Psychophysiological and Neural Support for Enhanced Emotional Reactivity in Female Adolescents With Nonsuicidal Self-injury

Leah M. Mayo, Irene Perini, Per A. Gustafsson, J. Paul Hamilton, Robin Kämpe, Markus Heilig, and Maria Zetterqvist

ABSTRACT

BACKGROUND: Nonsuicidal self-injury (NSSI) is prevalent in adolescent populations worldwide. Emotion dysregulation is believed to contribute to NSSI, but underlying mechanisms are less known. We combined psychophysiological and neural data with subjective self-report in close temporal proximity to examine the mechanisms underlying emotion processing in adolescents with NSSI relative to control adolescents without a psychiatric diagnosis.

METHODS: Thirty female adolescents with NSSI and 30 age-matched female control subjects were included in this case-control study. Participants were presented with negative affective pictures during a functional magnetic resonance imaging scan. In a separate facial electromyography session, the same participants were shown positive and negative affective images and also provided ratings of valence and arousal.

RESULTS: Participants with NSSI responded to affective images with greater positive (e.g., zygomatic) and greater negative (e.g., corrugator) reactivity. We found no differences in self-reported affect in response to the images. Analyses of the negative picture-viewing functional magnetic resonance imaging data showed a significant positive correlation between anterior insula response and the averaged electromyography magnitude in NSSI, but not in control subjects.

CONCLUSIONS: Adolescents with NSSI show enhanced emotional reactivity that is associated with anterior insula responding, but no abnormalities in self-reported affect. This discrepancy between self-report and objective measures of emotional reactivity potentially indicates a suppression of the emotional reaction in adolescents with NSSI. Moreover, the current data suggest potential targets for novel therapeutic approaches that can be combined with existing clinical treatment, such as real-time electromyography-based biofeedback focusing on emotional awareness, labeling, and expressing emotional experiences.

https://doi.org/10.1016/j.bpsc.2020.11.004

Nonsuicidal self-injury (NSSI) includes behaviors performed intentionally to harm oneself, such as cutting, burning, or scratching skin, without suicidal intent. NSSI is a significant mental health issue in adolescence (1,2) that, even after cessation of the behavior, can have lasting effects into adulthood, such as higher levels of anxiety and depression (3). Our understanding of NSSI has greatly improved over the last 10 to 15 years (4). There is consensus that NSSI is associated with impairments in emotion regulation and may serve as an attempt to regulate emotion (5–7). Self-report and ecological momentary assessment data indicate emotion dysregulation in NSSI patients, suggesting that NSSI is typically preceded by negative emotions and cognitions and that the act of NSSI may help to regulate distressing emotional experiences (8–11). Modern treatments therefore focus on increasing emotion regulation skills, which includes identifying, labeling, and accepting emotions, as opposed to using avoidance or suppression strategies (12).

Rates of NSSI increase during adolescence and decline toward adulthood (3,13). Developmental changes occur in the brain during childhood and adolescence, driven largely by activity of subcortical regions and subsequent interactions with prefrontal cortical areas. Emotional experiences and environmental influences can significantly alter the developmental trajectory of these regions, potentially contributing to difficulties in emotion processing and regulation later in life (14). Research on the neurobiology of NSSI in adolescents is only now emerging, but initial reports suggest that this population may indeed exhibit dysregulation of amygdala and prefrontal connectivity (15). For instance, previous functional magnetic resonance imaging (fMRI) pilot studies on NSSI and emotion regulation have shown altered activation in the amygdala, cingulate cortex, dorsolateral prefrontal cortex, and orbitofrontal cortex (16,17).

A core aspect of emotion dysregulation is emotional reactivity, which can refer to the threshold of the reaction, the...
strength of the emotional response, and the duration of the response (18). A low threshold for emotional reaction, high emotional intensity, and a long period to recover from peak back to baseline, for example, would make dealing with emotions more challenging. However, studies assessing potential emotional overreactivity in individuals with NSSI have shown incongruent results. Retrospective self-report studies have found strong evidence for increased emotion reactivity in NSSI; studies applying experimental, physiological, and longitudinal approaches, however, have reported weaker findings (19). The retrospective self-report findings show that individuals with NSSI rate their own reactivity to emotional events as higher than that of control subjects (20). In experimental contexts, results are less clear, with reports of NSSI patients showing greater (21) or no difference (22) in subjective and physiological stress reactivity. These inconsistencies indicate that more research on emotional reactivity using objective measures in NSSI is needed.

