG activity acquisition and processing procedures, as well as data extraction of ERP components (i.e., fN400 and LPP), were the same as described in Chapter 3, section 3.2.2.4.
4.2.3 Measures

4.2.3.1 Parent Report of Temperamental Surgency

Caregivers reported on children’s temperament style using one of two age-appropriate questionnaires designed by Rothbart and colleagues. For children under 7 years of age, caregivers completed the short form version of the Children’s Behavior Questionnaire (CBQ-short), which consists of 86 items used to assess temperamental behavior profiles for children between 3 and 7 years of age (Putnam & Rothbart, 2006). On the CBQ-short form, caregivers rated child behavior using a Likert scale ranging from “extremely untrue of your child” (1) to “extremely true of your child” (7).

For children 7 years of age and older, caregivers completed the Temperament in Middle Childhood Questionnaire (TMCQ), which comprises 157 items designed to assess temperament in children between 7 and 10 years of age (Nystrom & Bengtsson, 2017; Simonds et al., 2007). On the TMCQ, parents rated child behavior using a 5-point Likert scale range from “almost always true of your child” (1) to “almost always untrue of your child” (5).

The current study focused its analysis on items related to the Surgency composite score. For the CBQ-short (i.e., under-7 year old), the Surgency composite was derived by averaging across the following six subscales, in accordance with the published scaling procedure: 1) Positive Anticipation, 2) High Intensity Pleasure, 3) Smiling/Laughter, 4) Activity Level, 5) Impulsivity, and 6) Shyness-reversed (Putnam et al., 2008). In contrast, the Surgency composite score for the TMCQ (i.e., for 7-to-10-year-old) shares only four out of the six CBQ-short Surgency subscales (i.e., Activity Level, High Intensity Pleasure, Impulsivity, Shyness-reversed; unlike the CBQ-short, smiling/laughter
and positive anticipation are not part of Surgency). To date, there is scant research validating factor composites that incorporate subscales specific to the TMCQ. Thus, we adhered to the current published guidelines for calculating the Surgency composite, which advise calculate a composite score using the mean score of Surgency subscales that are consistent across both the TMCQ and CBQ-short (Nystrom & Bengtsson, 2017). To account for scale range differences between the CBQ-short and TMCQ (i.e., 5-point scale versus 7-point scale, respectively), all item scores were to be standardized (e.g., z-scored) prior to scale calculation. However, after concluding data collection, only 6 participants within our overall sample (N=116) were within the age range designated for the CBQ-short. Out of these 6 participants, only 2 participants reached criteria to be included in the final sample (i.e., N=78). Due to the sparse data collected for the CBQ-short, we decided to focus our analysis exclusively on participants with the TMCQ, thus bringing our final sample to 76 participants.

Although empirical examination of the psychometric properties underlying the TMCQ is sparse (i.e., extensive reliability and validity evidence was reported only in one unpublished dissertation study that established the new measure; Simonds, 2006), a handful of published studies have reported good reliability for all the TMCQ Surgency composite and its subscales (α’s ≥ .70) except for Activity Level (α =.63)(Kotelnikova et al., 2015, 2017). We calculated the internal consistency for the Surgency composite and its subscales with the current sample. Reliability estimates were consistent with prior literature; good to excellent internal consistency was found for all Surgency subscales (α’s ≥ .70) and the Surgency composite (α= .89) within our study sample.
4.2.3.2 Child Externalizing behavior

Child externalizing behavior was assessed using the parent-report version of the Behavioral Assessment System for Children-Second Edition (BASC-2, PRS-C). The current study evaluated the Externalizing Problems (EXT) composite score, which was comprised by calculating the sum of the Hyperactivity (HYP), Aggression (AGG), and Conduct Problems (CND) clinical subscales. A detailed description of the BASC-2 assessment and its externalizing scales can be found in Chapter 3, section 3.2.3.1.

4.2.4 Statistical Approach

Moderation regression analyses were conducted to investigate whether ERPs amplitudes (i.e., fN400 and LPP) moderated the relations between surgency and externalizing symptomatology in children. Each set of regression models was run separately for the fN400 and LPP, and separately for each of the four picture categories (interpersonal, intrapersonal, object, neural). Temperamental surgency, the ERP variable, and their two-way interaction (to test the ERP variable as a moderator) were entered as predictors, and the raw externalizing composite score was entered as the predicted outcome variable. Participants’ age and gender were entered as covariates to control for their possible confounds with Surgency and ERP activity. To limit the number of tests performed, regression analyses were only conducted at electrode regions where ERP amplitudes were found to be maximal based on statistical findings in Chapter 3. Simple slope analyses were conducted to probe any significant or trending interactions ($p < .05$ and $p < .10$, respectively). To minimize potential Type 1 error due multiple comparisons, the significance threshold for main effects and moderation effects was set at alpha = .01.
To directly investigate processing differences between social and non-social stimuli, we also calculated ERP difference scores between social and nonsocial categories (e.g., Interpersonal-Object ERP; Intrapersonal-Object ERP). We then conducted the same regression analyses (again separately for the fN400 and LPP) with the difference score as the ERP variable.

Based on previous reports suggesting neutral stimuli may elicit heightened responses in certain individuals (see, Schneider et al., 2016; van den Heuvel et al., 2018) and visual inspection of neutral ERP grand means, we decided not to include neutral ERP difference scores (e.g., affective – neutral ERP) in our main analysis. As ERP activity to neutral pictures could potentially reveal unique effects in relation to individual differences in surgency and externalizing outcomes, we chose not to control for reactivity to neutral stimuli as a baseline as doing so might have hindered our ability to interpret the results.

4.3 Results

4.3.1 Descriptive Statistics

Descriptive statistics (e.g., means and standard deviations) for participants’ TMCQ surgency composite score and subscales scores are detailed in Table 12. Gender comparisons revealed that male participants scored significantly higher on surgency than females ($p = .005$; see Table 13). When comparing across surgency subscales, results revealed that boys scored significantly higher than girls on the activity level ($p = .002$) and high intensity pleasure ($p = .051$) scales, and marginally higher than girls on impulsivity ($p = .057$); in contrast, there was no gender difference in shyness ($p = .498$).
Due to gender differences across the majority of surgency variables, participant gender was controlled for, along with age, in all regression analyses.

Bivariate correlations between the surgency composite and subscales were calculated (see Table 14). Significant positive correlations were found between the surgency composite and its subscales (all $p$’s <.001). Activity level, high intensity pleasure, and impulsivity subscales were all positively correlated with each other ($p$’s <.01). However, the shyness (reversed) scores were not correlated with the other surgency subscales ($p$’s >.50), therefore a new surgency composite was calculated with the shyness (reversed) subscale excluded (see Table 15). Before deciding which version of the surgency composite to use (i.e., the original and the adjusted composite with shyness removed), we compared both versions of the surgency composite with other variables.

Bivariate correlation analyses were conducted to examine relations between surgency variables and externalizing outcome variables (Table 16). The adjusted surgency composite was also included within the analyses to confirm that correlations with the original surgency composite and adjusted surgency composite followed the same direction. Very similar positive correlations with externalizing scales were found for both the original surgency composite and the adjusted composite.

