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Neurophysiological evidence for distinct biases in emotional face processing associated with internalizing and externalizing symptoms in children

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Abstract

Attentional bias to threat has been implicated in both internalizing and externalizing disorders. This study utilizes event-related potentials to examine early stages of perceptual attention to threatening (angry or fearful) versus neutral faces among a sample of 200 children ages 6–8 years from a low-income, urban community. Although both internalizing and externalizing symptoms were associated with processing biases, the nature of the bias differed between these two symptom domains. Internalizing symptoms were associated with heightened early attentional selection (P1) and later perceptual processing (P2) of fearful faces. In contrast, externalizing symptoms were associated with reduced early attentional selection (P1) of fearful faces and enhanced perceptual processing (P2) of neutral faces, possibly indicative of a hostile interpretation bias for ambiguous social cues. These results provide insight into the distinct cognitive-affective processes that may contribute to the etiology and maintenance of internalizing and externalizing psychopathology.

Keywords

externalizing; comorbidity; internalizing; childhood; attention biases; social threat; emotional face processing; event-related potentials

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Introduction

Biases in the earliest stages of social information processing, namely the detection and allocation of attention to potentially threatening cues, have been proposed to play an important role in the etiology of both externalizing symptoms such as aggression (Dodge & Crick, 1990), and internalizing symptoms such as anxiety (Mogg & Bradley, 1998). These early perceptual-attentional biases may contribute to the development and maintenance of emotional and behavioral problems by decreasing the threshold for detecting potential threats, amplifying negative emotional reactions to perceived threats, and/or increasing negative biases in subsequent cognitive processing of these threats. However, many details about the nature of biases in early social threat processing associated with internalizing and externalizing symptoms remain to be clarified.

One important detail is the timing of the bias, i.e., whether biases occur at early automatic information-processing stages versus later controlled information-processing stages. Understanding the timing of the biases may have important implications for the kinds of interventions that would be expected to be effective in reducing them. Furthermore, although research has indicated that both internalizing and externalizing symptoms are associated with attention bias to threat, there is some indication that the nature of the bias differs. Internalizing symptoms have been more consistently related to increased attentional biases to threat-related stimuli (Bar-Haim, Lamy, Lee, Bakermans-Kranenburg, & van IJzendoorn, 2007; Cisler & Koster, 2010), whereas externalizing symptoms have been related to increased biases toward ambiguous and anger-related stimuli more specifically and/or a reduction in attention to relevant non-hostile social cues (Dodge, 1993; Dodge et al., 2003). Finally, despite the high prevalence of internalizing-externalizing comorbidity (Bird, Gould, & Staghezza, 1993; Cosgrove et al., 2011; Lahey, Van Hulle, Singh, Waldman, & Rathouz, 2011), very few studies have examined how threat processing biases are associated with symptom comorbidity.

Environmental adversity also plays an important role in the development of internalizing and externalizing symptoms. It is well established that children growing up in low-income communities are at greater risk for emotional and behavioral problems (Qi & Kaiser, 2003). This heightened prevalence makes it imperative to study factors associated with symptom expression within these populations. Yet, the vast majority of research on attention biases in internalizing and externalizing psychopathology has been conducted in higher-SES communities, such as university student populations. Brain-behavior associations observed in higher-SES populations do not necessarily generalize to lower-SES populations (Gatzke-Kopp, 2016; Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006), underscoring the importance of examining associations in diverse populations. This paper contributes to the diversity of representation within neuropsychological science by examining social threat processing biases associated with emotional and behavioral symptom expression in children from a low-income, urban community.

Internalizing and Externalizing Symptoms and Attention Biases to Social Threat: Behavioral Paradigms

Internalizing Symptoms—Research on internalizing symptoms has focused on attention to threatening stimuli as a potential mechanism underlying anxiety-related behaviors. An extensive body of empirical research using behavioral paradigms, including dot-probe, emotional Stroop, and visual search tasks, has provided evidence for enhanced attention biases toward threatening (angry or fearful) faces and words in anxious adults (Bar-Haim et al., 2007; Cisler & Koster, 2010). Anxiety-related attention biases in adults have also been observed to subliminally presented stimuli (Bar-Haim et al., 2007), suggesting they reflect automatic facilitation of perceptual-attentional processing of potentially threatening environmental cues. In children, attention bias to threat has been widely studied as a possible neurocognitive factor in the etiology and maintenance of pediatric anxiety disorders and has been demonstrated across numerous studies using behavioral paradigms in clinical and non-clinical populations (Dudeney, Sharpe, & Hunt, 2015; Field, Hadwin, & Lester, 2011; Roy, Dennis, & Warner, 2015). Anxious children typically show an exaggerated attention bias to threat compared with typically developing children, although there is some heterogeneity with a few studies finding a bias away from threat (Roy et al., 2015). The developmental studies clearly demonstrate that attention biases are present in anxious children beginning as early as 5 years of age. A meta-analysis has also indicated that this effect is moderated by age, such that the difference between anxious children and controls increases with age (Dudeney et al., 2015).

Externalizing Symptoms—In contrast to the substantial literature available on attention biases in anxiety, a relatively small number of studies using behavioral paradigms provide evidence supporting threat-related attention biases in individuals with externalizing behavior problems. Some studies with adults have shown that those individuals with higher trait anger exhibit attention biases to angry/hostile versus neutral words or face stimuli (Smith & Waterman, 2003; van Honk, Tuiten, de Haan, van den Hout, & Stam, 2001). Several studies have also demonstrated that higher trait-angry individuals exhibit preattentive biases to subliminally-presented (masked) threat-related faces (Putman, Hermans, & van Honk, 2004; van Honk et al., 2001) or towards aggressive words at both preattentive and controlled information-processing stages when aggressive adults are experiencing state anger (Cohen, Eckhardt, & Schagat, 1998; Eckhardt & Cohen, 1997).

With respect to the development of externalizing symptoms, long-standing theories have posited that distorted social information processing plays a role in the development and maintenance of these behaviors (Dodge, 1993; Dodge et al., 2003). Research suggests that children with aggressive tendencies are more likely to be hypervigilant to hostile cues in the environment, attribute hostile intent to ambiguous social cues, and/or pay less attention to relevant social cues indicative of non-hostile intent. However, most of the research in this area has focused on top-down cognitive processing, such as vigilance to cues that are consistent with pre-existing schemas of hostile intent or the misinterpretation of ambiguous cues, including biases towards the perception of anger (Fine, Trentacosta, Izard, Mostow, & Campbell, 2004; Schultz, Izard, & Bear, 2004). Very few behavioral studies of automatic attention or bottom-up processing of threat have been conducted with externalizing children.

A couple of studies have provided evidence that aggressive children do have greater difficulty disengaging their attention from angry facial expressions and aggressive scenes (Gouze, 1987; Wilson, 2003), but more work is needed in this area.

Event-Related Potentials, Emotional Face Processing, and Symptoms

Interesting insights on attention biases have been gained through behavioral paradigms; however, behavioral studies have several important limitations. Most of these studies measure attention biases based on differences in discrete response times to emotional stimuli, and thus do not reveal the continuous time course of attention allocation. Additionally, the behavioral response times reflect processes other than attention allocation, such as motor speed or cognitive control during the execution of the response, which are also sensitive to emotional influences. In order to address some of these limitations, some researchers have turned to event-related potential (ERP) methodology to investigate attentional biases to threat-related faces at the neural level. ERPs are time-locked electrophysiological responses to stimulus presentations, measured on a millisecond time scale, that allow for the differentiation among very early stages of neural processing. The metrics used with this methodology include the *amplitude* and *latency* of the ERP components, each offering different information with respect to neural processing. The amplitude of the components represents both the consistency of neuronal firing and the magnitude of the neural source activity (i.e., how strong the signal is), while the latency reflects the millisecond-level timing of when the neuronal firing reaches its peak (i.e., when the signal occurs). Longer latencies for an ERP may reflect increased processing time needed to reach the peak of the component and/or interference from various other sources, including cognitive sources.

Emotional Face Processing—Due to their emotional significance and ecological validity, many studies have used emotional faces to study attention bias to social threat. Angry facial expressions communicate the potential danger of direct threat and hostility, while fearful expressions signal indirect threat from the environment that should be avoided. The quick detection of threat may have helped our ancestors to survive and reproduce and may have led to the evolution of visual systems that quickly and efficiently detect the presence of such stimuli. For example, research suggests that a bias for quickly detecting angry and fearful faces in search paradigms is evident by 5 years of age (LoBue, 2009). There is also some suggestion that these two threat-related faces are processed differently, such that angry faces hold/engage attention, whereas fearful faces guide attention (Fox, Calder, Mathews, & Yiend, 2007). Importantly, such differences may contribute to inconsistencies across studies that aim to identify associations with threat-related biases.