In addition to self-report and neural measures, affective reactivity also can be measured using psychophysiology. In particular, facial electromyography (EMG) of the corrugator (“frown”) and zygomatic (“smile”) muscles is proposed to assess the internal affective state of an individual (23) and can detect changes in affective processing that may not be accessible solely by self-report (24,25). Thus, the aim of this study was to use a multidimensional approach to assess objective and subjective measures of emotional reactivity in adolescent NSSI patients compared with matched controls. Based on previous literature (15,21), we expected NSSI patients to display a negative affect bias, indicated by greater neural and psychophysiological reactivity to negative stimuli, as well as self-reported impairments in affect regulation (7). By combining self-report, psychophysiological (e.g., facial EMG) indices, and neural indices of emotion processing, we aimed to gain a mechanistic insight into emotion regulation and thus identify potential treatment targets for NSSI patients.

**METHODS AND MATERIALS**

**Participants**

Thirty patients (mean age = 15.9 years, SD = 0.8) were recruited from the Child and Adolescent Psychiatric Clinic at Linköping University Hospital, Sweden. Thirty control subjects (mean age = 16.4 years, SD = 0.9) were recruited through advertisements in schools and on Facebook. Participants completed two sessions on separate days in a counterbalanced order. In one session, self-report and facial EMG was assessed; the other session consisted of fMRI scanning. All participants were accompanied to the sessions by the same clinician that had provided their initial diagnosis. All procedures were approved by the Regional Ethical Board of Linköping (Dnr 2015/273-31; 2016/224-32).

Inclusion criteria for the patients were NSSI, independent of psychiatric diagnosis (i.e., regardless of depression or anxiety diagnosis); being a female between 15 and 18 years of age; and having engaged in 5 or more instances of NSSI during the last 6 months. Exclusion criteria were current or lifetime diagnosis of schizophrenia, bipolar or psychotic disorder, or alcohol or drug dependence, and IQ below 80. Control subjects were included if they had no DSM Axis I or II disorder during the last year and no lifetime presence of NSSI. Patients taking psychotropic medications were included provided that these were ongoing and unchanged for at least 3 months. Written informed consent was obtained from all participants (and parents, if the participant was younger than 18 years of age). Clinical recruitment occurred from June 2016 to March 2018. Additional information is presented in Table 1. Participants have been described in an earlier paper by our research group (26).

At a screening session, retrospective self-report measures assessed perceived difficulties with emotion regulation (Difficulties with Emotion Regulation Scale [DERS]) (27) and alexithymia (Toronto Alexithymia Scale [TAS-20]) (28). Alexithymia refers to a person’s difficulty in identifying or verbally describing his or her feelings. Extensive clinical characteristics were obtained via clinical assessments described in detail in the Supplement and Table 1. Assessments were performed by the last author, a clinical psychologist with extensive experience in psychiatric assessment, together with the third author, an experienced child psychiatrist. Final psychiatric diagnoses for the clinical sample were based on all available information from diagnostic interviews and medical records, using DSM-5.

**Analysis**

Independent t tests and Pearson \( \chi^2 \) tests were used to detect possible differences between groups on demographic and clinical variables. Significant differences in demographic factors were included as covariates in subsequent analysis.

