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Neural Reactivity to Emotional Stimuli in Children With and Without a History of Self-Injurious Thoughts and Behaviors

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ABSTRACT

Suicide is a significant public health concern and a leading cause of death for children in the United States. As such, there is a growing need to identify correlates of self-injurious thoughts and behaviors in youth, particularly potentially modifiable factors that could be targeted by interventions. One potential factor is neural reactivity to emotional stimuli. Prior research has suggested that the late positive potential (LPP), an event-related potential (ERP) component that indexes this reactivity, may be blunted in adults with a history of suicidality (i.e., ideation and/or suicidal behaviors). These findings have been interpreted in the context of cognitive models of risk, which focus on blunted reactivity to emotional stimuli broadly or to positive stimuli specifically (with perhaps heightened reactivity to negative stimuli). The goal of this study was to determine whether blunted patterns of neural reactivity toward emotional stimuli are observed in children with a history of self-injurious thoughts and behaviors (SITBs) and whether this may differ across emotional contexts (afraid, happy, sad) and intensities (low, medium, high). The study focused on 7-11-year-old children (50.51% girls, 62.63% non-Hispanic White) with ($n = 16$) and without ($n = 83$) a history of SITBs. LPP amplitudes were indexed during a Morphed Faces task, in which stimuli displaying a variety of emotional expressions (afraid, happy, and sad) were morphed to display low, medium, and high levels of each emotion. The strongest between-group difference was observed for medium-intensity positive emotional stimuli, with children with SITBs showing blunted responses. These findings provide some support for the positive attenuation hypothesis and suggest that blunted LPP response to ambiguous positive emotional stimuli may be useful as a marker of risk and potential target for intervention.

Suicide is a significant public health concern and a leading cause of death for children in the United States. As of 2022, the most recent data available, suicide was the 2nd leading cause of death for 10–14 year olds (Centers for Disease Control and Prevention 2024). Recent data has also suggested that rates of suicide attempts and suicidal ideation (SI) among children are increasing (Ayer et al. 2020). Findings suggest that 33% of individuals with a history of suicidal ideation (i.e., thoughts of ending one's own life) make a suicide plan and 29% make a suicide attempt (Nock et al. 2008). In addition, among youth with a history of nonsuicidal self-injury (NSSI), 70% have attempted suicide and 55% report multiple prior suicide attempts (Hargus, Hawton, and Rodham 2009; Nock et al. 2006). As a result, suicide prevention efforts have largely focused on identifying individuals who endorse self-injurious thoughts and behaviors (SITBs), including SI, NSSI, and prior suicide attempts (e.g., Ribeiro et al. 2016).

To inform these interventions, research is needed to identify factors associated with SITBs in children, particularly modifiable factors that could be potential targets for intervention. Maladaptive patterns of cognitive and neural reactivity to emotional stimuli have been proposed as one such risk factor. Currently, there are two models of how reactivity may be disrupted in at-risk individuals, both of which were initially generated to explain risk for depression, but which have more recently been applied to SITBs specifically. According to one model (see Rottenberg, Gross, and Gotlib 2005), at-risk individuals may exhibit dampened responses to positive stimuli (i.e., positive attenuation) and/or heightened neural responses to negative emotional stimuli (i.e., negative potentiation). According to a second model, the emotion context insensitivity (ECI) model, at-risk individuals may exhibit blunted responses to both positive and negative stimuli, reflecting an inability to alters one's responses based on contextual information (Rottenberg and Gotlib 2004).

One method of assessing neural responses to emotional stimuli is via event-related potentials (ERPs) indexed using electroencephalography (EEG). One commonly examined ERP component reflecting neural reactivity to emotional stimuli is the late positive potential (LPP). The LPP emerges approximately 300–400 ms after stimulus onset (Hajcak et al. 2012) and is maximal at occipito-parietal sites in youth (e.g., Burkhouse et al. 2019; DeCicco, Solomon, and Dennis 2012; Dennis and Hajcak 2009; Kujawa et al. 2012; Kujawa, Klein, and Hajcak 2012). LPP amplitude is associated with activity in brain regions associated with emotional processing, including the amygdala, ventrolateral prefrontal cortex, and cingulate cortex (Liu et al. 2012) and is larger in response to emotional than neutral stimuli (Hajcak et al. 2012).