There is a well-established literature regarding ERPs and the time course of emotional face processing. The use of ERPs allows for the measurement of attentional biases to emotional faces at early stages of processing. One of the earliest ERP peaks showing sensitivity to emotional expressions is the P1, an early component (peaking at approximately 80 to 110 ms post-stimulus onset) that arises from ventral extrastriate visual areas and is sensitive to low-level visual information (i.e., contrast, luminosity, and spatial frequency) (Nakashima et al., 2008; Rossion & Jacques, 2011) and visual attention (Hillyard & Anllo-Vento, 1998). The

P1 is thought to reflect the initial attentional selection of a stimulus for further processing and may also be a necessary precursor to conscious awareness (Railo, Koivisto, & Revonsuo, 2011).

Immediately following the P1, the N170 component is observed at posterior lateral electrode sites peaking within roughly 130–340 ms post-stimulus onset. The N170 has been argued to reflect face detection processes, as its amplitude is heightened to faces relative to any other stimulus type, but it has also been shown to be modulated by stimuli consisting only of eyes (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Itier & Taylor, 2004b) as well as by heavily degraded face cues that are detected as faces based on configural or holistic properties of the stimulus (Eimer, Gosling, Nicholas, & Kiss, 2011). This component appears to reflect multiple neural sources in bilateral inferior occipital and temporal cortices including the face-sensitive fusiform gyrus (Herrmann, Ehlis, Muehlberger, & Fallgatter, 2005; Itier & Taylor, 2004b).

The posterior P2 is a component measured over parieto-occipital sites at approximately 150 to 275 ms post-stimulus onset. This posterior P2 should be distinguished from a positive peak at fronto-central sites occurring simultaneously with the N170, which has been variously referred to as a P2 or ‘vertex positive potential’ (VPP), and which has been suggested to reflect the same neural generator as the N170 (Joyce & Rossion, 2005). The posterior P2 has been less thoroughly investigated and is therefore less well understood than the earlier P1 and N170 peaks. The posterior P2 peak has been hypothesized to reflect re-entrant activity in primary and secondary visual cortices involved in the formation of a conscious visual percept (Kotsoni, Csibra, Mareschal, & Johnson, 2007). It has been suggested that higher amplitude of the P2 peak is associated with the allocation of neural resources to deeper perceptual processing of the stimulus (Latinus & Taylor, 2005).

Internalizing symptoms and ERP social threat-processing biases—Based on behavioral studies of attention biases in anxiety, we would expect to find indicators of vigilance (decreased latency) and threat potentiation (increased amplitude) in the early neural processing of threat-related cues. Across ERP studies, the majority of evidence supports the behavioral findings. Studies have demonstrated that anxious adults exhibit greater P1 amplitudes to threatening versus neutral facial expressions compared to their low-anxious counterparts, including for fearful (Holmes, Nielsen, & Green, 2008) and angry faces (Mueller et al., 2009), indicating that anxiety may potentiate initial threat evaluation. Other studies have observed that anxious or inhibited adults exhibit greater P1 amplitudes to face stimuli regardless of the emotional expression (Dennis & Chen, 2007; Frenkel & Bar-Haim, 2011; Kolassa et al., 2009; Kolassa, Kolassa, Musial, & Miltner, 2007; Muehlberger et al., 2009; Rossignol, Campanella, Bissot, & Philippot, 2013; Rossignol, Philippot, Bissot, Rigoulot, & Campanella, 2012), possibly reflecting potentiated processing of faces in general. Mixed findings have been reported for associations between anxiety symptoms and amplitude of the posterior P2 peak to emotional faces in adults, with some studies demonstrating associations between anxiety and greater P2 amplitudes specifically to angry versus neutral faces (Bar-Haim, Lamy, & Glickman, 2005; Rossignol et al., 2013), and others showing greater amplitudes regardless of the emotional expression (Dennis & Chen, 2007; Eldar, Yankelevitch, Lamy, & Bar-Haim, 2010; Felmingham, Stewart, Kemp, & Carr,

2016; Rossignol et al., 2012). With respect to latencies, one study has demonstrated that highly anxious adults show shorter latencies to faces in general (including emotional faces) beginning at the P1 stage of processing, with shorter latencies also evident at the N1 and P2 stages of processing (Bar-Haim et al., 2005).

The few ERP studies that have investigated the automatic processing of emotional faces in anxious children have yielded mixed results. Regarding P1 amplitude, studies have revealed enhanced P1 amplitudes to angry versus neutral facial expressions in children aged 8–15 years with anxiety disorders (Bechor et al., 2018), higher P1 amplitudes to face stimuli regardless of the emotional expression in children aged 8–12 years with anxiety disorders (Hum, Manassis, & Lewis, 2013), and no association of P1 amplitudes to face stimuli with social anxiety in children between the ages of 9 and 13 years (Keil, Uusberg, Blechert, Tuschen-Caffier, & Schmitz, 2018; Thai, Taber-Thomas, & Pérez-Edgar, 2016). For N170 amplitude, studies have revealed enhanced N170 amplitudes to faces in children aged 8–15 years with anxiety disorders (Bechor et al., 2018), as well as no association of N170 amplitudes with concurrent anxiety in children aged 5–7 years (O’Toole, DeCicco, Berthod, & Dennis, 2013) or with social anxiety in children between the ages of 9 and 13 years (Keil et al., 2018; Thai et al., 2016). To our knowledge, only one study has investigated associations of anxiety with the posterior P2 amplitude to emotional faces in children (Bechor et al., 2018). This study reported smaller P2 amplitudes to emotional faces, regardless of angry or neutral expression, among children with anxiety disorders versus control children aged 8–16 years. These ERP studies, although sparse and inconsistent, have provided some evidence for differences in the automatic neural processing of face stimuli as a function of anxiety as early as middle childhood.

Externalizing symptoms and ERP social threat-processing biases—Few studies have examined the association between externalizing symptoms and attention biases to social threat as measured by ERP response. A small number of studies have examined ERP correlates of emotional face processing in individuals with attention-deficit/hyperactivity disorder (ADHD), a disorder that falls within the externalizing spectrum. Similar to the study by Dennis and colleagues, children with ADHD have been observed to have blunted P1 amplitudes to face stimuli (Williams et al., 2008). This study also found that children with ADHD had greater N170 amplitudes to angry, fearful, and neutral expressions (Williams et al., 2008), although other studies have reported no associations between ADHD and N170 amplitude to faces (Tye et al., 2014). A recent study has also demonstrated reduced N170 amplitudes to fearful compared with neutral faces in children with ADHD (Flegenheimer, Lugo-Candelas, Harvey, & McDermott, 2018). Given the sparseness of the literature and the inconsistency of results to date, further studies examining associations between emotional face-processing ERP abnormalities and children’s externalizing behaviors are clearly justified.

Internalizing-externalizing comorbidity and ERP social threat processing biases—Despite the high cooccurrence of internalizing and externalizing symptoms in children (Bird et al., 1993), very little research has been conducted examining the implications of internalizing-externalizing comorbidity for ERP social threat processing

biases. It is important to explore the possibility that a different pattern of threat processing biases may underlie comorbid versus “pure” symptom presentations. Such a finding could suggest an etiological basis for symptom comorbidity. It is also possible that internalizing and externalizing symptoms are associated with biases to different emotional domains, such as fear and anger, respectively (Fortunato, Gatzke-Kopp, & Ram, 2013). Evidence of this dissociation would illustrate how a common process, attentional bias, could underlie pathways to both disorders either individually or concurrently depending on the target of the bias.

In one prior study that examined ERP social threat processing biases and internalizing-externalizing comorbidity, Bunford and colleagues (2017) observed that attenuated cognitive-elaborative processing of happy faces (as indexed by lower amplitudes of the late positive potential) was associated with greater rule-breaking behaviors among children diagnosed with an anxiety disorder, supporting prior research suggesting that externalizing behavior is related to reduced approach motivation (see Beauchaine, Gatzke-Kopp, & Mead, 2007 for a review). In contrast, these authors did not observe significant associations between processing of fearful or angry faces and externalizing behaviors among anxious children. However, this study did not examine face processing biases at the earlier P1, N170, or P2 information-processing stages.

The present study

As reviewed above, research on the neurophysiological basis of social threat processing biases in anxious children is currently sparse and inconsistent, and with regard to childhood externalizing symptoms (other than ADHD) and internalizing-externalizing comorbidity such research is extremely rare. Investigations of these associations within a low-SES population are even less common. The present study addresses these substantial research gaps by exploring associations between children’s internalizing, externalizing, and comorbid symptoms and their ERP indices of social threat processing biases, operationalized as ERP amplitude and latency differences to threatening (angry or fearful) versus neutral facial expressions, within a low-income urban community.