**Facial EMG**

**Data Acquisition.** Facial EMG of the corrugator (“frown”) and zygomatic (“smile”) muscles were assessed as previously described (29). Participants were outfitted with facial EMG sensors over the zygomatic and corrugator muscles, consisting of bipolar recording pairs of 4-mm silver/silver chloride electrodes filled with gel placed on muscles on the left side of the face with an 8-mm ground electrode placed on the forehead near the hairline (30). Sites were cleaned, and any site with impedance over 20 kΩ was reapplied. EMG signals were amplified, filtered through a 10–500 Hz bandpass and 50 Hz comb bandstop filter, digitized at 1 kHz, refiltered, rectified, and integrated over 20 ms using EMG100C amplifiers, the MP150 Data Acquisition system, and Acqknowledge software from Biopac Systems (Biopac Systems, Inc, Camino Goleta, CA).

**Affective Image Task.** The affective image task was used as previously described (29) and detailed in the Supplement. Briefly, affective images were selected from the International Affective Picture System (IAPS) (31) with the addition of NSSI-related images. NSSI images included pictures of razor blades, bandages around wrists, and images of cutting oneself (32). The task contained 16 images of each category (positive, neutral, negative, NSSI). Facial EMG recordings of the zygomatic and corrugator were collected throughout. Responses were quantified as the mean EMG amplitude during the 6-second picture presentation compared with the immediately preceding 1-second baseline and were averaged across stimulus category. Trials with excessive baseline activity or
### Table 1. Demographic and Clinical Characteristics

<table>
<thead>
<tr>
<th></th>
<th>NSSI Patients</th>
<th>Control Participants</th>
<th>Significance Values and Effect Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 30)</td>
<td>(n = 30)</td>
<td></td>
</tr>
<tr>
<td>Demographics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex, female</td>
<td>30 (100%)</td>
<td>30 (100%)</td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>15.9 (0.79)</td>
<td>16.4 (1.00)</td>
<td>( p = .049; \text{Cohen's } d = 0.55 )</td>
</tr>
<tr>
<td>IQ</td>
<td>96.6 (9.83)</td>
<td>101 (10.9)</td>
<td></td>
</tr>
<tr>
<td>Parental education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University/college</td>
<td>23 (41.8%)</td>
<td>32 (60.4%)</td>
<td></td>
</tr>
<tr>
<td>Theoretical high-school program</td>
<td>5 (9.10%)</td>
<td>6 (11.3%)</td>
<td></td>
</tr>
<tr>
<td>Vocational high-school program</td>
<td>23 (41.8%)</td>
<td>13 (24.5%)</td>
<td></td>
</tr>
<tr>
<td>Compulsory school</td>
<td>4 (7.3%)</td>
<td>2 (3.80%)</td>
<td></td>
</tr>
<tr>
<td>Clinical Presentation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depressive symptoms (CDRS-R)</td>
<td>45.7 (13.36)</td>
<td>22.2 (4.95)</td>
<td>( p &lt; .001; \text{Cohen's } d = 2.33 )</td>
</tr>
<tr>
<td>DSM-5 NSSI disorder diagnosis</td>
<td>18.0 (62.1%)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Age at NSSI onset</td>
<td>13.2 (1.25)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Number of NSSI methods</td>
<td>3.8 (2.13)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>NSSI 12-month frequency, mean (SD) median</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutting</td>
<td>54.6 (55.7)</td>
<td>30.0</td>
<td>-</td>
</tr>
<tr>
<td>Prevented wounds from healing</td>
<td>33.7 (79.4)</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>Severely scratched</td>
<td>15.1 (29.5)</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>Punched oneself</td>
<td>15.6 (56.2)</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>Banged head against something</td>
<td>6.07 (22.8)</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>Bit skin</td>
<td>3.10 (6.34)</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>Burned skin</td>
<td>2.97 (9.56)</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>Latest NSSI episode, weeks</td>
<td>3.50 (5.15%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Suicidal behaviors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lifetime suicide ideation</td>
<td>30 (100%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lifetime suicide attempt</td>
<td>11 (36.7%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ever inpatient psychiatric care</td>
<td>7 (23.3%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SCID-II BPD self-report</td>
<td>6.00 (2.80)</td>
<td>1.07 (1.50)</td>
<td>( p &lt; .001; \text{Cohen's } d = 2.19 )</td>
</tr>
<tr>
<td>SCID-II BPD clinical interview</td>
<td>3.23 (2.60)</td>
<td>0.13 (0.51)</td>
<td>( p &lt; .001; \text{Cohen's } d = 1.65 )</td>
</tr>
<tr>
<td>DSM-5 psychiatric diagnoses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major depressive disorder</td>
<td>15 (50.0%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Social anxiety disorder</td>
<td>9 (30.0%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Panic disorder</td>
<td>3 (10.0%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Agoraphobia</td>
<td>1 (3.30%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Generalized anxiety disorder</td>
<td>2 (6.67%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Unspecified anxiety disorder</td>
<td>1 (3.30%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Posttraumatic stress disorder</td>
<td>1 (3.30%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Borderline personality disorder traits</td>
<td>13 (43.3%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Anorexia nervosa</td>
<td>1 (3.30%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Atypical anorexia nervosa</td>
<td>2 (6.67%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Unspecified eating disorder</td>
<td>3 (10.0%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ADHD/ADD</td>
<td>15 (50.0%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Autism spectrum disorder (high functioning)</td>
<td>4 (13.3%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ODD/CD</td>
<td>3 (10.0%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Medications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSRI/SNRI</td>
<td>8 (26.7%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SSRI/SNRI + methylphenidate</td>
<td>1 (3.30%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Neuroleptic</td>
<td>1 (3.30%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SSRI/SNRI + neuroleptic</td>
<td>1 (3.30%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No medication</td>
<td>19 (63.3%)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
artificial activations were identified and excluded by trained, blinded raters (30).