Correlations were also assessed between original surgency variables and the adjusted surgency composite variable, with other predictor variables (e.g., age and ERP measures). Analyses again revealed very similar correlation patterns for both the original surgency composite and adjusted surgency composite variable with ERP measures and age (Table 17). Notably, higher adjusted surgency composite scores were significantly
associated with larger LPPs (more positive amplitudes) to object pictures ($r=.265$, $p=.021$); this correlation was slightly weaker and marginally significant, for the original surgency composite ($r=.212$, $p=.066$). Marginally significant negative associations emerged between Interpersonal-Object LPP difference scores and both the original surgency composite ($r=-.191$, $p=.098$) and adjusted surgency composite ($r=-.206$, $p=.074$), suggesting higher surgency scores were marginally associated with enhanced LPP reactivity to object pictures compared to interpersonal pictures among participants. Finally, correlation analyses revealed no significant associations between the shyness (reversed) subscale and other relevant predictor variables and outcome variables (see Table 16 & 17). Based on these findings, the adjusted surgency composite was entered as a main predictor variable instead of the original surgency composite for the following moderation regression analyses.

4.3.2 Regression Results

Multiple regressions were performed to test the moderating role of ERP amplitudes (e.g., fn400, LPP) on the relation between surgency and externalizing behavior. To avoid potential multicollinearity, continuous predictors were mean centered and interaction variables were calculated as products of mean-centered predictors (Aiken & West, 1991). The regression models were conducted separately for each of the four picture categories to untangle the unique effects of picture content on ERP patterns.

4.3.2.1 fN400 Regression Results

Table 18 summarizes regression results with the fN400 as a moderator variable. All moderation analysis were run with the fN400 amplitudes at frontal regions as the
fN400 component was demonstrated to be maximal at this scalp region (as reported in Chapter 3, section 3.3.2.1).

Higher surgency scores were associated with higher externalizing scores for regression models across all picture categories’ regression equations (interpersonal: \( b = 16.90, p = .011 \); intrapersonal: \( b = 17.19, p = .011 \); object: \( b = 17.32, p = .008 \); neutral: \( b = 15.67, p = .011 \)). In addition, for the regression analysis for neutral, there was a significant association between the fN400 and externalizing scores in which larger fN400 amplitudes (more negative) to neutral pictures were associated with higher externalizing scores (\( b = -1.04, p = .035 \)). For the other three picture category regression models, there were no additional significant relations involving the fN400 as a main effect or moderator.

Results for the fN400 difference scores between social and non-social pictures (i.e., Interpersonal-Object fN400; Intrapersonal-Object fN400) are presented in Table 19. Higher surgency scores were significantly associated with higher externalizing scores for both regression models (Interpersonal-Object fN400: \( b = 17.48, p = .006 \); Intrapersonal-Object fN400: \( b = 18.02, p = .003 \)).

Only one other effect was significant in both regression models. A significant interaction was found between surgency and Intrapersonal-Object fN400 difference scores, which negatively predicted children’s externalizing scores (\( b = -2.00, p = .024 \)). The same interaction term for the other regression model, examining Interpersonal-Object fN400 difference scores, was not significant; \( p = .170 \). Simple slope analyses for the significant interaction revealed that higher surgency scores were associated with higher externalizing scores among children exhibiting more negative Intrapersonal-Object fN400 difference scores, \( b = 28.95, SE = 8.37, t = 3.46, p = .001 \) (Figure 9). In other words,
higher levels of surgency were linked to increased parent-report of externalizing behavior among children showing larger fN400s to intrapersonal pictures relative to object pictures. Surgency and externalizing behavior scores were not significantly related among children exhibiting more positive Intrapersonal-Object fN400 difference scores (i.e., larger Object fN400s relative to Intrapersonal fN400s; \( p = .273 \)).

4.3.2.2 LPP Regression Results

Table 20 summarizes regression results with the LPP as a moderator variable. All moderation analyses were run with the LPP amplitudes at frontal regions as the LPP was demonstrated to be maximal at this scalp region (as reported in Chapter 3, section 3.3.2.2).

Significant positive associations emerged between surgency and externalizing symptomology for regression models across all picture categories. Within each category, higher surgency scores were associated with significantly higher externalizing scores (Interpersonal: \( b = 16.38, p = .013 \); Intrapersonal: \( b = 15.63, p = .053 \); Object: \( b = 17.10, p = .011 \); Neutral: \( b = 16.85, p = .017 \)). No other significant relations with remaining predictor variables (i.e., age, gender, the LPP, surgency x LPP) emerged from the regression models (all \( p \)'s >.10).

As with the fN400, we turned to analyses of the LPP difference scores between social and non-social pictures (i.e., Interpersonal-Object LPP; Intrapersonal-Object LPP), regression results are presented in Table 21. Higher surgency scores were

---

6 The LPP was found to be maximal at both frontal and central regions. Separate regressions were conducted at each region, results did not significantly differ between the two regions. Thus, only regression analyses for the frontal LPP are reported.
associated with higher externalizing scores for both regression models (Interpersonal-Object LPP: $b=17.38$, $p=.011$; Intrapersonal-Object LPP: $b=17.26$, $p=.016$). No significant relations with remaining predictor variables (i.e., age, gender, the LPP difference scores, surgency x LPP difference scores) emerged for either regression model (all $p$’s $>.10$).

4.4. Discussion

The current study aimed to examined whether ERP responses to social and non-social reward images moderated associations between surgery and externalizing in children. In line with previous literature, the current study found strong relations between surgery and externalizing behavior. Findings also revealed unique relations between surgery, externalizing behavior, and ERPs that varied between non-social and social reward categories. These findings and their implications are discussed further below.

When examining zero-order correlations between surgery and externalizing behavior measures, we found that higher surgery was associated with increased externalizing behavior, which confirmed our hypothesis and corresponds to previous literature linking high surgery with increased risk for externalizing behaviors in children (Gartstein et al., 2012a; Olino et al., 2014a; Stifter et al., 2008). We also found unique coupling between specific surgery components and externalizing (see Table 16). Specifically, we found greater trait impulsivity was associated with more externalizing problems in children. This result also echoes findings from previous work emphasizing trait impulsivity as a prominent risk factor for externalizing problems (Sánchez-Pérez et al., 2020; Scheper et al., 2017).
We also found unique zero-order correlations between surgency and the LPP (see Table 17). Specifically, higher surgency related to larger LPP amplitudes to object reward images. Surgency was also marginally negatively correlated with interpersonal-object LPP difference scores, such that higher surgency was related to greater LPP responses to object reward images relative to interpersonal images. Again, we found these patterns between surgency and the LPP specifically mapped onto the impulsivity subscale of the surgency composite. Overall, these findings indicate individual differences in positive reactivity are reflected in LPP responses to distinct types of reward. Furthermore, these results suggest that certain facets of surgency, specifically trait impulsivity, are associated with preferential processing of non-social rewards over certain types of social reward (e.g., social interaction).

When examining moderation regression analyses for the fN400, we found that larger fN400 amplitudes to intrapersonal reward images relative to object images moderated the positive association between surgency and externalizing behavior. Our findings suggest that, compared to non-social reward, the social content depicted by intrapersonal images uniquely engages attention in surgent children. As described in Chapter 2, intrapersonal images depicted positive, non-interactive social scenes related to achievement or fun activities. These displays relate to more to intrinsic rewards; thus, these cues may be more contextually meaningful and motivationally relevant to surgent children than the content depicted in object-based reward images. Therefore, a possible interpretation of our results is that greater allocation of attention to intrinsically salient stimuli (i.e., achievement, fun) compared to extrinsically salient stimuli (i.e., treats, prizes) reflects heightened risk of externalizing problems among high surgency children.
This interpretation is in line with converging research linking exaggerated attention to motivationally relevant cues with externalizing psychopathology in adults (Baskin-Sommers et al., 2015a; Lake et al., 2017, 2021).