Methods

Participants

The sample consisted of 200 1st-grade children who participated in a larger, longitudinal study ($n = 339$) of children’s neurodevelopment and response to a socioemotional intervention (the *PATHS to Success Study*; see Gatzke-Kopp, Greenberg, Fortunato, & Coccia, 2012). Children were recruited from elementary schools within a single urban school district in central Pennsylvania. The community was characterized by low socioeconomic resources; 79% of students in the district qualified for free or reduced-price school meals, 69% of households were headed by a single mother, and 79% of parents were estimated to have no more than a high school education. Regional statistics indicated that property crimes were twice as high and violent crimes were 4.5 times as high as comparable statistics for the entire state.

For the larger study, all kindergarten teachers in the district completed a 10-item aggressive/oppositional behavior screening questionnaire for each child in their class. Scores were rank ordered within classroom, and 61% of the larger study sample was recruited from the highest within-classroom quartile while the other 39% was recruited from the lowest within-classroom quartile. Because the study was designed to examine the effectiveness of a socioemotional intervention program, children recruited from the highest within-classroom quartile of aggressive/oppositional behavior were randomly assigned to participate in the intervention, which took place during the second half of kindergarten and first half of first grade. Thus, the sample for the larger study consisted of three groups: intervention (children with elevated aggressive/oppositional behaviors who received the intervention; 30%), control (children with elevated aggressive/oppositional behaviors who did not receive the intervention; 32%), and comparison (children with low levels of aggressive/oppositional behaviors who did not receive the intervention; 39%).

Data for the present analyses were from a 1st-grade follow-up assessment of the sample, collected after the intervention period. Intervention-group children did not differ from control-group children in 1st-grade teacher-reported externalizing symptoms ($t_{161} = 0.03$, $p = .972$) or internalizing symptoms ($t_{160} = 0.25$, $p = .805$) or in any of the ERP measures used as outcome variables in the present analyses (all $|t|$'s < 1.86 , all p 's > 0.063). Therefore, analyses were conducted pooling across all three study groups.

Of the original 339 participants in the larger study, 200 had 1st-grade teacher-reported symptom ratings and valid data for at least one ERP peak of interest (details on missing data are reported in the Measures section). The proportions of children in the analysis sample from each study group closely mirrored those of the larger sample: 61% of the sample were in the top quartile of their classroom on aggressive/oppositional behaviors in kindergarten, and 29% of the sample (47% of those high in aggressive/oppositional behaviors) had received the intervention.

A strength of recruiting from the top and bottom within-classroom quartiles of aggressive/oppositional behavior is that the resulting sample captured a wide range of symptom severity: children's scores on the teacher-report Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997), a norm-referenced behavior problems screening instrument, covered the full range of possible values on the conduct problems and hyperactivity/inattention subscales. Children in the sample also exhibited a wide range of internalizing symptom severity, with scores ranging from 0 to 8 out of a possible score of 10 on the SDQ emotional symptoms subscale.

Sixty-seven percent of the children in the analysis sample were male. Children's racial/ethnic identities were: 70.5% African American, 21.5% Hispanic/Latino, 7.5% Caucasian, and 0.5% Asian. At the time of the 1st-grade EEG data collection, children were an average of 7.2 years old ($SD = 0.39$, range = 6.5 – 8.7). Parents provided informed consent and children gave verbal assent for all study procedures. The study procedures were approved by the Pennsylvania State University Internal Review Board.

Measures

Teacher questionnaires—For each year of the larger longitudinal study (kindergarten, 1st grade, and 2nd grade), teachers were asked to complete questionnaires for each child in their classroom who was enrolled in the study. Teachers who returned their questionnaires received a \$15 gift card as compensation for their time. The present analyses utilized questionnaire responses from 1st-grade teachers. First-grade teacher-report data were obtained for a total of 272 children (80% of the full sample for the larger study).

The present analyses utilized teachers' reports of children's externalizing symptoms, including aggressive/oppositional and hyperactive/inattentive behaviors, and internalizing symptoms, including anxiety and social withdrawal. Each of these constructs was measured across multiple survey scales. Specifically, teachers completed the Strengths and Difficulties Questionnaire (Goodman, 1997), the Teacher Observation of Classroom Adaptation – Revised (Werthamer-Larsson, Kellam, & Wheeler, 1991), and a scale measuring internalizing symptoms compiled for the Head Start REDI Project (<http://csc.psych.psu.edu/research/head-start-redi-project>). An exploratory factor analysis was conducted on the items measuring internalizing and externalizing symptoms across these scales. These analyses are reported in Willner, Gatzke-Kopp, and Bray (2016).

The factor analyses revealed four symptom factors that were measurement-invariant across all three years of data collection. These factors were: aggression/oppositionality, hyperactivity/inattention, anxiety, and social withdrawal. Factor scores for aggression/oppositionality and hyperactivity/inattention were moderately highly correlated ($r = .55$), as were scores for anxiety and social withdrawal ($r = .58$). For the present analyses, children's 1st-grade aggression/oppositionality and hyperactivity/inattention factor scores were standardized and averaged to form an externalizing dimension score, and children's 1st-grade anxiety and social withdrawal factor scores were standardized and averaged to form an internalizing dimension score.¹ Despite the recruitment strategy targeting children with high or low levels of aggression/oppositionality relative to their classmates, children's internalizing and externalizing scores were both unimodally distributed and exhibited low skewness and kurtosis (internalizing: skewness = 0.10, kurtosis = -0.71; externalizing: skewness = -0.23, kurtosis = -0.69). Additionally, as expected given the high prevalence of comorbidity, children's internalizing and externalizing scores were moderately positively correlated ($r = .32$, $p < .001$). One child was excluded from the analyses due to incomplete teacher responses on the internalizing questionnaire items.

Psychophysiological assessment—Psychophysiological equipment was installed into a recreational vehicle (RV) and driven to each school to conduct the assessments. Children participated in a physiological assessment each of the 3 years of the study. Only data from the 1st grade assessment will be examined here, as the kindergarten assessment did not incorporate the affective face stimuli. The psychophysiological assessments took place

¹The decision to reduce these four factors to externalizing and internalizing dimension scores is also supported by a latent profile analysis of the factor scores that revealed that children in the sample could best be categorized as *internalizing*, *externalizing*, *comorbid*, or *well-adjusted* (Willner, Gatzke-Kopp, & Bray, 2016). Furthermore, examination of correlations of ERP measures with each factor score did not provide compelling evidence for differential associations across the two factors composing each of the externalizing and internalizing dimensions.

during the school day and lasted approximately 45 minutes. Assessments included electroencephalographic (EEG) and autonomic data, but only the EEG data will be examined here. A total of 273 children participated in a psychophysiological assessment in 1st grade; however, teachers did not complete behavioral ratings for 24 of these children, and an additional 49 children did not have valid EEG data. Children were missing EEG data for the following reasons: technical difficulties or equipment malfunction during data collection ($n = 36$); noisy data that resulted in 10 or fewer segments remaining for each face condition after artifact rejection ($n = 3$); the go/no-go task was not completed during the assessment ($n = 3$); the EEG cap could not be used due to the child's hair style preventing proper electrode contact with the scalp ($n = 1$); and human error during data collection or management ($n = 6$). Additionally, one child was missing P2 data because the peak was not scorable.

Emotional face go/no-go task: After electrode and EEG cap placement, children rested quietly for 2 minutes while watching a moving starfield video. Children then completed a go/no-go task consisting of 396 trials (approximately 12 minutes). Stimuli consisted of faces displaying specific emotional expressions. Children were instructed to press the response button as quickly as possible each time they saw a face stimulus (go condition; 70% of trials), but not to press the button if the face that appeared was identical to the one that had just appeared in the prior trial (no-go condition; 30% of trials). Because there were very few no-go trials for each emotional expression, only data from the go trials are examined here.

Participants were seated at a 50 cm distance from the computer screen. The visual angle for the stimuli measured 8.6 degrees horizontally and 12.1 degrees vertically. Prior to beginning the task, children completed a practice block of 27 trials using neutral face stimuli. To obtain a sufficient number of no-go error trials for calculation of the error-related negativity (results reported in DuPuis et al., 2015), the stimulus presentation speed was individualized to target a no-go error rate between 40% and 60%, repeating the practice session while adjusting the presentation speed as needed.