Analysis. Data were analyzed using a \( \times 2 \) analysis of variance with image type (positive, neutral, negative, NSSI) as the within-subjects factor and group (NSSI patients, controls) as the between-subjects factor. Each outcome measure (corrugator EMG, zygomatic EMG, self-reported valence, self-reported arousal) was analyzed individually. Significant interactions were further analyzed using Benjamini-Hochberg corrections (37). The 3dFWHMx function with the ACF option was implemented in combination with an outlier fraction threshold of 0.1.

Negative Affective Picture Viewing Task. Participants engaged in a well-validated negative affective-picture-matching task (34). During each trial, three pictures were displayed for 2 seconds; two on the bottom of the screen and one on the top. Participants were instructed to select the one picture on the bottom that was the same as the one on top by pressing with the index (left picture) or middle (right picture) finger on a button pad positioned under the right hand. Four picture categories were used: negatively valenced pictures (arousal = 6.5; valence = 3.2) from the IAPS (31), NSSI-related pictures (32), negative facial expressions (angry, fearful) (35), and geometric shapes as control images. Blocks of 6 trials from the same picture category were presented consecutively, with an interblock interval of 14,000 ms. Two blocks of each picture category were included, for a total of 8 blocks. Before each block, a 3000-ms instruction text indicated which category was presented (i.e., “match pictures,” “match faces,” or “match shapes”). Response times were assessed in each trial.

Analysis. In the first-level analyses, four regressors modeled each negative-affect picture category (IAPS, face, NSSI, shape), one regressor modeled the instruction text, and an additional regressor modeled general motor response during button presses. Each regressor was convolved with a gamma model of the hemodynamic response function. A univariate general linear model analysis was performed on voxel fMRI time series data within a whole-brain gray matter mask. A \( \times 2 \) analysis of variance was employed with within-subject factor “Category” (IAPS, face, NSSI, shape) and between-subject factor “Group,” using AFNI 3dMVM (36). A linear contrast comparing IAPS, face, and NSSI pictures (collectively referred to as “negative affect pictures”) versus shapes was included to identify regions involved in processing negative-affect pictures compared with control shape pictures. AFNI’s 3dClustSim determined cluster-size thresholds necessary for identifying effects significant at familywise-error corrected alpha \( \alpha = 0.05 \) (per voxel \( p = .002 \), 2-sided) according to current recommendations (37). The 3dFWHMx function with the ACF option was added as regressors of no interest in the main regression. A motion censoring threshold of 0.3 mm per repetition time was implemented in combination with an outlier fraction threshold of 0.1.