As of yet, research evaluating links between SITBs and LPP responses to emotional stimuli has not extended to child samples. This said, there has been research in adult populations, though this has yielded mixed results (for a review, see Gallyer et al. 2021). For example, one study found smaller LPP responses to positive, but not negative, stimuli in adults with versus without a history of SI (Albanese et al. 2019). A second study found blunted LPP response to negative (threatening), but not positive, stimuli among psychiatric outpatients with a history of suicide attempts compared with individuals with a history of SI but no prior suicide attempt (Weinberg et al. 2017). A third study found smaller LPPs to both positive (rewarding) and negative (threatening) images in adults with versus without current SI, even after statistically controlling for current symptoms of depression (Weinberg et al. 2016). Therefore, although there is general support for blunted reactivity in individuals with current or past SITBs, whether this is valence-specific versus observed across emotional stimulus types remains unclear. In addition, it remains unclear whether patterns observed in children would be more consistent with positive attenuation models of risk, negative potentiation models, or emotion context insensitivity. This type of investigation is important because there could be developmental differences in markers of risk.

The goal of this study, therefore, was to evaluate neural reactivity to emotional cues, indexed via LPPs, in children with and without a history of SITBs. We chose to focus on children because this is a highly significant and understudied population and identifying potential markers of SITB risk in childhood may point the way toward interventions to reduce later risk of suicide attempts, which are known to increase dramatically in adolescence (e.g., Shain et al. 2016). In evaluating neural reactivity, we used a Morphed Faces task in which emotional stimuli (afraid, happy, and sad faces) are presented at a variety of intensity levels (i.e., low, medium, and high-intensity levels of each emotion). Given the lack of research in this area, we did not make specific predictions. However, the design of our task allowed us to determine whether differences in neural reactivity are observed broadly across emotion types, which would be consistent with the ECI model, versus being stronger for some stimuli than others, which may be more consistent with positive attenuation versus negative potentiation models. It also allowed us to address a potential limitation of prior research, which has focused almost exclusively on full-intensity emotional stimuli, leaving unanswered the question of whether processing biases may be observed for more ambiguous stimuli. This is important because some research has shown that individuals with SI may show greater sensitivity to milder stimuli (e.g., Wang et al. 2021).

1 | Method

1.1 | Participants

Participants included 103 children ages 7–11 recruited from the community and their caregivers. The only exclusion criterion was the presence of a learning or developmental disorder in the child that would make participation in the study difficult, per parent report. Prior to data analysis, we identified 4 multivariate outliers (2 with lifetime reports of SITBs, and 2 without) based on their LPP amplitudes during the Morphed Faces Task (low, medium, and high-intensity afraid, happy, and sad faces) (Mahalanobis distance $p < 0.001$), leaving 99 children for analysis.

The average age of the final sample was 9.64 years (SD = 1.46), and 50.51% were girls. Of the children, 17.17% were Hispanic and, in terms of race, 74.74% were White (62.63%), 12.12 were African American, 11.11% were multi-racial, and the remaining 2.02% were from another racial group. Of the children, 16 had a history of SITBs (8 with SI alone, 4 with NSSI alone, 4 with co-occurring SI and NSSI, and 1 with a prior suicide attempt who also had a history of SI and NSSI) and 83 children had no lifetime history of any SITBs.

1.2 | Measures

1.2.1 | Self-Injurious Thoughts and Behaviors

Children's histories of SITBs were assessed via parent and child reports during the Schedule for Affective Disorders and Schizophrenia—Present and Lifetime Version (K-SADS; Kaufman et al. 1997). During the interview, children and parents were separately asked, "Sometimes children who get upset or feel bad think about dying or even killing themselves. Have you [Has your child] ever had these types of thoughts?" If a child endorsed suicidal ideation, the interviewer asked follow-up questions to ensure the child was specifically endorsing thoughts of suicide and not thoughts of death more generally (i.e., considering doing something to kill themselves rather than only thinking they may be better off dead). Children rated as a 2 ("occasional thoughts of suicide") or as a 3 ("recurrent thoughts of suicide with or without thoughts of a specific method") on the K-SADS based on child or parent report were coded as having a history of SI. Reports of passive thoughts of death without active SI were not considered SI. As part of the K-SADS interview, children and parents were also asked about children's history of intentional self-injury, with NSSI defined as intentional self-injury without intent to die and a suicide attempt defined as intentional self-injury with at least some intent to die at that time. For all analyses, endorsement of past or current SI, NSSI, or a prior suicide attempt, based on parent or child report, were collapsed into a single dichotomous classification to indicate whether a child reported at least one form of self-injurious thought or behavior (SITB).