During the task, each stimulus remained on the screen for between 400 and 900 ms, with the initial value depending on the child's performance on the practice trials. If the participant responded prior to the end of the pre-set stimulus duration, stimulus presentation was terminated at the time of the participant's response. Throughout the task, the stimulus duration was automatically adjusted up or down in 50 ms increments based on the subject's performance to target a no-go error rate between 40% and 60% (see Stieben et al., 2007, for details). Each go trial was followed by a blank screen for 900 ms before the next face stimulus appeared.

The stimuli consisted of computer-generated images of human faces displaying either a neutral or an emotional expression, balanced across gender (male, female) and race (black, white). The face stimuli were generated using FaceGen Modeller version 3.1 (Singular Inversions Inc., www.facegen.com). This program uses a data-driven statistical model based on 3D laser scans of faces (Banz & Vetter, 1999) and allows for the generation of novel faces. Expressions of emotions were controlled for intensity based on Facial Action Coding (Ekman & Friesen, 1978) using the muscular contractions composing standard emotions. The images generated in FaceGen Modeller were then manipulated using Adobe Photoshop

to control for stimulus features such as luminosity and contrast that may affect sensory processing. Each face was centered within a black oval template that conceals peripheral features and allows for increased focus on emotional information. Examples of the emotional face stimuli are provided in Figure 1. For the present analyses, the effect of the emotional expression was examined collapsing across gender and race.

The no-go condition was signaled by the repetition of the same stimulus (i.e., the same face with the same emotional expression) on immediately adjacent trials. The task instructions were made into an astronaut-themed game in order to capture children's interest. Children's engagement in the task was further incentivized by the opportunity to earn points that could be exchanged for a prize at the end of the task. During the task, children were provided with visual feedback approximately every 10 trials informing them of their progress in earning points. The task was administered in three equal-sized blocks, with the algorithm for awarding points differing across blocks [patterned after an affective go/no-go paradigm first reported by Lewis, Lamm, Segalowitz, Stieben, and Zelazo (2006) and Stieben et al. (2007)]. In the first and third block, the algorithm resulted in a rapid accumulation of points, whereas in the second block the algorithm resulted in a loss of points regardless of equivalent performance. In the present study, because the research question of interest was not related to the effects of the manipulation of reward context and in order to maximize the number of trials available for each emotional face condition, data were collapsed across all three task blocks. Children's mean response accuracy on go trials was 71% ($SD = 13\%$, range = 25% to 91%), and the mean response time was 487 ms ($SD = 66$, range = 313 ms to 668 ms).

EEG data acquisition: EEG was recorded using an extended 10–20 montage with a 32-channel elastic stretch BioSemi headcap with the Active Two BioSemi system (BioSemi, Amsterdam, Netherlands). Two additional electrodes were placed on the left and right mastoids, and four additional facial electrodes were used to measure eye movement. Vertical eye movements were measured from electrodes placed on the infra-orbital ridges centered under the pupils of both eyes and corresponding supra-orbital electrodes embedded within the cap. Horizontal eye movements were measured from electrodes placed approximately 1 cm outside the participants' right and left outer canthi. Data were recorded at 512 Hz with Actiview Software, v8.0.

EEG data post-processing: EEG data were post-processed using Brain Vision Analyzer 2.0. Voltages were re-referenced to the average of all electrode sites. EEG data were strongly affected by very low frequency power in the delta band, considered typical of young children and conceptualized as a marker of developmental immaturity (Somsen, van't Klooster, van der Molen, van Leeuwen, & Licht, 1997; Yordanova & Kolev, 2008). In order to reduce the impact of sub- and very low delta frequency noise, a 1 to 30 Hz Butterworth Zero Phase filter was employed (see, e.g., Lewis et al., 2006), as has been done in previously published studies of ERPs in the present sample (DuPuis et al., 2015; Gatzke-Kopp et al., 2015; Willner, Gatzke-Kopp, Bierman, Greenberg, & Segalowitz, 2015). The high-pass filter at 1 Hz also served to remove very slow wave drift that was present in the data.

Event-related potentials to angry, fearful, and neutral face go-trial stimuli were used for the present analyses. Each facial expression was presented on 48 go trials across the full task. Trials were segmented from -200 to 1000 ms relative to stimulus onset, separately for each emotional face condition, and voltages were baseline-corrected to the mean voltage during the 200 ms pre-stimulus period. Corrections were made for eye blink artifacts using the Gratton and Coles algorithm, as implemented by Brain Vision Analyzer 2.0 (Gratton, Coles, & Donchin, 1983). After this correction, trials with a voltage step of more than 100 μV between sampling points or a voltage reading outside the range of -75 μV to 75 μV were marked as artifactual and were excluded from the calculation of average voltages across trials. Average waveforms were calculated across all valid segments for each emotional face condition. ERP measures were recoded to missing if they were based on fewer than 10 valid segments. Following these procedures, there were an average of 40.6 segments ($SD = 6.7$, range = [13, 48]) for angry faces, 41.1 segments ($SD = 6.1$, range = [17, 48]) for fearful faces, and 41.0 segments ($SD = 6.0$, range = [21, 48]) for neutral faces. The number of valid segments for each emotional expression condition was not correlated with the severity of internalizing or externalizing symptoms (all $|r|$'s ≤ 0.06 , all p 's $> .415$). Even so, in order to adjust for effects of the number of individual segments on average ERP peak amplitudes (Luck, 2005), the number of segments was included as a covariate in analyses of all peak amplitude measures.

ERP peak measures: Peak amplitudes and latencies were calculated for the occipital P1, temporo-parietal N170, and parieto-occipital P2 ERP peaks. ERP peaks were identified based on visual inspection of the waveform, guided by previously-reported scalp locations and latencies for these peaks in children (e.g., Meaux et al., 2014; Thomas & Nelson, 1996; Tye et al., 2014). The grand-average ERP waveforms and scalp topographies across angry, fearful, and neutral face go-trial stimuli are presented in Figure 2.

All peaks were scored based on each child's average waveform for each emotional face condition by trained research assistants using a computer-assisted hand-scoring peak analysis program (Segalowitz, 1999). P1 amplitude and latency were measured at the peak of the first positive deflection at the occipital electrodes O1, Oz, and O2, occurring between 80 and 170 ms after stimulus onset. N170 amplitude and latency were measured at the peak of the first major negative deflection at the temporo-parietal electrodes P7 and P8, occurring between 130 and 340 ms after stimulus onset. P2 amplitude and latency were measured at the peak of the second positive deflection at the parieto-occipital electrodes PO3 and PO4, occurring between 216 and 453 ms after stimulus onset.

Analytic approach

Peak amplitude and latency measures were entered as dependent variables in separate linear mixed models using the MIXED procedure in SAS 9.4 with restricted maximum likelihood estimation. Maximum likelihood estimation uses all available data for each case, under the assumption that data are missing at random. Thus, cases were not excluded for missing data at a particular electrode site or for a particular emotion, allowing us to maximize the amount of information available to the model. Emotional expression (angry, fearful, or neutral) and electrode site (P1: O1, Oz, & O2; N170: P7 & P8; P2: PO3 & PO4) were modeled as within-

subjects repeated measures. Based on optimization of model information criteria for the baseline model [Akaike's Information Criterion (AIC; Akaike, 1974) and the Bayesian Information Criterion (BIC; Schwartz, 1978)], the site effect was modeled using an unstructured error covariance matrix and the emotion effect was modeled using a compound symmetry error covariance matrix for all outcomes except the N170 peak latency. For the N170 peak latency, both the emotion and site effects were modeled using an unstructured error covariance matrix, which minimized the AIC and BIC for this outcome measure. All models used the Kenward-Roger approximation of the denominator degrees of freedom (Kenward & Roger, 1997).

The analyses focused on associations of ERP measures with children's internalizing and externalizing symptoms. Children's internalizing and externalizing symptom scores were entered simultaneously as between-subjects continuous predictors in order to assess the unique association of each symptom dimension controlling for the other symptom dimension. Furthermore, the interaction between these symptom dimensions was examined to test for comorbidity effects. Symptom associations with emotional face processing biases (i.e., angry-neutral and fearful-neutral differences in ERP measures) were tested by interacting symptom scores with the emotional expression condition (angry, fearful, or neutral), with neutral as the comparison condition. Gender and age as of the EEG assessment were included as between-subjects covariates. For models predicting peak amplitude measures, the number of segments contributing to each child's averaged ERP for each emotional expression was entered as a covariate. Given the relatively wide range of response accuracy on go trials observed in this sample and the possibility that children with lower go-trial response accuracy may be paying less attention to the task, we examined whether including go-trial response accuracy as a covariate in all analyses influenced the results. The inclusion of this covariate did not substantively change the results.² Therefore, this covariate was not included in the final models.