Table 1. Continued

<table>
<thead>
<tr>
<th>NSSI Patients</th>
<th>Control Participants</th>
<th>Significance Values and Effect Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n = 30 )</td>
<td>( n = 30 )</td>
<td></td>
</tr>
<tr>
<td>Emotion regulation (DERS)</td>
<td>124 (23.3)</td>
<td>70.3 (15.1)</td>
</tr>
<tr>
<td>Alexithymia (TAS-20)</td>
<td>63.2 (11.4)</td>
<td>44.3 (8.90)</td>
</tr>
</tbody>
</table>

Values represent mean (SD) or \( n \) (%) unless otherwise indicated.

- Attention-deficit/hyperactivity disorder (ADHD), conduct disorder (CD), oppositional defiant disorder (ODD), Borderline personality disorder (BPD), CD, conduct disorder; CDRS-R, Children’s Depressive Rating Scale, Revised; DERS, Difficulties with Emotion Regulation Scale; fMRI, functional magnetic resonance imaging; NSSI, nonsuicidal self-injury; ODD, oppositional defiant disorder; SCID-II, Structural Clinical Interview for DSM-IV Axis II Personality Disorders; SNRI, serotonin-norepinephrine reuptake inhibitor; SSRI, selective serotonin reuptake inhibitor; TAS-20, Toronto Alexithymia Scale.

Based on \( n = 30 \).

Each participant could have several diagnoses.

Medication at time of fMRI.
used to obtain the average spatial smoothness estimates from residual maps rendered from the first-level analysis and entered into 3dClustSim.

We also investigated the association between neural responses during the picture-matching task and facial EMG activity measured during the out-of-scanner facial EMG session. Twenty-five patients and 24 control subjects were included in the within-group fMRI analyses. To estimate valence-general facial muscle reactivity, we calculated a facial EMG composite score by adding estimates of zygomatic response to positive pictures and corrugator response to negative pictures individually for each subject (38). Next, we performed within-group correlation analyses between brain response to each picture category and the facial EMG composite score using AFNI function 3dttest++ with facial EMG score as a covariate of interest. Familywise error correction of resulting statistical maps was done using 3dClustSim. Using Fisher’s r-to-z transformation, we compared Spearman’s correlation coefficients between groups. Given the volatility of most correlation matrices, we tested the robustness of significant correlations by applying statistical bootstrapping, in which regional β values from the first-level fMRI analysis and associated facial EMG composite scores were sampled randomly with replacement (100,000 bootstrapping iterations) (39). Resulting brain-by-EMG correlation distributions in which the middle 95% did not overlap with 0 were considered robust. To further test whether correlations were reliably different between groups, an additional distribution consisting of the difference in correlation coefficients between groups for each round of bootstrapping was computed. The resulting “difference distribution,” in which the middle 95% did not overlap with 0, indicated significantly different correlations between groups.

To determine whether the relationship between neural and EMG responses was independent of valence, we also correlated the neural response with each muscle (corrugator, zygomaticus major, and zygomaticus minor) and EMG composite score by adding estimates of zygomaticus major response to negative pictures and corrugator response to positive pictures independently (neural response–zygomaticus major response to negative material correlation: mean = 16.4, SD = 1.0). Age was thus included as a covariate in analysis of the DERS (p = .89) and TAS (p = .23), but it was not significant.

**Facial EMG**

Patients and controls displayed significantly different affective reactivity as indexed by EMG of the corrugator and zygomaticus muscles during the processing of affective images (Figure 1). As expected, negative and NSSI pictures elicited increased corrugator reactivity, and positive pictures elicited a reduction in corrugator response (Figure 1A; main effect of stimulus type: \( F_{3,171} = 15.0, p < .001 \)). We found a significant picture-type-by-group interaction for corrugator reactivity (\( F_{3,171} = 2.91, p = .036 \) but no effect of group (p = .18), with post hoc tests suggesting that patients responded more intensely to negative images than did controls (p = .034).