1.2.2 | Morphed Faces Task

Children also completed the Morphed Faces Task (cf. Burkhouse, Siegle, and Gibb 2014), during which they observed a standardized set of child actors (Egger et al. 2011) displaying a variety of emotional expressions (afraid, happy, sad, neutral). Stimuli, consisting of images of emotional and neutral faces from two male and two female actors, were morphed in 10% increments (e.g., 0% afraid, 100% neutral; 10% afraid, 90% neutral, etc.) to display low (10%, 20%, and 30%), medium (40%, 50%, 60%, and 70%), and high (80%, 90%, and 100%) levels of each emotion (see Figure 1). Each image was presented to the participant for 3 s in random order and across 2 blocks (132 trials total), and participants were instructed to indicate which emotion was being presented after viewing each image. Stimuli were presented semi-randomly to participants, with the only constraint that two pictures from the same actor could not be displayed consecutively. The inter-trial interval varied randomly between 500 and 750 ms. To provide

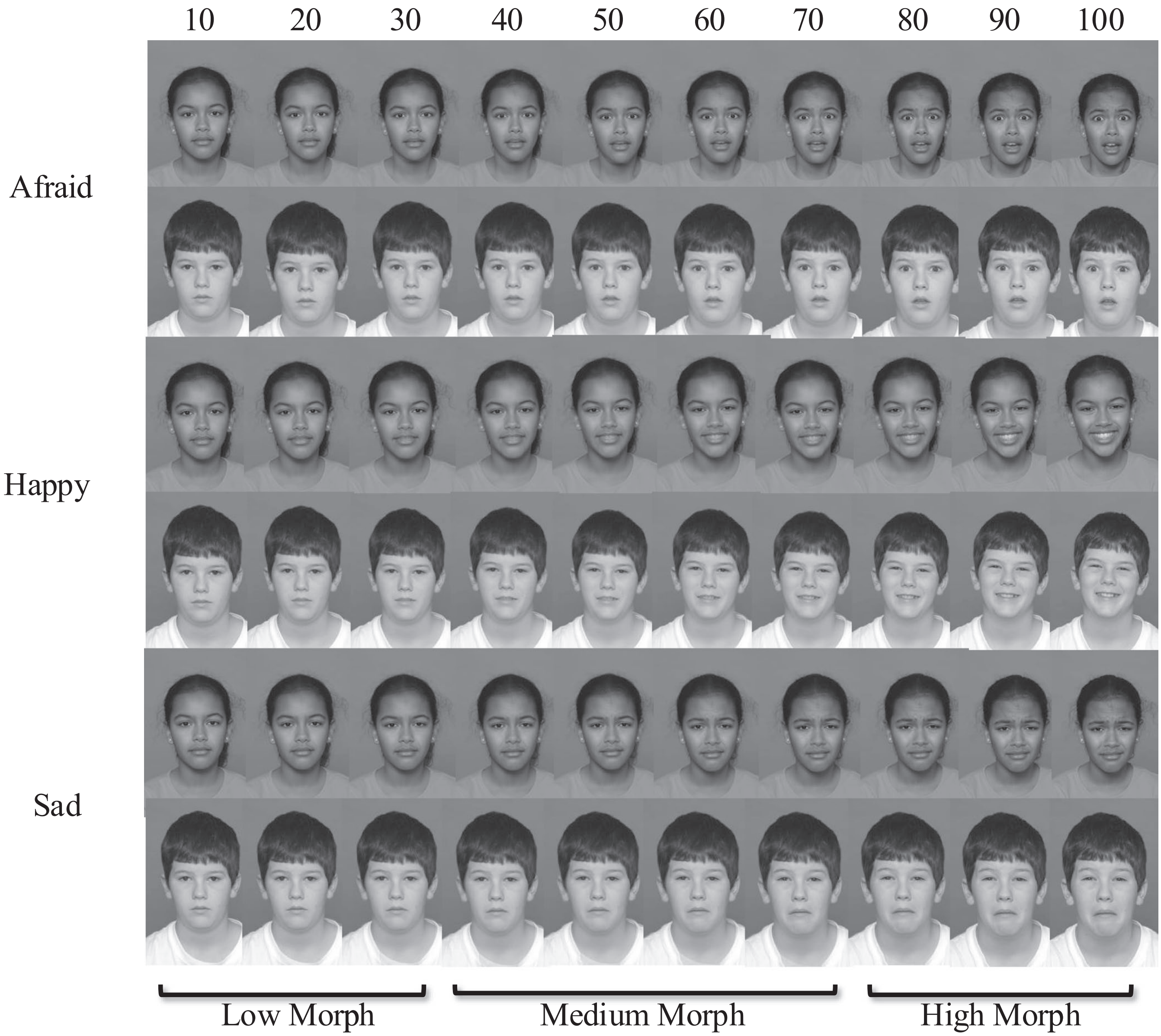

FIGURE 1 | Stimuli used in the Morphed Faces Task. Each emotion was represented by four children (two male, two female). Morphed images were created using emotional and neutral images of each child to represent a continuum of 10% increments between the two photographs.

enough trials for analysis, images were binned into low (10%, 20%, and 30%), medium (40%, 50%, 60%, and 70%), and high (80%, 90%, and 100%) levels of each emotion.

EEG was recorded during the task using a custom cap and the 32-channel BioSemi ActiveTwo system (Amsterdam, Netherlands). The EEG was digitized at 24-bit resolution with a sampling rate of 512 Hz. Recordings were taken from 34 scalp electrodes based on the 10/20 system. The electrooculogram was recorded from four facial electrodes. Offline analysis was performed using the MATLAB extension EEGLAB (Delorme and Makeig 2004) and the EEGLAB plug-in ERPLAB (Lopez-Calderon and Luck 2014). All data were re-referenced to the average of the left and right mastoid electrodes and bandpass-filtered with cutoffs of 0.1 and 30 Hz. EEG data