Since our hypotheses focused on biases in the processing of angry or fearful versus neutral faces, effects for angry-neutral and fearful-neutral contrasts were examined regardless of the significance of the omnibus test of the emotion condition. A drawback of focusing on the *difference* between angry or fearful and neutral faces is that significant associations with symptoms could be driven by the "control" condition – in this case, neutral faces – rather than by the condition of interest – in this case, angry or fearful faces (Church, Petersen, & Schlaggar, 2010). To clarify the source of effects, where significant symptom associations were observed with the angry-neutral or fearful-neutral contrasts, post-hoc tests were conducted separately for the angry, fearful, and neutral face conditions to test whether these effects may be accounted for by differential processing of neutral faces as opposed to biases in the processing of the angry or fearful faces. These post-hoc models controlled for the same set of covariates that were included in the original models.

²The mean difference in the standardized regression coefficients for internalizing and externalizing symptoms predicting ERP measures, with and without go-trial response accuracy included in the model, was 0.0002 (SD = 0.0032, range = [-0.0064, 0.0116]). Only one *p*-value shifted across the traditional .05 threshold with the addition of this covariate. Specifically, the association of externalizing symptoms with P1 amplitudes (averaged across all emotional face conditions) shifted from $\beta = -0.13$, $p = .047$ to $\beta = -0.12$, $p = .058$.

Since ERP peaks reflect potentially interrelated processes in a continuous information-processing stream, it is possible that the amplitude or latency of a given ERP component could exert a “feed-forward” influence on ERP peak amplitudes and latencies reflecting later information-processing stages. For example, greater allocation of resources to a stimulus at the early attentional selection stage may also enhance the resources allocated to this stimulus in later processing stages. Therefore, to assess whether any significant symptom associations with emotional face processing biases in the N170 and P2 peaks may be partially accounted for by “feed-forward” effects from components reflecting earlier information-processing stages, analyses were conducted covarying earlier ERP component measures. These tests were conducted using linear mixed models with within-subjects repeated measures for hemisphere (left/right) and emotional expression (angry, fearful, or neutral). N170 amplitudes over left (P7) and right (P8) sites were predicted by ipsilateral P1 amplitudes (left: O1, right: O2). P2 amplitudes over left (PO3) and right (PO4) sites were predicted by ipsilateral P1 (left: O1, right: O2) and N170 (left: P7, right: P8) amplitudes. As in the original models, the number of segments contributing to the averaged ERP for each emotional expression, age, and gender were included as covariates, and the angry-neutral and fearful-neutral effects were estimated using model-based linear contrasts.

Results

Emotional expression effects on ERP peak amplitudes and latencies

Mean ERP peak amplitudes and latencies to each emotional expression, averaged across the full sample, are reported in Table 1. ERP waveforms for each emotional expression, and difference topographies for angry and fearful versus neutral expressions, are presented in Figure 3. A main effect of emotional expression was observed at the early P1 information processing stage: P1 peak amplitudes were smaller on average to both angry and fearful versus neutral faces (angry-neutral: $\beta = -0.07$, 95% CI = $[-0.13, -0.02]$, $p = .009$; fearful-neutral: $\beta = -0.08$, 95% CI = $[-0.13, -0.03]$, $p = .007$). Additionally, the P1 peak occurred later to angry versus neutral faces ($\beta = 0.09$, 95% CI = $[0.01, 0.18]$, $p = .028$). However, at subsequent information-processing stages, ERP amplitudes were *greater* to threatening versus neutral faces: N170 peak amplitudes were greater (more negative) to fearful versus neutral faces ($\beta = -0.07$, 95% CI = $[-0.13, 0.00]$, $p = .040$), and P2 peak amplitudes were greater to angry versus neutral faces ($\beta = 0.08$, 95% CI = $[0.00, 0.15]$, $p = .034$).

Symptom associations with average ERP peak amplitudes and latencies

The associations of internalizing and externalizing symptoms with ERP peak amplitudes and latencies averaged across the three emotional expression conditions are reported in Table 2. Note that all reported symptom associations are controlling for the other symptom dimension. In these models, greater externalizing symptoms were uniquely associated with smaller P1 amplitudes averaged across all emotional face conditions ($\beta = -0.13$, 95% CI = $[-0.25, 0.00]$, $p = .047$), suggesting a difference in early stimulus processing. Additionally, there was a significant interaction between internalizing and externalizing symptoms predicting average P1 latencies ($\beta = 0.11$, 95% CI = $[0.01, 0.20]$, $p = .030$; Figure 4). To probe this interaction, simple slope analyses were conducted for internalizing symptoms with externalizing symptoms held at ± 1 standard deviation from the mean. These analyses

revealed that greater internalizing symptoms were associated with earlier P1 latencies among children with low co-occurring externalizing symptoms ($\beta = -0.16$, 95% CI = $[-0.29, -0.04]$, $p = .010$), but not among children with high co-occurring externalizing symptoms ($\beta = 0.05$, 95% CI = $[-0.10, 0.20]$, $p = .531$). More specifically, a region of significance analysis (Preacher, Curran, & Bauer, 2006) revealed that greater internalizing symptoms were associated with a significantly earlier P1 peak latency only among children whose externalizing symptoms were at least 0.39 standard deviations below the sample mean.

Symptom associations with emotional expression processing biases

The associations of internalizing and externalizing symptoms with differences in the amplitudes and latencies of ERP peaks to threatening (angry or fearful) versus neutral faces are reported in Table 3. Again, internalizing and externalizing symptoms were entered simultaneously in each model such that all reported associations are controlling for the other symptom dimension. The analyses revealed symptom associations with face processing biases at all three information-processing stages (P1, N170, and P2).

At the P1 stage, greater internalizing symptoms were associated with greater P1 amplitudes to fearful versus neutral faces ($\beta = 0.06$, 95% CI = $[0.01, 0.12]$, $p = .025$). In contrast, externalizing symptoms were associated with *lower* P1 amplitudes to fearful versus neutral faces ($\beta = -0.06$, 95% CI = $[-0.11, 0.00]$, $p = .054$). Post-hoc tests were conducted examining symptom associations with neutral and fearful faces separately to test whether the associations with the fearful-neutral P1 amplitude difference may be driven by differential processing of neutral faces. These analyses indicated that the association of internalizing symptoms with greater P1 amplitudes to fearful versus neutral faces was driven primarily by a trend for enhanced amplitudes to fearful faces ($\beta = 0.12$, 95% CI = $[-0.02, 0.25]$, $p = .095$) rather than deriving from reduced amplitudes to neutral faces ($\beta = 0.04$, 95% CI = $[-0.09, 0.18]$, $p = .553$). Similarly, post-hoc tests indicated that the association of externalizing symptoms with *lower* P1 amplitudes to fearful versus neutral faces was driven by lower amplitudes to fearful faces ($\beta = -0.18$, 95% CI = $[-0.32, -0.04]$, $p = .011$) rather than deriving from enhanced amplitudes to neutral faces – in fact, there was a trend-level *negative* association between externalizing symptoms and P1 amplitudes to neutral faces ($\beta = -0.13$, 95% CI = $[-0.27, 0.01]$, $p = .062$).

At the N170 stage, internalizing symptoms were associated with significantly smaller (less negative) amplitudes to angry versus neutral faces ($\beta = -0.08$, 95% CI = $[-0.14, -0.01]$, $p = .024$; Table 3) and to fearful versus neutral faces ($\beta = -0.07$, 95% CI = $[-0.13, 0.00]$, $p = .053$). Post-hoc tests were conducted examining all three emotional expression conditions separately to test whether the associations of internalizing symptoms with the angry-neutral and fearful-neutral difference scores might be attributable to differential processing of neutral faces. The results revealed greater effect sizes for angry and fearful faces relative to neutral faces (angry: $\beta = -0.09$, 95% CI = $[-0.22, 0.03]$, $p = .155$; fearful: $\beta = -0.06$, 95% CI = $[-0.19, 0.06]$, $p = .302$; neutral: $\beta = 0.00$, 95% CI = $[-0.12, 0.13]$, $p = 0.953$), suggesting that the associations of internalizing symptoms with the difference scores cannot be attributed to differential processing of neutral faces. No associations were found between

externalizing symptoms and N170 amplitude differences to angry or fearful versus neutral faces.