Similarly, we found that positive pictures elicited the greatest zygomatic reactivity (Figure 1B; main effect of stimulus type: \( F_{3,171} = 10.2, p < .001 \)). Again, we found a picture-type-by-group interaction (\( F_{3,171} = 10.2, p = .026 \)) but no main effect of group (p = .14), with patients showing greater zygomatic reactivity to positive pictures than did control subjects (p = .049).

We found minimal differences between groups in self-reported ratings of the images assessed immediately after image presentation. Positive pictures were rated as more positive and negative pictures as more negative (Figure 1C; main effect of stimulus type \( F_{3,171} = 215, p < .001 \)), but these self-reported ratings did not differ between groups (effect of group; p = .20), nor was there an interaction effect (p = .13).

Self-reported ratings of arousal were also influenced by picture type (Figure 1D: \( F_{3,174} = 14.1, p < .001 \)). We found a picture-type-by-group interaction \( F_{3,174} = 7.28, p < .001 \) such that NSSI patients rated NSSI pictures as significantly more arousing than did control subjects (p = .002). There was no main effect of group (p = .50).

**Functional Magnetic Resonance Imaging**

The 2 × 4 voxelwise analysis of variance revealed a main effect of picture category. Compared with shapes, viewing of negative affect pictures (i.e., IAPS, faces, and NSSI pictures) resulted in widespread activations in occipital regions, bilateral amygdala, and frontal regions (p = .002, familywise-error corrected; Figure 2; Table 2). No differences in neural response were observed between the negative affect picture categories (e.g., IAPS vs. faces vs. NSSI images), nor between groups. There was no group-by-picture category interaction. There was a main effect of picture category in response times \( F = 3.79, p = .012 \), with faster response times for NSSI compared with IAPS pictures (p = .001). No between-group effect or picture category by group interaction were identified (p > .2).

For the negative IAPS picture condition, a positive correlation was observed between right anterior insula (MNI coordinates 37, 28, −2; 15 voxels) response and facial EMG composite score (Figure 3A, B; \( r_{ij} = .69, p < .005 \)). The correlation remained significant also when considering EMG composite score components independently (neural response–by-corrugator response to negative material correlation: \( r_{ij} = .54, p = .005 \); neural response–by-zygomatic reactivity response to negative material correlation: \( r_{ij} = .54, p = .005 \); neural response–by-zygomatic reactivity response to positive material correlation: \( r_{ij} = .49, p = .013 \)).
**Emotional Reactivity in NSSI**

**Figure 1.** Nonsuicidal self-injury (NSSI) patients demonstrate dysregulation of emotion processing assessed via facial electromyography but not self-report. NSSI patients showed enhanced corrugator reactivity to negative images (A) and greater zygomatic reactivity to positive images (B). The groups did not differ in self-reported ratings of image valence (C), whereas NSSI patients reported higher arousal ratings only in response to NSSI-related images (D). *N* = 30 NSSI, 29 controls in panels (A, B) and 30 controls in panels (C, D); bars represent means and standard errors of the mean; "*" *p* < .05 effect of group.

**Figure 2.** Activations associated with processing of negative affect pictures (International Affective Picture System, face, and nonsuicidal self-injury combined) compared with shape pictures in both groups, thresholded at per-voxel *p* = .002, cluster corrected at alpha = 0.05. No difference across categories was identified at group level.

positive correlation: \( r_s = .55, p = .005 \). Spearman’s \( r_s \) indicating association between insula’s \( B \) scores and facial EMG composite values was significantly different between groups (\( z = 2.07, p = .038 \); NSSI \( r_s = .69, p < .001 \); controls \( r_s = .21, p = .3 \)). The distributions of Spearman’s \( r \) derived during bootstrapping permutations were different from 0, with \( >95\% \) confidence in patients (CI [0.38, 0.84]) but not in controls (CI [−0.23, 0.59]). The distribution of correlation differences was more different from 0, with \( >95\% \) confidence (CI [−0.01, 0.9]), driven by a reliable positive correlation in NSSI, which was not seen in controls (Figure 3C).