were processed using both artifact rejection and correction. Large and stereotypical ocular components were identified and removed using independent component analysis (ICA) scalp maps (Jung et al. 2001). Artifact detection and rejection was then conducted on epoched uncorrected data to identify and remove trials containing blinks and large eye movements at the time of stimulus presentation. Epochs with large artifacts (> 100 lV) were excluded from analysis. The groups did not differ in the number of trials retained for analysis (SITB: $n = 213.88$; no SITB: $n = 206.51$), $t(97) = 0.76$, $p = 0.45$. The LPP was calculated as the mean activity 400–1000 ms following stimulus onset averaged across occipital (O1, O2, and Oz) and parietal (P3, P4, PO3, PO4, and Pz) electrodes for each emotion and morph level (see Figure 2). This is consistent with prior research from our lab and others showing that the LPP is maximal at occipital and parietal sites in children (e.g., Burkhouse et al. 2019; DeCicco, Solomon, and Dennis 2012; Dennis and Hajcak 2009; Kujawa et al. 2012; Kujawa, Klein, and Hajcak 2012).

1.2.3 | Symptoms and Diagnoses of Depression and Anxiety

To characterize the sample, we also assessed children's current symptoms of depression and anxiety. Children's symptoms of depression were assessed with the Children's Depression Inventory (CDI; Kovacs 1981) and symptoms of anxiety were assessed using the Multidimensional Anxiety Scale for Children (MASC; March et al. 1997). Both scales have demonstrated strong psychometric properties in previous research (e.g., Smucker et al. 1986; March et al. 1997). In the current study, the CDI and MASC exhibited adequate internal consistency (αs = 0.75 and 0.87, respectively). Rates of MDD and anxiety disorders in the sample were assessed as part of the K-SADS interviews. Of the children, 4 had a lifetime history of major depressive disorder (MDD) and 6 had a lifetime history of an anxiety disorder (generalized anxiety disorder: $n = 1$, obsessive-compulsive disorder: $n = 1$, posttraumatic stress disorder: $n = 2$, separation anxiety disorder: $n = 1$, social anxiety disorder: $n = 1$).