At the P2 stage, internalizing symptoms were associated with greater amplitudes to fearful versus neutral faces ($\beta = 0.09$, 95% CI = [0.01, 0.16], $p = .026$). In contrast, externalizing symptoms were associated with *smaller* P2 amplitudes to fearful versus neutral faces ($\beta = -0.09$, 95% CI = [-0.17, -0.01], $p = .020$; Table 3). Again, post-hoc tests were conducted examining all three emotional expression conditions separately to test whether the associations might be attributable to differential processing of neutral faces. For internalizing symptoms, these tests revealed greater effect sizes for fearful faces relative to neutral faces (fearful: $\beta = 0.07$, 95% CI = [-0.08, 0.22], $p = .338$; neutral: $\beta = -0.02$, 95% CI = [-0.15, 0.11], $p = .782$), suggesting that the P2 difference-score associations with internalizing symptoms are not driven by differential processing of neutral faces. In contrast, for externalizing symptoms, the negative association with the fearful-neutral contrast appeared to be driven primarily by heightened P2 amplitudes to *neutral* faces ($\beta = 0.15$, 95% CI = [0.01, 0.29], $p = .031$) rather than by attenuated processing of fearful faces ($\beta = 0.09$, 95% CI = [-0.06, 0.24], $p = .224$).

There were no associations of symptoms with emotional expression processing biases in the *latencies* of ERP peaks. Additionally, comorbidity did not moderate any of the associations of symptoms with angry-neutral or fearful-neutral emotional expression processing biases.

Feed-forward effects from earlier ERP components

We tested the extent to which symptom associations with N170 and P2 peak amplitudes were accounted for by symptom associations with ERP components reflecting earlier stages of processing. Models in which symptoms were significantly associated with N170 or P2 peak measures were re-run covarying earlier ERP components, measured at the sites at which the peaks reflecting those components were maximal. First, the associations of internalizing symptoms with smaller N170 angry-neutral and fearful-neutral amplitude differences were tested controlling for P1 peak amplitudes at O1 and O2. With P1 amplitudes controlled, the associations of internalizing symptoms with the angry-neutral N170 amplitude difference ($\beta = -0.08$, 95% CI = [-0.14, -0.01], $p = .029$) and the fearful-neutral N170 amplitude difference ($\beta = -0.07$, 95% CI = [-0.14, 0.00], $p = .052$) both remained significant, suggesting that these findings cannot be fully accounted for by feed-forward effects from the earlier P1 component.

Second, the associations of both internalizing and externalizing symptoms with P2 fearful-neutral amplitude differences were tested covarying both P1 and N170 peak amplitudes. With both of these earlier peak amplitudes covaried, the association between internalizing symptoms and a greater fearful-neutral P2 amplitude difference became non-significant ($\beta = 0.06$, 95% CI = [-0.02, 0.13], $p = .143$) whereas the association between externalizing symptoms and a smaller fearful-neutral P2 amplitude difference was reduced but remained significant at the trend level ($\beta = -0.07$, 95% CI = [-0.15, 0.00], $p = .064$). Notably, the association between internalizing symptoms and the fearful-neutral P2 amplitude difference was primarily accounted for by amplitudes of the P1 rather than the N170 peak. With only the N170 peak covaried, the association of internalizing symptoms with P2 fearful-neutral

amplitudes remained significant ($\beta = 0.08$, 95% CI = [0.00, 0.16], $p = .045$), whereas when only the P1 peak was covaried, the association of internalizing symptoms with P2 fearful-neutral amplitudes was non-significant ($\beta = 0.06$, 95% CI = [-0.01, 0.14], $p = .104$). This suggests that the association of internalizing symptoms with larger P2 fearful-neutral amplitude differences may be at least partially a result of enhanced processing of fearful versus neutral faces at the earlier P1 stage.

Discussion

The present study examined the associations between children's social threat processing biases, as indexed by the amplitudes of early ERPs to threat-related versus neutral faces, and internalizing and externalizing symptoms in a sample of first-grade children from a low-SES community. Our findings demonstrate associations between children's symptoms and processing biases for threat-related faces within the first 400 ms of stimulus presentation. Internalizing symptom severity was associated with enhanced sensitivity at both early (P1) and later (P2) perceptual processing stages to fearful facial expressions, and reduced sensitivity of the face-sensitive N170 for threat-related expressions. Externalizing symptom severity was associated with attenuated P1 to fearful faces, and enhanced responses to neutral faces at the slightly later P2 stage of perceptual processing. Findings did not show differential threat processing biases with comorbid symptom presentations; however, children high on internalizing symptoms who were also low on externalizing symptoms were faster to process faces at early stages (P1 latency) regardless of the emotional expression.

Internalizing symptoms and emotional face processing

In the present study, higher internalizing symptoms were associated with larger P1 amplitudes to fearful versus neutral faces, suggesting heightened very early attentional selection of fearful faces. This finding is similar to that of a prior study with adults that demonstrated increased attentional processing of fearful faces at the P1 stage in high-anxiety individuals (Holmes et al., 2008). This result is also consistent with findings from numerous behavioral studies which have found enhanced attention biases to subliminally-presented threatening information in anxious adults (Bar-Haim et al., 2007).

Although ERP measures do not directly measure underlying neural source activity, amygdala damage has been associated with a reduction in P1 (but not N170) amplitude to fearful versus neutral faces (Rotshtein et al., 2010). A greater P1 amplitude to fearful faces in anxious individuals may index amygdala-mediated enhancement of the preconscious feedforward sweep of perceptual information to higher-order visual information-processing regions (Lamme & Roelfsema, 2000). Functional neuroimaging studies have provided evidence that greater trait anxiety is associated with greater amygdala activation to fearful faces in adults (Calder, Ewbank, & Passamonti, 2011; Etkin et al., 2004) as well as in children (Thomas et al., 2001). The present results build on these functional neuroimaging findings by providing evidence that this bias occurs at early, pre-conscious visual information-processing stages and is present by middle childhood in children from a low-SES community.

In the present study, the very early (P1) attention bias associated with internalizing symptoms was specific to fearful but not angry faces. We are not aware of prior studies of the P1 amplitude bias to fearful faces in child anxiety, and the literature on child anxiety associations with P1 amplitude biases to angry faces is mixed; one study found that youth with anxiety disorders aged 8–15 years showed greater P1 amplitudes to angry versus neutral faces in a dot-probe task (Bechor et al., 2018), but three other studies have failed to find an association of childhood anxiety with P1 amplitude bias to angry faces (Hum et al., 2013; Keil et al., 2018; Thai et al., 2016). Thus, the bulk of research fails to find P1 amplitude biases to angry faces in child anxiety. However, since these prior studies did not include fearful face stimuli, further research is required to confirm the differentiation between fearful and angry face processing observed in the present study.

Early biases in sensory processing may also influence a cascade of events affecting later stages of processing. Indeed, our results show that higher internalizing symptoms were also associated with heightened P2 amplitudes to fearful faces, indexing attentional enhancement to fear cues during slightly later information-processing stages. Furthermore, this enhanced processing of fearful faces at the P2 stage was accounted for by enhanced processing at the P1 stage. These analyses suggest that enhanced preconscious attentional selection at the P1 stage sweeps forward to enhance attention at later stages of processing.

In the present study, internalizing symptoms were also associated with a reduction in the N170 amplitude to angry and fearful versus neutral faces. Our findings are somewhat consistent with studies of social anxiety in adults which have noted reductions in the N170 or the M170 (the MEG equivalent of the N170) to faces in general (emotional and neutral) among those who are high on social anxiety (Mueller et al., 2009; Riwkes, Goldstein, & Gilboa-Schechtman, 2015; Wieser & Moscovitch, 2015), potentially indicating perceptual avoidance or more superficial processing of faces. However, other findings have indicated greater N170 amplitudes to angry and neutral faces in children with anxiety disorders (Bechor et al., 2018) and no association of the N170 to angry or neutral faces with anxiety in children aged 5–7 years (O'Toole et al., 2013) or in children aged 10–13 years (Keil et al., 2018).

In contrast to the findings for the P1 amplitude, N170 amplitude did not account for the association between internalizing symptoms and the subsequent P2 amplitude to fearful versus neutral faces. These results provide some support for the dissociable function of the N170 peak relative to the preceding P1 and the subsequent P2 peak. That is, both the P1 and P2 peaks are sensitive to emotion-biased attention allocation, whereas the N170 peak may be more strongly implicated in structural encoding (Eimer & Holmes, 2002, 2007).

Interestingly, a study with adults has demonstrated that a single independent component accounts for the majority of the scalp voltage variance in the P1 and P2 time periods, whereas a separate and unique component accounts for the variance in the N170 time period (Desjardins & Segalowitz, 2013). While this does not suggest that the P1 and P2 peaks are functionally identical, it does suggest that similar underlying cortical activity is contributing to these ERP peaks.