The EMG composite score was not associated with retrospective assessments of emotion regulation (DERS; \( r_s = .14, p = .32 \)) or alexithymia (TAS; \( r = .12, p = .40 \)).

**DISCUSSION**

We provide psychophysiological and neural data showing dysregulation of emotion processing in adolescent females with NSSI behavior. We find that patients with NSSI behaviors show enhanced emotional reactivity as indexed via facial EMG of the corrugator and zygomatic muscles. In contrast, we found no differences in self-reported ratings collected in close temporal proximity to the emotional reaction, which potentially implies that the awareness of basic emotional responses is impaired in adolescent patients with NSSI. Of note, this enhanced emotional response is evident for both positive and negative stimuli.

This study presents novel evidence of difficulties with emotional regulation and possible emotional avoidance in female adolescents with NSSI. In the EMG session, patients showed greater positive affect (zygomatic activity) to positive images, as well as greater affect (corrugator reactivity) to negative images. At the same time, no significant differences between control subjects and NSSI patients were evident in self-report ratings of valence or arousal of emotional pictures, except that NSSI patients rated NSSI pictures as more arousing. This potentially confirms the known limitations of self-report when measuring introspective processes (40).
Consistent with our results, Glenn et al. (20) reported no difference between controls and those with NSSI in their ratings of valence or arousal of emotional stimuli (IAPS). However, adolescents with NSSI in our study displayed stronger reactivity to the same pictures as measured with an objective psychophysiological measure (facial EMG).

This is the first study to combine both psychophysiological and neural data with self-report in an adolescent sample of patients with NSSI, identifying unique brain–behavior associations in this population. Although we did not identify general differences in brain reactivity to affective images, we present brain–EMG correlates that are specific to the altered emotional reactivity observed in NSSI. Observations from large cohorts have reported similar neural–emotional relationships between groups, even in the absence of overall group differences in neural response (41), and their significance has been explained in the context of major depression (42).

When combining neuroimaging and psychophysiological data, we find that enhanced facial EMG responses to affective pictures were associated with greater neural response when processing negative affect pictures, but only in the patient population. In particular, the facial EMG composite score, which provides a measure of a general emotional reactivity, correlated with anterior insula activation in NSSI patients but not in control subjects. The anterior portion of the insula is thought to integrate interoceptive information into subjects. The anterior portion of the insula is thought to integrate interoceptive information into emotional reactivity and salience processing in NSSI patients, who might fail to access overt self-reports of emotions. The fMRI finding thus suggests an association between emotional reactivity and salience processing in NSSI patients, who might fail to access overt self-reports of emotions. The fMRI task only included negative affect images, however, and as such, whether neural response to positive affective images would differ between groups is unclear. However, the association with anterior insula response included both positive (zygomatic) and negative (corrugator) affective reactivity, suggesting that this association is not valence dependent.

One potential consequence of greater emotional reactivity in individuals with NSSI and subsequent difficulty in regulating the emotional experience is attempts to alter the intensity by suppressing or avoiding the emotional response, possibly as a
form of experiential avoidance in accordance with the Experi-
ential Avoidance Model of NSSI (5). Experiential avoidance
also could explain the absence of differences in self-report
ratings provided immediately after emotional picture expo-
sure, even when psychophysiological differences are evident.
Of note, the lack of between-groups differences observed in
self-reported emotion at the laboratory session are in contrast
to retrospective self-report measures of difficulties with
emotion regulation, such as those presented in Table 1 and in
a recent meta-analysis (7), which reliably detected differences
in subjective reports of difficulties with emotion regulation
between controls and participants with NSSI. Thus, the deficits
in emotion processing may have a time-dependent facet, with
impairments in self-reports of emotion most pronounced in real
time when in close temporal proximity to an emotional trigger
and reaction, which is suppressed and hence not acknowl-
edged, as opposed to retrospective reporting of emotions,
which is perceived as less provoking and consequently can be
confirmed.