1.3 | Procedure

Potential participants were recruited from the community through a variety of means (e.g., television, bus ads, flyers, and newspapers). Upon arrival at the laboratory, parents provided consent and children provided assent to participate in the study. Following this, an interviewer administered the K-SADS to the parent and then to the child. Children and parents each completed questionnaires assessing demographic information, and children completed measures assessing symptoms of depression and anxiety. Children also completed the Morphed Faces Task (described above) while EEG was recorded. Families were compensated monetarily for their participation in the study. All study procedures were approved by the Institutional Review Board at Binghamton University.

1.4 | Analytic Plan

To examine patterns of neural reactivity to facial displays of emotion in children with and without a history of SITBs, we used a 2 (Lifetime SITBs: yes, no) × 3 (Emotion: afraid, happy, sad) × 3 (Morph Level: low, medium, high) repeated measures ANOVA with LPP amplitude serving as the dependent variable.[1] Significant interactions were probed to determine the pattern of the effect. We then conducted a separate series of analyses to examine the impact of SITB history on children's behavioral sensitivity to facial displays of emotion in the Morphed Faces Task.

2 | Results

Descriptive characteristics of the two groups are presented in Table 1. As can be seen in the table, children with and without a history of SITBs did not differ significantly on any of the demographic or clinical characteristics examined, although there were nonsignificant trends for children with a history of SITBs to be more likely to be from a racial/ethnic minority group and have a lifetime history of MDD. Next, we tested our primary hypotheses. The full results of this analysis are presented in Table 2. Of particular interest, the SITB × emotion × morph level interaction was significant, $F(4, 388) = 2.60$, $p = 0.04$, $\eta_p^2 = 0.03$. To determine the form of this interaction, post hoc tests examined the SITB × emotion interaction separately for each morph level. The SITB × emotion interaction was significant for medium intensity, $F(2, 194) = 3.30$, $p = 0.04$, $\eta_p^2 = 0.03$, but not low, $F(2, 194) = 0.47$, $p = 0.63$, $\eta_p^2 = 0.01$, or high, $F(2, 194) = 0.87$, $p = 0.42$, $\eta_p^2 = 0.01$, intensity stimuli. For high, $F(1, 97) = 2.80$, $p = 0.097$, $\eta_p^2 = 0.03$, but not low, $F(1, 97) = 0.44$, $p = 0.51$, $\eta_p^2 = 0.005$, or medium, $F(1, 97) = 1.00$, $p = 0.32$, $\eta_p^2 = 0.01$, morph levels there was a nonsignificant trend for the SITB main effect, with children with a history of SITBs exhibiting a somewhat smaller LPP ($M = 10.37$, SE = 1.52) across emotions than children with no SITB history ($M = 13.15$, SE = 0.67).[2] Examining the form of the significant SITB × emotion interaction for medium-intensity facial stimuli, we found that children with a history of SITBs, compared to children without, displayed a significantly smaller LPP for happy faces, $t(97) = -2.02$, $p = 0.047$, Cohen's $d = -0.55$, but not afraid, $t(97) = -1.16$, $p = 0.25$, Cohen's $d = -0.32$, or sad, $t(97) = 0.66$, $p = 0.51$, Cohen's $d = 0.18$, faces. The group difference for medium-intensity happy faces is depicted in Figure 3.