Externalizing symptoms and emotional face processing

Externalizing symptom severity was associated with *reduced* P1 amplitudes to faces regardless of emotional expression, suggesting that in general, the face stimuli captured less attention in children with greater externalizing symptoms during this early stage of processing. This finding is similar to that of a prior study which found that, among children diagnosed with ADHD, lower P1 amplitudes to face stimuli were associated with greater emotional lability regardless of the emotional expression of the face (Williams et al., 2008). However, since face stimuli were not contrasted with non-face stimuli in either of these studies, it is not clear whether this P1 amplitude blunting may be specific to face stimuli or whether it may reflect a more general blunting of attention to task-relevant stimuli.

Greater externalizing symptoms were also associated with greater blunting of P1 amplitudes to fearful versus neutral faces, suggesting that externalizing symptom severity in this low-SES sample is associated with a specific reduction in early attentional capture by social fear cues. Theoretically, lower P1 amplitudes to fearful faces may reflect reduced automatic recruitment of perceptual-attentional resources to processing these faces, potentially due to deficient activation of the amygdala to preconsciously-transmitted visual information conveying the threat content of the fearful face (Pourtois, Schettino, & Vuilleumier, 2013). Indeed, functional neuroimaging studies have observed that children and adolescents with high levels of callous-unemotional traits show lower amygdala activation to fearful faces, but not to angry or neutral faces (Jones, Laurens, Herba, Barker, & Viding, 2009; Marsh et al., 2008; White et al., 2012). Similarly, antisocial individuals have been shown to exhibit a particularly strong deficit in recognizing fearful facial expressions (Marsh & Blair, 2008). Given that fearful expressions are a signal of distress, individuals who are less responsive to others' fearful expressions are thought to be more likely to engage in antisocial behaviors because they do not perceive others' distress as personally aversive (Blair, 2003).

To our knowledge, this is the first study to examine the association between the posterior P2 amplitude to emotional faces and externalizing symptoms in children. The present study found that children with greater externalizing symptoms had blunted P2 amplitudes to fearful versus neutral faces and that this effect was driven primarily by heightened P2 amplitudes to *neutral* faces. There are two theoretical explanations that may account for this pattern. One possibility is that high-externalizing children allocate more attentional resources to processing neutral faces at the P2 stage due to a tendency to perceive these faces as ambiguous and potentially threatening – essentially, a hostile attribution bias (De Castro, Veerman, Koops, Bosch, & Monshouwer, 2002; Dodge & Crick, 1990). Since hostile attribution biases are hypothesized to operate during the interpretation of encoded social cues (Dodge & Crick, 1990), it stands to reason that these biases may only begin to emerge at the later P2 information-processing stage versus the earlier P1 and N170 stages. Another related explanation is that externalizing children may have emotion recognition deficits and may engage in more in-depth, sustained perceptual processing of the neutral faces in order to resolve their emotional ambiguity. Indeed, adolescents with early-onset conduct disorder (Fairchild, Van Goozen, Calder, Stollery, & Goodyer, 2009) and children with ADHD (Bora & Pantelis, 2016) have been shown to exhibit facial emotion recognition deficits across a variety of discrete emotions.

Fearful versus angry face processing

At the P1 and P2 stages of processing, significant relations were present for internalizing/externalizing symptoms and biases to fearful, but not angry faces. As discussed earlier, there are potential differences in processing anger (direct threat) and fear (indirect/ambiguous threat). The ambiguity of threat conveyed by fearful face stimuli may leave more room for individual differences associated with emotional-behavioral symptoms to emerge. Findings also indicate that there may be maturational differences in the processing of these emotions. For example, studies have demonstrated that the sensitivity to fearful faces precedes a more general bias to threat-related faces early in development (Leppänen, Cataldo, Enlow, & Nelson, 2018) and also the protracted development of sensitivity to angry expressions (extending beyond 10 years of age) (Gao & Maurer, 2010; Rodger, Vizioli, Ouyang, & Caldara, 2015). In the present study, children, on average, showed longer latencies to angry compared to neutral faces, indicating increased processing time for angry faces across the sample. Latencies of face-related components tend to decrease over childhood most likely reflecting maturation in the speed of stimulus processing (Batty & Taylor, 2006; Itier & Taylor, 2004a). It is possible that the lack of findings for symptom-related anger biases in the present study may be due in part to maturational factors that influence the timing of the sensitivity to threatening faces, such that our cohort was less sensitive to angry compared to fearful faces at their age of testing.

Comorbid internalizing-externalizing symptoms and emotional face processing

None of the ERP amplitude biases in the processing of threatening versus neutral faces were moderated by comorbidity of internalizing and externalizing symptoms. Thus, for example, the association of internalizing symptoms with heightened early and later attention to fearful faces held regardless of the level of co-occurring externalizing symptoms. In contrast, we did observe an interaction between internalizing and externalizing symptoms in predicting average P1 latencies to all faces. Specifically, greater internalizing symptoms were associated with a faster neural response to faces, but only among those children who also exhibited low externalizing symptoms. This suggests a distinction in processing speed between children with “pure” internalizing symptoms versus those with comorbid internalizing-externalizing symptoms in this low-SES sample. This speeded response to face stimuli among children with “pure” internalizing symptoms may reflect a hypervigilance to faces or to task-relevant stimuli in general.

Few prior studies have examined the issue of comorbidity of internalizing and externalizing symptoms in relation to ERP face processing biases. One prior study (Bunford et al., 2017) found that attenuated cognitive-elaborative processing of happy, but not angry or fearful, faces predicted rule-breaking among children with an anxiety disorder. However, this study did not examine emotional expression processing biases at the P1, N170, or P2 stages.

That the P1 latency effect observed here was only present for children with “pure” internalizing symptoms highlights the importance of considering the role of symptom comorbidity in social information-processing. Children exhibiting elevations on both internalizing and externalizing symptoms do not show speeded P1 peaks. This suggests either that (1) the presence of comorbid externalizing symptoms may counteract any

association between internalizing symptoms and faster P1 latencies, or (2) internalizing symptoms expressed comorbidly with externalizing symptoms may be of a different nature than “pure” internalizing symptoms, resulting in different associations with attentional vigilance as measured by P1 latency. Given the dearth of research, this topic warrants investigation in future studies.

The Role of Socioeconomic Status

When interpreting findings from the present study, it is important to note that the study sample was recruited from a low-income urban community. This is different from most samples used in psychophysiological research; thus, this paper makes an important contribution to the diversity of representation within psychophysiological research (Gatzke-Kopp, 2016). Children from low-SES families are more likely to be exposed to a variety of risk factors, such as parental stress, harsh or neglectful parenting, and violence in the community, that could influence social-emotional functioning (Bradley & Corwyn, 2002). For example, low perceived parental socioeconomic status has been linked to increased amygdala reactivity to threatening facial expressions in adults (Gianaros et al., 2008) and maltreatment has been shown to increase children’s sensitivity to social threat cues (Pollak, Klorman, Thatcher, & Cicchetti, 2001; Pollak, Messner, Kistler, & Cohn, 2009). Thus, it is possible that social threat processing biases may have been somewhat elevated in this sample relative to higher-SES community samples, which may have increased the variance in our ERP threat bias measures and thereby facilitated the detection of associations with emotional-behavioral symptoms. Further research would be required to assess the generalizability of the present findings to more socially advantaged samples.

Limitations

The design of the present study has several limitations that should be considered when interpreting the results. First, the cross-sectional analyses do not allow for the determination of causality. Thus, it is not clear whether the observed associations between children’s symptoms and their perceptual-attentional biases to threatening faces may reflect a causal role of these biases in symptom manifestation, or if these biases may be epiphenomenal to children’s symptoms.

Second, the recruitment strategy for the study sample was intended to maximize variance in aggressive and oppositional behaviors. Although remarkable variance was also observed in internalizing symptoms (due in part to the prevalence of externalizing-internalizing comorbidity), there was greater representation of severe externalizing than severe internalizing symptoms. It is possible that stronger associations between social threat processing biases and children’s internalizing symptoms may have been observed had the sampling strategy involved explicit over-selection for severe internalizing symptoms. Additionally, associations with externalizing symptoms may have been different had the sample been over-selected for a different facet of the externalizing spectrum – for example, elevated hyperactivity and inattention.

Third, it is possible that the reward manipulation in the task may have heightened feelings of frustration during the task and increased sensitivity to social threat cues. If so, it may have

increased our ability to demonstrate the associations that we report. The manipulation may have also influenced the processing of threat-related stimuli differentially for children with varying degrees of internalizing or externalizing symptoms. Unfortunately, we were unable to explore these effects due to the low trial numbers for each emotional face condition within each block.