Contrary to our predictions, we did not find evidence that patterns in the LPP moderated relations between surgency and externalizing behavior. It is not clear as to why we did not find a moderation, but one possibility could be related to the nature of the stimuli used in this study. Prior work has shown that children are highly responsive to positive stimuli (Hajack & Dennis, 2009; McNanis, 2001; Wang, Liu, & Shi, 2020), thus, variation in the LPP may have been limited across participants. Another explanation is that, within the context of this study, LPP responses to reward categories may reflect processes that contribute to reward sensitivity, but do not directly map to temperamental processes that contribute to externalizing behavior. Notably, we found relations between trait impulsivity (a facet of surgency) and distinct patterns in the LPP and externalizing behavior (i.e., larger LPPs to objects relative to interpersonal images). It is possible that relations with the LPP and trait impulsivity could be related to individual differences in both reactive and regulatory traits (Mullins-Sweatt et al., 2019; Nielsen et al., 2019a). Therefore, for future studies, it would be important to examine LPP patterns to social and non-social reward cues in the context of reactivity and regulation challenges to see if distinct patterns in neural processing during these conditions better reflect processes linking surgency and externalizing behavior in children.

The current study is one of the first to use ERP measures of affective processing to explore relations between temperamental surgency and externalizing behavior in children. However, there are several limitations that should be considered. First, surgery
and externalizing variables in this study were both assessed using parent-report measures. Thus, relations between these variables could be confounded as their scales might be defined by similar item or constructs, which may bias caregivers responding (Olson et al., 2005). Future research should also incorporate additional methods for assessment (e.g., behavioral measures) and/or gather measures using multiple informants (e.g., mother, father, teacher) when assessing relations between temperament and externalizing variables. Second, our sample was representative of the local area, which consists mostly of well-educated, White families. As such, the homogeneity of our community sample should be considered before generalizing findings to more socioeconomic and racial/ethnically diverse populations. Finally, our analyses revealed robust gender differences in surgency. Although gender was entered as a covariate to account for these differences in our regression models, it is possible that gender differences in surgency and ERP measures uniquely contribute to relations between surgency and externalizing risk in children. Additional data collection may be needed to gain adequate power to tests these effects.

Despite these limitations, the current study expands our understanding of affective processing patterns associated with surgency traits and in temperamental risk for externalizing problems. Namely, we found that greater sustained processing (i.e., larger LPPs) of non-social reward stimuli (objects) relative to interpersonal, social reward (positive social interactions) was associated specific aspects of surgency (i.e., impulsive reactivity), suggesting that affective processing patterns to different types of reward stimuli can distinguish distinct traits associated with surgency. Extensive research indicates that children with the propensity to react impulsivity are at higher risk for
developing externalizing problems (Eisenberg et al., 2009; Gartstein et al., 2012b; Scheper et al., 2017). Thus, this LPP pattern (i.e., larger LPP to objects vs interpersonal stimuli) could be a potential neural marker of externalizing susceptibility that could be used to identify at-risk children with impulsive traits. Furthermore, our results indicate greater, early processing of intrinsic reward stimuli (i.e., achievement, fun) compared to extrinsic rewards (i.e., treats, prizes) may reflect increased externalizing risk in high surgency children. These findings are novel and raise questions about relations between individual differences in intrinsic and extrinsic motivation and externalizing risk in children and, although beyond the scope of this current study, these LPP patterns, as well as fN400 findings, deserve further exploration in future work on unique neural markers of externalizing risk related to temperament.
<table>
<thead>
<tr>
<th>Rating Scale</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgency</td>
<td>3.41</td>
<td>.441</td>
<td>76</td>
</tr>
<tr>
<td>Activity Level</td>
<td>3.97</td>
<td>.661</td>
<td>76</td>
</tr>
<tr>
<td>High Intensity Pleasure</td>
<td>3.41</td>
<td>.595</td>
<td>76</td>
</tr>
<tr>
<td>Impulsivity</td>
<td>2.69</td>
<td>.663</td>
<td>76</td>
</tr>
<tr>
<td>Shyness-Reversed</td>
<td>3.56</td>
<td>.806</td>
<td>76</td>
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Table 13. Gender Comparisons of Surgency Scales

<table>
<thead>
<tr>
<th>Rating Scale</th>
<th>Males (N=40)</th>
<th>Females (N=36)</th>
<th>Statistics (df=1,73)</th>
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<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
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<td>.401</td>
<td>3.41</td>
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<tr>
<td>Activity Level</td>
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<td>.600</td>
<td>3.73</td>
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<td>High Intensity Pleasure</td>
<td>3.54</td>
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<td>3.27</td>
</tr>
<tr>
<td>Impulsivity</td>
<td>2.83</td>
<td>.653</td>
<td>2.54</td>
</tr>
<tr>
<td>Shyness-Reversed</td>
<td>3.63</td>
<td>.705</td>
<td>3.50</td>
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Table 14. Bivariate Correlations Among Surgency Scales

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surgency</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Activity Level</td>
<td>.707***</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. High Intensity Pleasure</td>
<td>.739***</td>
<td>.597***</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Impulsivity</td>
<td>.672***</td>
<td>.326**</td>
<td>.413***</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>5. Shyness-Reversed</td>
<td>.507***</td>
<td>.016</td>
<td>.047</td>
<td>.073</td>
<td>--</td>
</tr>
</tbody>
</table>

*Notes.* †p ≤ .10; *p ≤ .05; ** p ≤ .01; *** p ≤ .001.
Table 15. Bivariate Correlations Among Surgency Scales with Adjusted Surgency Scale Included

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surgency</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Surgency 2.0</td>
<td>.889***</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Activity Level</td>
<td>.707***</td>
<td>.811***</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. High Intensity Pleasure</td>
<td>.739***</td>
<td>.831***</td>
<td>.597***</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Impulsivity</td>
<td>.672***</td>
<td>.740***</td>
<td>.326**</td>
<td>.413***</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>6. Shyness-Reversed</td>
<td>.507***</td>
<td>.057</td>
<td>.016</td>
<td>.047</td>
<td>.073</td>
<td>--</td>
</tr>
</tbody>
</table>

Notes. Surgency 2.0 = Surgency excluding Shyness-Reversed.
†p ≤ .10; *p ≤ .05; ** p ≤ .01; *** p ≤ .001.
Table 16. Bivariate Correlations Among Bivariate Correlations of Externalizing Scales (Raw Scores) with Surgency Scales

<table>
<thead>
<tr>
<th>Variable</th>
<th>Surg</th>
<th>Surg 2.0</th>
<th>ACT</th>
<th>HIP</th>
<th>IMP</th>
<th>SHY-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Externalizing</td>
<td>.284**</td>
<td>.343**</td>
<td>.088</td>
<td>.205†</td>
<td>.515***</td>
<td>-.027</td>
</tr>
<tr>
<td>Hyperactivity</td>
<td>.307**</td>
<td>.376***</td>
<td>.131</td>
<td>.234*</td>
<td>.522***</td>
<td>-.038</td>
</tr>
<tr>
<td>Aggression</td>
<td>.176</td>
<td>.228*</td>
<td>-.037</td>
<td>.126</td>
<td>.447***</td>
<td>-.046</td>
</tr>
<tr>
<td>Conduct Problems</td>
<td>.251*</td>
<td>.282**</td>
<td>.095</td>
<td>.189</td>
<td>.387***</td>
<td>.015</td>
</tr>
</tbody>
</table>

Notes.  Surg = Surgency (original); Surg 2.0 = Surgency 2.0 (excluding Shyness-Reversed); ACT = Activity Level; HIP = High Intensity Pleasure Surgency; IMP = Impulsivity; SHY-R = Shyness-Reversed.