Although we were primarily interested in children's neural reactivity to the facial stimuli, we also examined whether children's SITB history was related to their behavioral responses during the Morphed Faces Task (i.e., the proportion of trials in which children correctly indicated which emotion was being depicted) to determine whether LPP

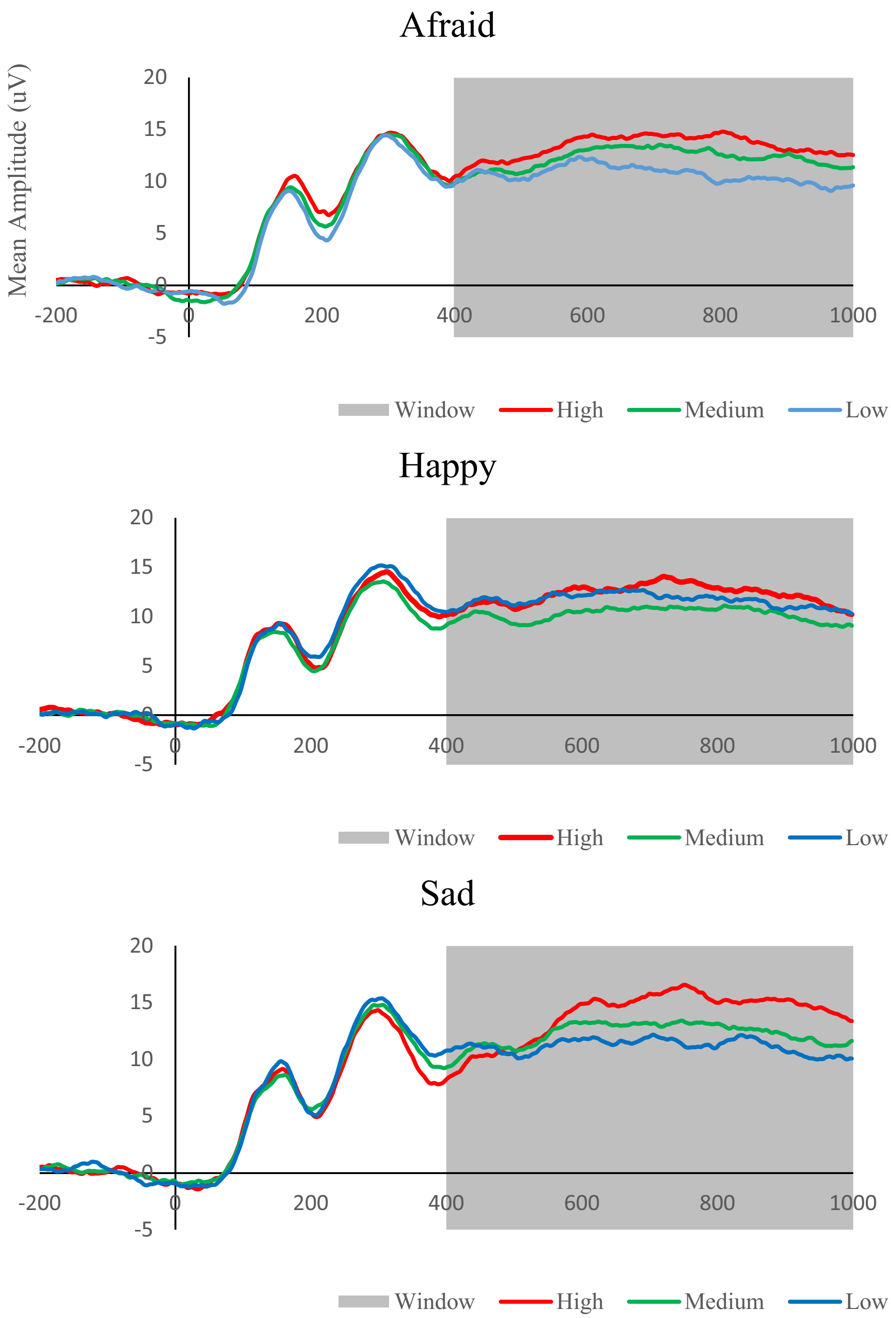

FIGURE 2 | Waveforms depicting the late positive potential 400–1000 ms following onset of each stimulus type for all participants, averaged across occipital (O1, O2, and Oz) and parietal (P3, P4, PO3, PO4, and Pz) electrodes.