Finally, the psychometric properties of the ERP threat biases examined in the present study have not been established. This is unfortunately a very common situation in psychophysiological research, and only relatively recently have psychophysiological scientists begun to systematically document the psychometric properties of ERP measures. Encouragingly, a recent investigation (Kappenman, Farrens, Luck, & Proudfit, 2014) has revealed at least moderate internal reliability for an ERP component called the N2pc elicited during a dot-probe task in young adults, whereas no internal reliability was observed for the behavioral measure of threat biases on this task, suggesting that ERP measures of threat biases may be more reliable than the commonly-used dot-probe behavioral measures. However, far more research needs to be conducted to establish the reliability of ERP measures of social threat processing biases, particularly in children.

Summary

The present study contributes substantially to the limited research base on neurophysiological indices of social threat processing biases and children's patterns of externalizing and internalizing symptoms. The results suggest that children with more severe externalizing symptoms exhibit reduced early attentional capture (P1) by faces in general and fearful faces in particular, and blunted differences in perceptual processing of fearful versus neutral faces at later stages of processing (P2) that are driven by heightened attention to neutral faces. This enhancement of attention to neutral faces may reflect hostile interpretation biases or less efficient processing of neutral expressions. In contrast, our results suggest that children with more severe internalizing symptoms exhibited greater attentional capture by fearful faces at both early (P1) and later (P2) stages of processing. Analyses suggested that the enhanced processing of fearful faces at the P2 stage was at least partially accounted for by feed-forward effects from biases at the P1 stage. Finally, when examining comorbidity of symptoms, internalizing children with low co-occurring externalizing symptoms processed all face types faster, as reflected by an earlier P1 peak latency, than those exhibiting greater co-occurring externalizing symptoms. This finding highlights the importance of considering the influence of internalizing-externalizing comorbidity on social threat processing.

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Highlights

- Internalizing symptoms correlate with greater P1 & P2 amplitudes to fearful faces
- Externalizing symptoms correlate with reduced P1 amplitudes to fearful faces
- Externalizing symptoms correlate with greater P2 amplitudes to neutral faces
- Symptom associations are evident within the first 100 ms of face processing
- These associations emerge virtually as soon as faces are registered in the cortex

Fig 1.

Examples of emotional face stimuli. The face stimuli were balanced across race and gender.

Fig 2. Grand-averaged ERP waveforms and scalp topographic maps across angry, fearful, and neutral faces. (a) P1 peak as measured at electrode sites O1, Oz, and O2, and scalp topographic map at 125 ms post-stimulus. (b) N170 peak as measured at electrode sites P7 and P8, and scalp topographic map at 200 ms post-stimulus. (c) P2 peak as measured at electrode sites PO3 and PO4, and scalp topographic map at 320 ms post-stimulus.

Fig 3.

ERP waveforms for angry, fearful, and neutral faces, and scalp topographic maps of the angry-neutral and fearful-neutral differences. (a) P1 peak averaged across electrode sites O1, Oz, and O2, and scalp topographic maps for the angry-neutral and fearful-neutral differences at 125 ms post-stimulus. (b) N170 peak averaged across electrode sites P7 and P8, and scalp topographic maps for the angry-neutral and fearful-neutral differences at 200 ms post-stimulus. (c) P2 peak averaged across electrode sites PO3 and PO4, and scalp topographic maps for the angry-neutral and fearful-neutral differences at 320 ms post-stimulus.

Fig 4.

Association of P1 mean latency with internalizing symptoms, by level of comorbid externalizing symptoms. Lines reflect simple-slope estimates from the linear mixed model, with externalizing symptoms held at -1, 0, or +1 standard deviation from the mean.

Table 1.

ERP peak amplitudes and latencies to angry, fearful, and neutral faces.

	Angry	Fearful	Neutral	Significant Differences ($p < .05$)
<u>Amplitude (μV)</u>				
P1	30.1 (0.5)	30.1 (0.5)	30.7 (0.5)	Angry, Fearful < Neutral
N170	-7.2 (0.3)	-7.3 (0.3)	-6.9 (0.3)	Fearful < Neutral
P2	12.3 (0.4)	12.2 (0.4)	11.8 (0.4)	Angry > Neutral
<u>Latency (ms)</u>				
P1	125.3 (0.5)	124.8 (0.5)	124.4 (0.5)	Angry > Neutral
N170	206.8 (1.1)	206.2 (1.2)	208.1 (1.3)	
P2	302.3 (2.5)	304.4 (2.5)	302.5 (2.5)	

Note. Mean amplitudes and latencies are reported with standard errors in parentheses. Amplitude values are adjusted for the number of segments contributing to the averaged ERP.

Table 2.

Internalizing and externalizing symptom associations with average ERP peak amplitudes and latencies.

	P1	N170^a	P2
<u>Amplitude (μV)</u>			
Step 1			
Internalizing	0.06 [−0.06, 0.19]	−0.05 [−0.16, 0.06]	0.07 [−0.04, 0.19]
Externalizing	−0.13 * [−0.25, 0.00]	−0.05 [−0.16, 0.07]	0.08 [−0.04, 0.20]
Step 2			
Int x Ext	0.06 [−0.06, 0.18]	−0.08 [−0.19, 0.02]	0.02 [−0.10, 0.13]
<u>Latency (ms)</u>			
Step 1			
Internalizing	−0.08 [−0.18, 0.02]	−0.05 [−0.15, 0.05]	0.04 [−0.06, 0.15]
Externalizing	0.04 [−0.06, 0.15]	0.01 [−0.09, 0.11]	−0.08 [−0.19, 0.03]
Step 2			
Int x Ext	0.11 * [0.01, 0.20]	0.08 [−0.02, 0.17]	−0.03 [−0.13, 0.08]

Note. Standardized regression coefficients are presented with 95% confidence intervals in brackets. All models control for electrode site, emotion condition, site x emotion condition, gender, and age. Models predicting amplitude measures also control for the number of segments contributing to the averaged ERP.

^aN170 amplitude values are multiplied by −1 so that a positive coefficient indicates an association with greater (more negative) peak amplitude.

* p .05

Table 3.

Angry-neutral and fearful-neutral ERP peak amplitude and latency differences: Associations with symptoms.

	P1			N170 ^a			P2	
	Angry - Neutral	Fearful - Neutral	Angry - Neutral	Angry - Neutral	Fearful - Neutral	Angry - Neutral	Fearful - Neutral	Fearful - Neutral
<u>Amplitude (μV)</u>								
Step 1								
Internalizing	0.04 [-0.02, 0.09]	0.06* [0.01, 0.12]	-0.08* [-0.14, -0.01]	-0.07* [-0.13, 0.00]	0.06 [-0.01, 0.14]	0.09* [0.01, 0.16]		
Externalizing	0.01 [-0.05, 0.07]	-0.06* [-0.11, 0.00]	0.01 [-0.06, 0.08]	0.04 [-0.03, 0.11]	-0.06 [-0.13, 0.02]	-0.09* [-0.17, -0.01]		
Step 2								
Int x Ext	-0.01 [-0.06, 0.05]	0.01 [-0.05, 0.06]	0.01 [-0.06, 0.08]	0.01 [-0.05, 0.08]	0.06 [-0.02, 0.13]	0.05 [-0.03, 0.12]		
<u>Latency (ms)</u>								
Step 1								
Internalizing	-0.07 [-0.16, 0.02]	-0.07 [-0.16, 0.02]	0.02 [-0.07, 0.12]	-0.04 [-0.14, 0.06]	0.04 [-0.08, 0.15]	0.02 [-0.10, 0.14]		
Externalizing	-0.01 [-0.09, 0.08]	0.02 [-0.07, 0.11]	0.08 [-0.01, 0.18]	0.02 [-0.08, 0.13]	-0.09 [-0.21, 0.03]	0.01 [-0.11, 0.13]		
Step 2								
Int x Ext	-0.03 [-0.11, 0.06]	0.01 [-0.07, 0.10]	-0.03 [-0.12, 0.06]	-0.07 [-0.17, 0.03]	-0.01 [-0.12, 0.10]	0.07 [-0.04, 0.19]		

Note. Standardized regression coefficients are presented with 95% confidence intervals in brackets. Estimates for the angry-neutral and fearful-neutral effects reflect model-based linear contrasts between these emotion conditions. All models control for electrode site, site x emotion condition, gender, gender x emotion condition, age, and age x emotion condition effects. Models predicting amplitude measures also control for the number of segment contributing to the averaged ERP.

^aN170 amplitude values are multiplied by -1 so that a positive coefficient indicates an association with greater (more negative) N170 amplitude to angry or fearful versus neutral faces.

* p .05