†p ≤ .10; *p ≤ .05; **p ≤ .01, ***p ≤ .001.
Table 17. Bivariate Correlations for Age and ERP measures (fN400, LPP, Difference Scores) with Surgency Scales

<table>
<thead>
<tr>
<th>Variable</th>
<th>Surg</th>
<th>Surg 2.0</th>
<th>ACT</th>
<th>HIP</th>
<th>IMP</th>
<th>SHY-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child Age</td>
<td>-.097</td>
<td>-.159</td>
<td>-.019</td>
<td>-.170</td>
<td>-.194†</td>
<td>.088</td>
</tr>
<tr>
<td>\textbf{fN400}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpersonal</td>
<td>-.016</td>
<td>-.010</td>
<td>.045</td>
<td>-.106</td>
<td>.027</td>
<td>-.016</td>
</tr>
<tr>
<td>Intrapersonal</td>
<td>-.012</td>
<td>.006</td>
<td>.039</td>
<td>-.091</td>
<td>.056</td>
<td>-.036</td>
</tr>
<tr>
<td>Object</td>
<td>.086</td>
<td>.068</td>
<td>.027</td>
<td>-.016</td>
<td>.143</td>
<td>.059</td>
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<tr>
<td>Neutral</td>
<td>-.110</td>
<td>-.112</td>
<td>-.123</td>
<td>-.091</td>
<td>-.053</td>
<td>-.028</td>
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<tr>
<td>\textbf{Δ fN400 Score}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ Inter-Obj</td>
<td>-.148</td>
<td>-.114</td>
<td>.014</td>
<td>-.102</td>
<td>-.183</td>
<td>-.108</td>
</tr>
<tr>
<td>Δ Intra-Obj</td>
<td>-.132</td>
<td>-.089</td>
<td>.004</td>
<td>-.073</td>
<td>-.142</td>
<td>-.121</td>
</tr>
<tr>
<td>\textbf{LPP}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpersonal</td>
<td>.040</td>
<td>.099</td>
<td>.050</td>
<td>.115</td>
<td>.075</td>
<td>-.099</td>
</tr>
<tr>
<td>Intrapersonal</td>
<td>.088</td>
<td>.127</td>
<td>.000</td>
<td>.068</td>
<td>.229*</td>
<td>-.045</td>
</tr>
<tr>
<td>Object</td>
<td>.212†</td>
<td>.265*</td>
<td>.124</td>
<td>.220†</td>
<td>.287**</td>
<td>-.037</td>
</tr>
<tr>
<td>Neutral</td>
<td>-.089</td>
<td>-.121</td>
<td>-.283**</td>
<td>-.040</td>
<td>.040</td>
<td>.034</td>
</tr>
<tr>
<td>\textbf{Δ LPP Score}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ Inter-Obj</td>
<td>-.191†</td>
<td>-.206†</td>
<td>-.095</td>
<td>-.149</td>
<td>-.245*</td>
<td>-.029</td>
</tr>
<tr>
<td>Δ Intra-Obj</td>
<td>-.145</td>
<td>-.170</td>
<td>-.125</td>
<td>-.169</td>
<td>-.113</td>
<td>.002</td>
</tr>
</tbody>
</table>

Notes. \textbf{Surg} = Surgency (original); \textbf{Surg 2.0} = Surgency 2.0 (excluding Shyness-Reversed); \textbf{ACT} = Activity Level; \textbf{HIP} = High Intensity Pleasure Surgency; \textbf{IMP} = Impulsivity; \textbf{SHY-R} = Shyness-Reversed.

Δ \textbf{Inter-Obj} = Interpersonal-Object ERP difference score; Δ \textbf{Intra-Obj} = Intrapersonal-Object ERP difference score.

†p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001.
Table 18. Regression Analyses Per Image Category with Age, Surgency, fN400, and Gender by fN400 Interaction Predicting Externalizing Behavior Problems

<table>
<thead>
<tr>
<th>Picture Category</th>
<th>Predictors</th>
<th>B (SE)</th>
<th>t</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpersonal</td>
<td>Age</td>
<td>-.945 (2.93)</td>
<td>-.322</td>
<td>.748</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>3.52 (6.28)</td>
<td>.560</td>
<td>.577</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>16.90 (6.47)</td>
<td>2.61</td>
<td>.011**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fN400</td>
<td>-.419 (.426)</td>
<td>-.984</td>
<td>.329</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x fN400</td>
<td>.192 (.831)</td>
<td>.231</td>
<td>.818</td>
<td></td>
</tr>
<tr>
<td>Intrapersonal</td>
<td>Age</td>
<td>-.286 (2.91)</td>
<td>-.098</td>
<td>.922</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>3.86 (6.36)</td>
<td>.607</td>
<td>.546</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>17.19 (6.56)</td>
<td>2.62</td>
<td>.011**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fN400</td>
<td>-.299 (.432)</td>
<td>-.643</td>
<td>.491</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x fN400</td>
<td>-1.33 (.858)</td>
<td>-1.55</td>
<td>.125</td>
<td></td>
</tr>
<tr>
<td>Object</td>
<td>Age</td>
<td>-1.09 (3.03)</td>
<td>-.356</td>
<td>.723</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>2.14 (6.32)</td>
<td>.339</td>
<td>.736</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>17.32 (6.35)</td>
<td>2.73</td>
<td>.008**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fN400</td>
<td>-.268 (.323)</td>
<td>-.829</td>
<td>.410</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x fN400</td>
<td>.617 (.870)</td>
<td>.708</td>
<td>.481</td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>Age</td>
<td>.008 (2.75)</td>
<td>.003</td>
<td>.998</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>5.32 (6.36)</td>
<td>.837</td>
<td>.405</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>15.67 (5.98)</td>
<td>2.62</td>
<td>.011**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fN400</td>
<td>-1.04 (.482)</td>
<td>-2.16</td>
<td>.035**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x fN400</td>
<td>-1.44 (.984)</td>
<td>-1.46</td>
<td>.148</td>
<td></td>
</tr>
</tbody>
</table>

Notes. †p ≤ .10; *p ≤ .05; ** p ≤ .01; *** p ≤ .001. a No longer significant after correcting for multiple comparisons (α=.01)
Table 19. Regression Analyses with Age, Surgency, fN400 Difference Score, and Gender by fN400 Difference Score Interaction Predicting Externalizing Behavior Problems

<table>
<thead>
<tr>
<th>Picture Category</th>
<th>Predictors</th>
<th>B (SE)</th>
<th>t</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Inter-Obj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>-.878 (.277)</td>
<td>-.317</td>
<td>.752</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>1.67 (6.13)</td>
<td>.272</td>
<td>.787</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>17.48 (6.21)</td>
<td>2.81</td>
<td>.006**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Δ fN400</td>
<td>.095 (.481)</td>
<td>.197</td>
<td>.845</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x ΔfN400</td>
<td>-1.19 (.859)</td>
<td>-1.39</td>
<td>.170</td>
<td></td>
</tr>
<tr>
<td>Δ Intra-Obj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>-1.11 (2.78)</td>
<td>-.397</td>
<td>.692</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>.581 (5.88)</td>
<td>.099</td>
<td>.922</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>18.02 (5.78)</td>
<td>3.12</td>
<td>.003**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Δ fN400</td>
<td>.194 (.457)</td>
<td>.424</td>
<td>.673</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x ΔfN400</td>
<td>-2.00 (.864)</td>
<td>-2.31</td>
<td>.024**</td>
<td></td>
</tr>
</tbody>
</table>

Notes. Δ Inter-Obj = Interpersonal-Object difference score; Δ Intra-Obj = Intrapersonal-Object difference score; Δ fN400 = fn400 difference score.