differences were due to differences in children's basic ability to recognize the facial expressions. The main effect of SITB group was not significant, $F(1, 85) = 1.08$, $p = 0.30$, $\eta_p^2 = 0.01$, though there were significant main effects of emotion, $F(2, 170) = 4.35$, $p = 0.014$, $\eta_p^2 = 0.05$, and morph level, $F(2, 170) = 946.83$, $p < 0.001$, $\eta_p^2 = 0.92$. These main effects were modified by a significant emotion × morph interaction, $F(4, 340) = 5.71$, $p < 0.001$, $\eta_p^2 = 0.06$. Examining the form of this interaction, the main effect of emotion type was not no significant at low, $F(2, 170) = 0.35$, $p = 0.71$, $\eta_p^2 = 0.004$, or high, $F(2, 170) = 0.16$, $p = 0.852$, $\eta_p^2 = 0.002$, morph levels, with all children exhibiting similar accuracy levels for all three emotions. However, there was a significant emotion difference at medium-morph levels, $F(2, 170) = 19.92$, $p < 0.001$, $\eta_p^2 = 0.19$, such that children were most accurate at identifying medium-intensity afraid faces ($M = 0.96$, SE = 0.01), followed by happy ($M = 0.91$, SE = 0.01), and then sad ($M = 0.84$, SE = 0.02) faces (all $ps < 0.01$). However, there was no evidence for moderation of any of these effects by children's SITB history (all $ps > 0.05$), indicating that the two groups in the study did not differ significantly in their ability to correctly identify emotions, presented at any valence or morph level, in the behavioral task.

3 | Discussion

The present study examined the association between children's lifetime histories of self-injurious thoughts and behaviors and

TABLE 1 | Demographic information and child psychopathology measures.

	Children with SITBs	Children without SITBs	t/χ^2	*p*
Age	9.43 (1.56)	9.68 (1.45)	−0.63	0.53
Gender (% girls)	56.25	49.40	0.25	0.62
Race/ethnicity (% non-Hispanic White)	43.75	67.47	3.26	0.07
CDI	2.41 (0.85)	2.04 (0.96)	1.47	0.15
MASC	6.89 (1.53)	6.54 (1.16)	1.03	0.31
Lifetime MDD (% yes)	12.50	2.41	3.52	0.06
Lifetime anxiety disorder (% yes)	12.50	4.82	1.39	0.24

Note: Unless otherwise noted, values represent means (and standard deviations).
Abbreviations: CDI, Children's Depression Inventory; MASC, Multidimensional Anxiety Scale for Children; MDD, major depressive disorder; SITBs, Self-Injurious Thoughts and Behaviors.

TABLE 2 | Summary of the Mixed Effects ANOVA Analyses.

Predictor	*F*	df	*p*	η_p^2
SITB	1.48	1, 97	0.23	0.02
Emotion	2.16	2, 194	0.12	0.02
Morph	2.18	2, 194	0.12	0.02
SITB × Emotion	0.15	2, 194	0.86	0.02
SITB × Morph	0.97	2, 194	0.38	0.01
Emotion × Morph	3.16	4, 388	0.01	0.03
SITB × Emotion × Morph	2.6	4, 388	0.04	0.03

Note: η_p^2 = partial eta-squared.
Abbreviation: SITB = self-injurious thoughts and behaviors.

their neural responses to emotional stimuli. Although there was some support for the emotion context insensitivity hypothesis when focused on high-intensity emotional stimuli, group differences were strongest for positive stimuli, specifically medium-intensity positive stimuli. Consistent with the positive attenuation hypothesis and with findings in depressed individuals (Weinberg et al. 2016), children with a history of SITBs displayed a significantly smaller LPP responses to ambiguous (i.e., medium intensity) positive emotional stimuli than children without a history of SITBs. Importantly, the two groups of children did not differ in current levels of depressive or anxiety symptoms, suggesting that these altered neural responses to emotion are at least partially independent of children's current symptoms. Further, findings from children's behavioral responses suggest that children do not display a difficulty correctly identifying emotional expressions (i.e., the presence of an interpretation bias), but rather a neural sensitivity to emotional stimuli.