†p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001. a No longer significant after correcting for multiple comparisons (α=.01)
<table>
<thead>
<tr>
<th>Picture Category</th>
<th>Predictors</th>
<th>B (SE)</th>
<th>t</th>
<th>p</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpersonal</td>
<td>Age</td>
<td>-.915 (2.72)</td>
<td>-.336</td>
<td>.738</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>2.75 (6.20)</td>
<td>.443</td>
<td>.659</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>16.38 (6.44)</td>
<td>2.55</td>
<td>.013**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LPP</td>
<td>.209 (.629)</td>
<td>.332</td>
<td>.741</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x LPP</td>
<td>.953 (1.42)</td>
<td>.670</td>
<td>.505</td>
<td></td>
</tr>
<tr>
<td>Intrapersonal</td>
<td>Age</td>
<td>-.477 (3.01)</td>
<td>-.158</td>
<td>.875</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>2.06 (6.24)</td>
<td>.330</td>
<td>.743</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>15.68 (7.98)</td>
<td>1.97</td>
<td>.053**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LPP</td>
<td>.602 (.579)</td>
<td>1.04</td>
<td>.302</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x LPP</td>
<td>-.593 (1.40)</td>
<td>-.424</td>
<td>.673</td>
<td></td>
</tr>
<tr>
<td>Object</td>
<td>Age</td>
<td>-1.34 (2.75)</td>
<td>-.487</td>
<td>.628</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>2.43 (6.13)</td>
<td>.396</td>
<td>.693</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>17.10 (6.52)</td>
<td>2.62</td>
<td>.011**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LPP</td>
<td>-.190 (.376)</td>
<td>-.506</td>
<td>.615</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x LPP</td>
<td>.480 (.483)</td>
<td>.994</td>
<td>.324</td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>Age</td>
<td>-1.24 (2.94)</td>
<td>-.421</td>
<td>.675</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>3.50 (6.23)</td>
<td>.563</td>
<td>.575</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>16.85 (6.91)</td>
<td>2.44</td>
<td>.017**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LPP</td>
<td>-.106 (.460)</td>
<td>-.230</td>
<td>.819</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgency x LPP</td>
<td>-.711 (.894)</td>
<td>-.795</td>
<td>.429</td>
<td></td>
</tr>
</tbody>
</table>

Notes. †p ≤ .10; *p ≤ .05; ** p ≤ .01; *** p ≤ .001. a No longer significant after correcting for multiple comparisons (α=.01)
Table 21. Regression Analyses with Age, Surgency, LPP Difference Score, and Gender by LPP Difference Score Interaction Predicting Externalizing Behavior Problems

<table>
<thead>
<tr>
<th>Picture Category</th>
<th>Predictors</th>
<th>B (SE)</th>
<th>t</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Inter-Obj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-1.29 (2.83)</td>
<td>-.457</td>
<td>.649</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>2.37 (6.12)</td>
<td>.387</td>
<td>.700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgency</td>
<td>17.38 (6.68)</td>
<td>2.60</td>
<td>.011**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ LPP</td>
<td>.310 (.342)</td>
<td>.908</td>
<td>.367</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgency x Δ LPP</td>
<td>-.247 (.505)</td>
<td>-.489</td>
<td>.626</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ Intra-Obj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-1.35 (2.71)</td>
<td>-.498</td>
<td>.620</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>1.30 (6.16)</td>
<td>.210</td>
<td>.834</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgency</td>
<td>17.26 (7.00)</td>
<td>2.47</td>
<td>.016**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ LPP</td>
<td>.498 (.378)</td>
<td>1.31</td>
<td>.198</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgency x Δ LPP</td>
<td>-.701 (1.04)</td>
<td>-.674</td>
<td>.503</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes. Δ Inter-Obj = Interpersonal-Object difference score; Δ Intra-Obj = Intrapersonal- Object difference score; Δ LPP = LPP difference score.

†p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001. a No longer significant after correcting for multiple comparisons (α=.01).
Figure 9: Simple slopes with fN400 difference score between interpersonal and object images (e.g., Intrapersonal-Object) moderating the relation between the fN400 and externalizing behavior.

Notes. Surg = Surgency composite (excluding Shyness-reversed), Neg fN400 DS= Negative fN400 Difference Score, Mean fN400 DS= Mean fN400 Difference Score, Pos fN400 DS= Positive fN400 Difference Score.
CHAPTER 5
GENERAL DISCUSSION AND FUTURE DIRECTIONS

5.1 Comparing Affective Processing of Social and Non-Social Reward Stimuli Using a Novel Stimuli Set

The current dissertation used a novel, affective stimuli set to examine affective processing of social and non-social reward stimuli in children. Within the existing child literature, many studies employ standardized stimuli sets designed for use in adult populations. A great degree of the content within these stimuli sets depict themes that are highly inappropriate for children (e.g., erotica, mutilation). Thus, child researchers are not only confined to choosing from a limited range of stimuli for affective processing studies, but they are also resigned to selecting content that may not be as motivationally relevant to children (Hajcak & Dennis, 2009; McManis et al., 2001). Moreover, affective content is often selected based on broad dimensions of valence and arousal. However, several studies within the adult literature have demonstrated that the semantic themes depicted within affective stimuli significantly influence emotional responses at both the behavioral and neural levels (Blekić et al., 2021; Czekóová et al., 2016; Kosonogov et al., 2020; Marchewka et al., 2014; Weinberg & Hajcak, 2010). Therefore, we aimed to address current limitations within available standardized stimuli sets. To achieve this, we developed a new set of affective images that depicted various reward-related themes and, most importantly, were suitable for use with child populations.

Consistent with the literature using adult image sets (Hajcak & Dennis, 2009; Hua et al., 2014), this research found that children rated reward image categories as more positive and arousing than neutral categories (Chapter 2 & Chapter 3). In addition, robust...
differences in self-report ratings emerged between reward categories. Object reward images were rated as significantly more positive and arousing than both interpersonal and intrapersonal pictures (Chapter 3). Intrapersonal images also received higher positive and arousal ratings than interpersonal images (Chapter 2 & Chapter 3). These findings collectively support that the affective stimuli used for this dissertation were motivationally relevant to children. Furthermore, these results indicate that children evaluate specific types of reward differently. Children showed a preference for non-social reward stimuli over social stimuli. Most notably, children showed robust distinctions between the two types of social reward categories (i.e., inter- and intrapersonal).

Beyond the self-report findings, important affective processing patterns were revealed in fN400 waveforms. Specifically, object and intrapersonal images elicited larger fN400 amplitudes compared to interpersonal images, suggesting greater attentional engagement for these two reward categories (Chapter 2 & Chapter 3). Notably, fN400 patterns converged with self-report patterns, providing further support for the interpretation that object and intrapersonal reward content were more motivationally salient to children relative to interpersonal content.

Surprisingly, there were no significant difference patterns between image type when examining the LPP. Previous studies have reported that children show biased responding to positive valence (Hajcak & Dennis, 2009; McManis et al., 2001; Wang et al., 2020), therefore, it is possible that reward categories equally elicited sustained processing due to their positive valence. Thus, exposure to positive content could have enhanced LPP responses to neutral stimuli by priming the neutral stimuli as more positive. Also, the time window scored for the LPP in the current research is wider than
other affective processing studies in children. Therefore, there may have been some minute differences between image categories across the time course of the LPP that may have been masked by the selected time window in the current study. Some studies have employed scoring separate time windows to account for spatiotemporal changes in the LPP (Dennis & Hajcak, 2009; Hua et al., 2014; McLean et al., 2020; Solomon et al., 2012). However, these time windows are inconsistent across studies and often paradigm specific. In the current study, the time window for the LPP was based on visual inspections of participants grand means. However, future work would benefit from exploring different types of ERP scoring measures that take in account both magnitude and latency differences in ERPs when comparing responses between image categories (e.g., fractional area technique; see Kappenman et al., 2021; Kiesel et al., 2008).

Combined, the results are in accord with previous adult studies highlighting semantic content as an important factor influencing affective processing (Weinberg & Hajack, 2010; Czekoova et al., 2016). Based on the current findings, it is important for researchers to consider distinct semantic themes (especially for social stimuli) when selecting stimuli for affective research in children. Furthermore, the current work emphasizes the value of research focused on designing and validating stimuli sets with distinct types of stimuli appropriate for children. Together, implementing such principles could help researchers better assess and track neural functioning that contribute to externalizing etiology, as well as characterize different developmental pathways that influence risk for psychopathology.
5.2 Relations between Neural Markers of Affective Processing and Externalizing Risk

The current research also found unique correlations between the LPP and externalizing problems in children. Specifically, larger LPP amplitudes to intrapersonal rewards were associated with increased externalizing behavior (Chapter 3) whereas LPP amplitudes to interpersonal and object reward categories were not related to externalizing behavior. Furthermore, externalizing behavior in children was not related fN400 amplitudes. These findings are consistent with work from behavioral studies linking externalizing behavior with attention biases to social reward stimuli in children (Cremone et al., 2018; Morales et al., 2020). It is important to note that both these studies both used reward stimuli that depicted social situations with no social interaction (i.e., happy faces). The intrapersonal images implemented in the current study also depict social situations lacking social interaction. Therefore, the current data suggests that externalizing risk in children is specifically associated with heightened attention and sustained processing of social reward without an interactive component.

Externalizing psychopathology has previously been linked to abnormal functioning of neural circuits involved in mediating motivational salience and reward-seeking behavior in children and adolescents (Hawes et al., 2020; Holroyd et al., 2008; Matthys et al., 2013b). The LPP, in response to positive stimuli, has been shown to positively correlate with neural activity within similar motivational circuits implicated in externalizing psychopathology (Liu, Huang, McGinnis-Deweese, et al., 2012; Sabatinelli et al., 2012; Sabatinelli, Lang, et al., 2007). Taken together, our current results indicate that heightened LPP responses to social, intrapersonal rewards (i.e., stimuli without social
interaction) may reflect altered motivational salience leading to increased risk for externalizing problems in children.

Interestingly, relations were also found between the LPP and self-regulation issues (Chapter 2). Specifically, larger LPP amplitudes to intrapersonal and object reward images were associated with increased self-regulation issues. Poor self-regulation has been highlighted as a prominent feature strongly predicting externalizing behavior problems and later psychopathology in children (N. Eisenberg et al., 2010; Perry et al., 2018). Accumulating evidence suggests that biased attention toward rewards may reflect impulsive tendencies in children (Frick, 2004; Gatzke-Kopp et al., 2009; Luman et al., 2012). Furthermore, it is strongly suggested that these impulsive tendencies underscore links between self-regulation issues and externalizing behavior problems (Kuhn et al., 2018; White et al., 2013). Hence, current patterns indicate that LPP responses to intrapersonal social reward and, to some extent, non-social reward may relate to individual differences in impulsivity related to externalizing risk (Brown et al., 2006; Kirkpatrick et al., 2015).

It is important to note that the current research used parent-report measures to examine LPP associations between self-regulation and externalizing behavior, so we are limited in our ability to infer if these processing patterns in LPP map on to direct measures of impulsivity. Future work is needed to confirm whether these LPP patterns correspond with multi-measure approaches, including behavioral observation paradigms, to assessing self-regulation deficits (i.e., impulsivity) and externalizing in children.
5.3. Gender Differences in Affective Processing and Externalizing Risk

Converging evidence suggests that gender differences in externalizing risk are attributed to differences in the way that males and females process emotions (Eme, 2016; Maguire et al., 2015). However, very little work has used ERP measures to examine whether gender differences in affective processing relate to variation in externalizing patterns between males and females. Furthermore, no work has yet explored whether gender differences in processing of specific types of stimuli (e.g., social and non-social reward) relates to different types of externalizing patterns between males and females (i.e., greater problems in boys; less problems in girls). Thus, a major aim of the current dissertation work was to address these gaps.

Gender differences in affective processing were revealed in LPP responses to object reward images. Specifically, boys exhibited larger LPPs to object images relative to girls (Chapter 2 & Chapter 3). These findings were in line with a substantial literature reporting biased processing to positive stimuli in males (Fine et al., 2009; Solomon et al., 2012; Wrase et al., 2003; Zhang et al., 2017). This work also corresponds with a small, but growing literature, suggesting stronger processing of non-social reward in males compared to females (Greimel et al., 2018a; Spreckelmeyer et al., 2009; Warthen et al., 2020b). Interestingly, boys and girls did not show differences in their valence and arousal ratings. These results highlight the utility of ERPs in characterizing unique gender-related patterns in affective processing to specific types of reward.

Extensive prior research has reported that males exhibit greater responses to positive information, whereas females process social information more strongly (Fine et al., 2009; Kemp et al., 2004; Sharp et al., 2006; Wrase et al., 2003; Zhang et al., 2017).
Our findings showed that, boys and girls showed similar patterns in their LPP responses to social reward images (i.e., intrapersonal and interpersonal images). This slight deviation from the literature may have been because the social stimuli used in this research were both positive and socially oriented. Thus, we may not have found gender differences in ERP amplitudes between the social image categories because our results were conflated by gender-specific emotion biases. Moreover, prior studies have reported that children tend to show a positive bias toward affective stimuli compared to adults, so processing of social reward may have also been influenced by age (Hajcak & Dennis, 2009; McManis et al., 2001). Future research should incorporate social and non-social stimuli across the valence spectrum (e.g., positive, neutral, negative) to better characterize gender and age specific patterns in affective processing during childhood.

Findings also revealed important gender differences in the associations between ERPs and externalizing behavior (Chapter 3). For the fN400, larger amplitudes to all image categories were related to increased externalizing behavior in boys. This pattern suggests that boys with higher externalizing risk showed greater attention allocation throughout the task, irrespective of stimuli type. Thus boys with greater externalizing problems may have found all image categories highly salient and/or had issues distinguishing between different stimuli categories (Schupp et al., 2007; Wu et al., 2014). No association emerged between fN400 amplitudes and externalizing behavior for girls, suggesting that these patterns in the fN400 specifically confer risk for boys.

Although preliminary, these findings indicate that gender differences in early attentional and perceptual stages of affective processing might reflect an externalizing risk mechanism that is unique to boys. Extensive research suggests that boys show slower
development of neural connections between prefrontal and temporal brain areas (e.g., amygdala) than girls during childhood (Kaczkurkin, Raznahan, et al., 2019; Zahn-Waxler et al., 2008); these neural connections support the development of several processes such as emotion perception, memory, attention, and decision-making (Folloni et al., 2019; Olson et al., 2007). This slight delay in neural development in boys may result in less efficient emotion discrimination between different stimuli in boys compared to girls (Alegria et al., 2016; Arnsten & Rubia, 2012; Qin et al., 2012; Whittle et al., 2020).

Weaker prefrontal-amygdala connectivity has previously been associated with attention problems, emotion dysregulation, poor self-control, and elevated externalizing behavior in children (Bertocci et al., 2014; Gaffrey et al., 2021; Park et al., 2018). Additionally, individual differences in prefrontal-amygdala connectivity and dopamine function (a neurotransmitter involved in reward processing) have both been posited as possible neurobiological mechanisms involved in emerging externalizing behavior in children (Beauchaine & Gatzke-Kopp, 2012; Beauchaine & McNulty, 2013). Slower neural development of affective processing in boys, in conjunction with biases to positive/reward stimuli, may impact boys’ ability to extract relevant information and make appropriate decisions.