These findings suggest that there may be a pattern of disengagement from, or blunting to, more ambiguous positive stimuli (i.e., discounting the positive) present in individuals who are experiencing or have previously experienced SITBs. This is consistent with prior research highlighting the role of anhedonia in risk for SITBs in youth (for a review, see Auerbach, Pagliaccio, and Kirshenbaum 2022). Specifically, youth with a history of SITBs appear less responsive to mild positive stimuli, though they largely retain their response to high-intensity positive stimuli. Future research is needed to determine whether blunted neural responses to moderate intensity positive stimuli can help to identify youth at risk for SITBs in the future (either first onsets or recurrences). If so, then interventions designed specifically to target, and restore, reactivity to positive stimuli in the environment—such as Positive Affect Treatment (Craske et al. 2023) or the Family Promoting Positive Emotions intervention (Burkhouse et al. 2023)—may be particularly effective at reducing future risk.

The study exhibited a number of notable strengths, including the focus on a potential neural marker of risk in a clinically significant but understudied population—children with a history of SITBs. However, there were limitations as well, which highlight important areas of future search. First, as mentioned above, the

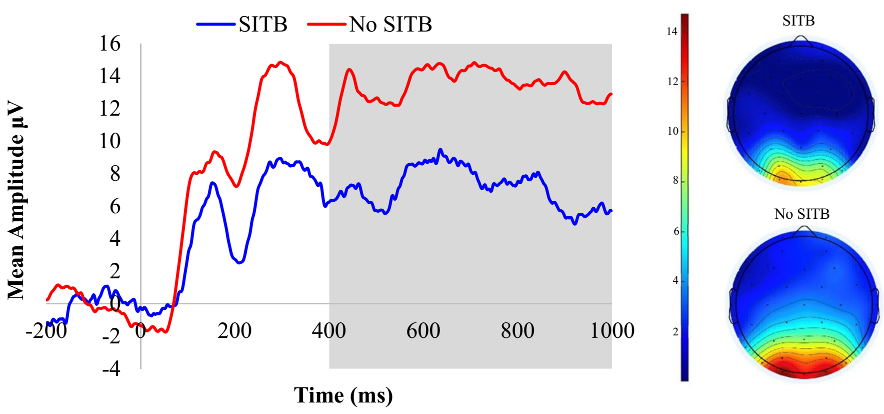

FIGURE 3 | Waveforms and scalp topographies depicting the late positive potential 400–1000 ms following onset of medium-morph happy faces, averaged across occipital (O1, O2, and Oz) and parietal (P3, P4, PO3, PO4, and Pz) electrodes, in children with and without a history of self-injurious thoughts and behaviors.

cross-sectional design does not allow us to determine whether blunted LPP responses to ambiguous positive emotional stimuli represent a risk factor for future SITBs in children. Second, the use of a community sample, while beneficial in helping to generalize findings to broader groups of children, resulted in relatively low rates of SITBs. Therefore, replication in additional, ideally larger, samples is needed. In addition, because of this, we examined dichotomous classifications of children's histories of any SITBs and were not able to look at more continuous levels of SITBs as a whole or for each form of SITB individually. Given evidence that different forms of SITBs may be associated with unique risk profiles among youth (e.g., Castellví et al. 2017), researchers have suggested that each form be examined separately to allow for greater nuance and specificity in the findings and to allow for the examination of potential additive or multiplicative associations with comorbid forms of SITBs (e.g., Scott et al. 2015).

Overall, the current results offer some support for the hypothesis that SITBs in children are associated with blunted neural responses to positive stimuli, particularly milder or more ambiguous positive stimuli. As such, they provide stronger support for models of risk focusing on blunted responses to positive stimuli rather than blunted responses to all stimuli regardless of valence. Future research, incorporating prospective methodologies, is needed to determine whether blunted LPP responses toward mild or ambiguous positive emotional stimuli represent a true risk factor for future SITBs and, if so, whether focused interventions targeting these blunted responses reduce risk for future SITBs in youth.

Author Contributions

Pooja Shankar: conceptualization, formal analysis, writing – original draft. **Brandon E. Gibb:** conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing – review and editing.

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Ethics Statement

The authors confirm that we have obtained written consent and/or assent from each subject.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Research data are not shared.

Endnotes

[1] Based on a power analysis, our sample size provided adequate power (0.80) to detect partial eta-squared (η_p^2) values of 0.013 or greater.

[2] For interested readers, the waveforms and scalp maps for this effect are presented in Figure S1.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.