Therefore, greater fN400 amplitudes in response to stimuli may reflect a neural marker of global information processing associated with emerging externalizing behavior in boys, but not in girls. To better understand gender differences in these mechanisms, future studies should employ child-friendly, active (versus passive) paradigms (e.g., tasks that involve decision making) to confirm whether gender patterns in the fN400 in
response to various affective cues relate to different performance patterns between boys and girls across different kinds of tasks (e.g., Lake et al., 2021).

Larger LPP amplitudes to object reward images were related to increased externalizing behavior in girls. No relation between the LPP to object rewards and externalizing behavior emerged for boys. Since we had hypothesized that this relation between the LPP to non-social (object) reward images would emerge in boys, not girls, this finding was unanticipated. Although we did not find any relation with the LPP to object reward images and externalizing behavior in boys, they did exhibit larger amplitudes to object pictures than girls overall. Therefore, this suggests that although boys show greater sustained processing of non-social reward compared to girls, it this pattern may not be as much of a risk marker for them as it is for girls.

Larger LPP amplitudes to neutral images were related to increased externalizing behavior in girls, which was also unexpected. Neutral stimuli are often conceptualized as a non-affective “comparison” group, so very little research has explored potential links between neutral processing patterns and problem behavior within a normative child sample. However, within psychopathology research, heighted processing of neutral stimuli has been linked to greater internalizing\(^7\) symptoms, such as anxiety (Cooney et al., 2006; Kirschner et al., 2016; Li et al., 2020; Sharp et al., 2008; Wieser & Moscovitch, 2015) Therefore, larger LPP amplitudes to neutral stimuli relate to increased risk for both externalizing and internalizing problems in girls.

---

\(^7\) Internalizing behaviors are problematic actions and/or states that are directed inward towards one’s self (J. Liu et al., 2011). Examples of internalizing symptoms are anxiety, depression, behavioral withdrawal, and somatic disturbances.
There is limited research focus on externalizing behavior in girls, as girls tend to show lower rates of externalizing difficulties than boys (Eme, 2016). However, a growing body of literature suggests that girls who show externalizing behavior difficulties are also more likely to show co-occurring externalizing and internalizing symptoms over time (Lau et al., 2021; Maschi et al., 2008; Russo & Beidel, 1994). Further evidence suggest that girls exhibiting this comorbid profile are at higher risk for psychopathology than boys (Loeber & Keenan, 1994; Zahn-Waxler et al., 2008). Thus, elevated neural reactivity to neutral stimuli might be a marker that indicates heightened risk in girls.

Importantly, these findings indicate that the neural processing patterns associated with externalizing risk in boys and girls are temporally distinct. Externalizing risk in boys was associated with neural activity occurring during earlier stages in affective processing. Whereas, for girls, externalizing risk was associated with neural activity occurring during later stages of affective processing. These patterns suggest that the neural mechanisms underlying externalizing behaviors can differ between boys and girls. The current data are from a cross-sectional design, so caution should be taken before extrapolating these results. Thus, future work, especially studies employing longitudinal designs, should explore gender-related trajectories in temporal processing of social and nonsocial reward to clarify how and when these patterns reveal etiological pathways that diverge between boys and girls.

5.4 Individual differences in Affective Processing and Relations to Externalizing Risk

Extensive research suggests that children exhibiting high surgency traits are at higher risk for developing externalizing problems (Gartstein et al., 2012a; Nielsen et al.,
However, converging research also suggests that surgency is associated with greater social responsiveness, affiliative behavior, and social competence (Davis & Suveg, 2014; Endedijk et al., 2015; Salley et al., 2013b; VanSchyndel et al., 2017). Thus, it is possible that sensitivity to social rewards (compared to non-social rewards) may be a factor that protects children from developing externalizing problems.

No existing research has examined interactions between surgency and neural markers of attention toward distinct types of social and non-social reward stimuli, nor how these interactions might relate to differing patterns of externalizing behavior problems in children. Therefore, the final study in this dissertation sought to examine whether ERP responses to distinct forms of social and non-social reward moderated relations between temperamental surgency and externalizing problems in children (Chapter 4).

Our results revealed important relations between surgency, the LPP and externalizing problems. As predicted, higher surgency was related with increased externalizing behavior in children. We also found that externalizing behavior was strongly related to higher impulsive reactivity (an aspect of surgency). These findings were in accord with prior studies reporting associations with trait impulsive reactivity and increased externalizing problems in children (Eisenberg et al., 2009; Gartstein et al., 2012b; Scheper et al., 2017).

Results also revealed that higher levels of surgency were associated with larger LPP amplitudes to object reward images. These findings are in line with previous behavioral and neural studies reporting associations with impulsive reactivity traits and heightened attention and sensitivity to non-social reward (Bunford et al., 2021; Chase et
al., 2017; Miller et al., 2012; Novak et al., 2016). Moreover, these relations have also been linked to externalizing psychopathology (Bunford et al., 2021; Carlson et al., 2013; Marmorstein, 2013).

In addition, higher surgency was related to greater LPP responses to object reward relative to interpersonal reward images. Similar to other findings related with externalizing behavior, these patterns in the LPP were specifically related to impulsive reactivity, suggesting that children with high impulsive, reactive traits preferentially process non-social, object rewards stimuli compared to social, interpersonal rewards (e.g., positive social interactions). The current results expand on past literature and indicate a link between impulsive reactivity in children and contrasting patterns in neural processing to non-social reward and distinct types of social reward (i.e., greater processing of object reward compared to interpersonal reward).

Interestingly, we did not find evidence that patterns in the LPP to distinct reward categories moderated relations between surgency and parent-reported externalizing behavior. It is not clear why an interaction between surgency and the LPP did not emerge in predicting externalizing behavior in children. However, it could be that the task paradigm we used (i.e., passive-viewing of reward) does not tap on the temperamental processes underscoring externalizing risk. Another limitation is that surgency and externalizing behavior variable were examined using parent-report measures; surgency and externalizing behavior scales could have items between them that load on to similar constructs and confound caregiver’s responses (Olino et al., 2005, 2014b; Olson et al., 2017). Therefore, future research should incorporate additional methods for assessment.
(e.g., passive versus active tasks; parent-report versus behavioral measures) to examine relations between temperament and externalizing variables.

Surprisingly, relations between surgency and externalizing behavior were moderated by fN400 amplitudes. Specifically, high surgery children exhibiting larger fN400 amplitudes to intrapersonal reward images, relative to object-based reward, had greater externalizing problems. The intrapersonal reward category depicted social content related to intrinsic rewards (i.e., achievement, fun). Therefore, our results indicate that preferential, early processing of intrinsic reward compared to extrinsic rewards (i.e., treats, prizes) may reflect increased externalizing risk in high surgery children. Little work has compared effects of intrinsic versus extrinsic reward in relation to surgery and externalizing problems children, thus these results are quite novel. However, considering that intrinsic and extrinsic motivation are important factors involved in shaping self-regulation in childhood (Carver & Scheier, 2002; Derryberry & Rothbart, 1988; Martin & Olson, 2015; Scholer et al., 2018), a useful route for future study would to examine the relations between individual differences in reactivity to intrinsic versus extrinsic rewards and emerging risk in children.

Notably, these findings build upon results discussed in previous chapters of this dissertation in important ways. In Chapter 2, we reported associations with larger LPP responses to non-social reward stimuli and greater self-regulation issues in children. We also reported associations between LPP amplitudes to non-social reward stimuli and externalizing problems in Chapter 3. In the final study (Chapter 4), we reported relations between impulsive, reactive temperament and larger LPPs to object-based reward images (relative to interpersonal images), as well as positive relations between impulsive
reactivity traits and externalizing behavior problems in children. Although the results did not provide evidence supporting our hypothesis that LPP amplitudes to object-based reward images would moderate relations between surgency and externalizing risk in children, this research suggests individual differences in temperamental reactivity can be distinguished by distinct neural patterns to different types of reward. Furthermore, our results reveal novel findings that highlight the fN400 as a unique marker of temperamental risk for externalizing behavior problems in children.

5.5 Future Directions

The current project is one of first to examine neural markers of affective processing toward distinct types of reward stimuli and their associations with externalizing behavior in typically developing children. Although we did not find evidence supporting our hypotheses that externalizing risk in children would relate to clear and contrasting patterns in ERPs to social and non-social reward stimuli, this work provides important insights regarding the affective processing mechanisms associated with externalizing risk. Namely, our findings indicate that the semantic content of reward stimuli (social, non-social), in conjunction with the temporal processing of that semantic content, are important factors that distinguish children’s risk for externalizing problems. These novel findings also highlight several important avenues for future research which are discussed below.

First, future research should examine interactions between patterns in the fN400 and LPP, and how these interactions predict children’s risk for externalizing problems. The analyses in this dissertation examined patterns in the fN400 and LPP separately. However, as described in Chapter 1, the processes indexed by these ERP components can
be highly dynamic and dependent on each other. To gain a more comprehensive view of neural mechanisms affected in at-risk children, it would be important to track how patterns during early stages of affective processing impact later stages of affective processing. Furthermore, tracking the impacts of both gender and individual differences in temporal processing and how these patterns may change over time would help researchers better understand diverse development pathways that led to greater risk for psychopathology in children.

Second, future work should compare neural processing of social and non-social stimuli across valence. This dissertation intentionally compared neural processing between specific categories of social and non-social reward on account of limited research examining how processing patterns in attention to specific types of reward (beyond faces and objects) relate to externalizing behavior in a normative child sample. However, previous work has linked childhood externalizing behavior with altered patterns in neural processing of both reward and punishment (Fowles, 2000; Newman & Wallace, 1993; Sharp et al., 2008; Van Goozen et al., 2004). Furthermore, emerging evidence suggests that deficits in both affiliative reward (i.e., interpersonal) and global threat cues are traits associated with severe and persistent externalizing trajectories in children (Waller et al., 2021b; Waller & Wagner, 2019). Thus, future research is needed to unpack social/non-social distinctions in neural processing of positive and negative valence to clarify etiological pathways of externalizing problems.

Additional work is also needed to explore relations between neural processing of neutral stimuli and externalizing risk. Across the literature, neural reactivity to neutral stimuli is often characterized as a baseline condition. For example, a common method
seen in the literature is to create ERP difference scores when comparing neural reactivity to different affective categories (positive versus negative); these difference scores are calculated by subtracting neural activity to neutral stimuli from affective stimuli (Brown et al., 2012; McLean et al., 2020; Mulligan & Klein, 2019). However, neutral ERP difference have been shown to be inconsistent in their reliability (Clayson et al., 2021; E. A. Martin et al., 2020; Meyer et al., 2017) The current research demonstrated that neutral is not processed as neutral for everyone, and variation in neural processing of neutral stimuli can provide important insights regarding externalizing risk specifically related to gender. Therefore, in future studies, more focus should be placed on neutral processing as its own unique measure when examining research questions concerning childhood externalizing risk.

Third, future research should explore patterns in neural processing of social and non-social reward stimuli and how these patterns interact with other temperament dimensions to predict externalizing risk in childhood. As this dissertation was centered on externalizing risk in relation to neural processing of distinct types of reward, the current research focused on temperamental traits related to surgency (see Chapter 1, section 1.4.2). However, other temperamental dimensions, such as negative affect⁸ and effortful control⁹, have also been implicated in externalizing risk (Olson et al., 2017; Sanson et al., 2009; Schepet et al., 2017; Stifter et al., 2008; VanSchyndel et al., 2017). Interactions between temperamental dimensions (i.e., surgency, negative affect, effortful control)

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³ Negative affect refers to the tendency to experience and express negative emotions (fear, sadness, anger, frustration), discomfort, and irritability (M. K. Rothbart et al., 1994)
⁹ Effortful control references children’s capacity to engage in self-regulatory actions such as attention focusing and shifting and inhibitory control (Rothbart et al., 1994)
have also been shown to predict different trajectories in externalizing risk (Forbes et al., 2017; Nielsen et al., 2019b). Additionally, specific facets within these broader dimensions have been associated with greater risk than others (Morales et al., 2021; Oldehinkel et al., 2004). Thus, it is important to unpack interactions between temperamental traits to better understand how individual differences in affective processing contribute to various paths that lead to externalizing or other types of problems in children (i.e., equifinality and multifinality; Cicchetti & Rogosch, 1996).

Fourth, future research should also examine how patterns in neural processing of distinct social and non-social reward types relate to risk for different kinds of psychopathology. Disrupted affective processing of rewards are not unique to externalizing problems; aberrant neural processing of positive stimuli has also been linked to internalizing symptoms, such as depression and anxiety. Also, a single individual can present with co-occurring externalizing and internalizing symptoms; therefore, children within this profile might display neural markers distinct from children with predominant forms of externalizing and internalizing symptoms (Cosgrove et al., 2011; McElroy et al., 2018). Moreover, middle childhood marks a turning point in development where trajectories of externalizing and internalizing problems start to stabilize (Ladd, 2006; Nivard et al., 2017). Therefore, future studies are needed to assess whether neural markers of affective processing of social and non-social reward stimuli reveal different (or similar) relations with externalizing and internalizing behavior problems during middle childhood.

Fifth, future research should expand on findings and replicate this research using a clinical or combined clinical/community sample. To effectively quantify abnormal
patterns in development, it is important to first establish the bounds that designate typical functioning in children. Thus, the research questions in this dissertation were examined in a normative community sample. However, it would be useful to examine not only how neural processing patterns vary across the externalizing levels in normative development (e.g., low, average, high externalizing), but how these processing patterns compare to processing patterns in children displaying clinical levels of psychopathology. Together, these data would help elucidate neural mechanisms that differentiate typical and atypical development of affective processing.

Finally, future work should examine the role of contextual factors (e.g., parenting, socioeconomic status, social adversity) in influencing connections between neural processing of distinct types of reward content and externalizing behavior in children. Extensive research suggest that externalizing behavior problems can be exacerbated by children’s environmental context (Beauchaine, 2015; Beauchaine & McNulty, 2013; Campbell et al., 2000; Liu, 2004). Therefore, research exploring interactions between contextual factors and intrinsic factors (e.g., individual differences in reward sensitivity and attention) would help identify environmental contexts that promote (or buffer) risk for externalizing in children.

In conclusion, the three studies in this dissertation provide important insights into temporal and contextual factors related to externalizing risk in children. Collectively, this research contributes to our understanding regarding normative variations in pathways underlying externalizing problems in children. Namely, we found that these factors are important in differentiating between risk patterns associated with gender and temperament. The current work also addresses gaps in the child development literature by
examining neural patterns to distinct categories of reward using a novel image set designed especially for children. Most importantly, the findings highlight future routes for explorations that may be useful in the early identification of children at-risk for externalizing problems and could potentially inform prevention/intervention efforts.
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