Together, we provide evidence of dysregulated emotion
processing in adolescent females with NSSI, using psycho-
physiological and neural measures. Importantly, these groups
did not differ on self-report measures of emotion processing in
close temporal proximity to the emotional stimulus, suggesting
that subjective self-report may not be sensitive enough to
detect emotion processing deficits within this population. The
cross-sectional nature of the data, however, precludes any
causal inference, and the all-female sample limits information
on potential sex/gender differences in this area. This study
provides novel support that is consistent with clinical obser-
vations of adolescents with NSSI. One major limitation is the
lack of a psychiatric control group. However, our results did
remain significant after controlling for borderline personality
disorder traits, a condition that is also characterized by intense
emotional reactions, emotional avoidance, and difficulties with
emotion regulation. Given that NSSI is a behavior that is
prominent in adolescence and decreases in adulthood (3,13),
one possibility is that the reported results might be specific to
the developmental period, although with the current evidence,
we cannot exclude the possibility that these results also might
represent the adult population with NSSI. Future studies may
address differences between specific methods of NSSI, although
that is beyond the scope of the current manuscript. Strengths
include a transdiagnostic approach to recruiting in-
dividuals with NSSI behavior and a unique, multimodal
assessment of emotion processing.

Figure 3. (A) Significant positive correlation be-
tween right anterior insula response and facial elec-
tromyography (EMG) composite score during
International Affective Picture System (IAPS) picture
viewing in nonsuicidal self-injury (NSSI) patients. Map
thresholded at per-voxel $p < .002$, cluster
corrected at alpha $= .05$. Right is right. (B) Scatter-
plot showing the positive Spearman’s correlation
between $\beta$ values, indicating anterior insula (A1)
response during negative IAPS picture processing
and facial EMG composite score ($\rho = .69, p < .001$).
(C) Histograms from 100,000 bootstrap iterations
computing correlations between insula response and
facial EMG composite scores correlations. Fre-
quency distribution for bootstrap iterations for NSSI
(red, 95% CI [0.38, 0.84]), for control subjects (blue,
95% CI [-0.23, 0.59]), and for their respective dif-
fERENCE (DIFF) (gray, 95% CI [-0.01, 0.9]). We found
that the distribution of the difference appears to be
reliably greater than 0, driven by reliable increase in
correlation in NSSI patients, which is not evident in
control subjects.
Results from this study have direct implications for clinical practice and illuminate potential targets for treatments, such as real-time EMG-based biofeedback focusing on increasing emotional awareness, labeling and expressing emotional experiences, and reducing avoidance and suppression strategies that, although adaptive in the short term to reduce unwanted emotional experiences, can potentially contribute to the need to engage in NSSI. Finally, clinicians treating NSSI should address emotional processing and skills for emotion regulation, and the data presented here highlight objective, quantitative measures for testing the efficacy of clinical interventions designed to improve abilities to regulation emotions.

ACKNOWLEDGMENTS AND DISCLOSURES

This research was supported by The Swedish Research Council (Grant No. 538-2013-7434 [to MH]) and the ALF Grants, Region Östergötland (Grant Nos. LIO-535931 [to MZ] and LIO-520131 [to MZ and PAG]). LMM, IP, MZ, PG, and MH designed research; LMM, IP, RK, and MZ performed research; LMM, IP, and PH analyzed data; LMM and IP made figures; LMM, IP, PH, RK, MZ, PG, and MH wrote the paper and approved the final manuscript. LMM and IP confirm that they had full access to the data and take responsibility for data integrity.

We gratefully acknowledge staff at the Center for Medical Imaging and Visualization (CMIV), the Center for Social and Affective Neuroscience (CSAN), and the Child and Adolescent Psychiatric (CAP) clinic, Linköping University Hospital, Sweden. The authors report no biomedical financial interests or potential conflicts of interest.

ARTICLE INFORMATION

From the Department of Biomedical and Clinical Sciences (LMM, IP, PAG, JPH, RK, MH, MZ), Center for Social and Affective Neuroscience, and the Center for Medical Image Visualization (IP, JPH, RK, MZ), Linköping University; and the Department of Child and Adolescent Psychiatry (PAG) and the Department of Psychiatry (MH), Region Östergötland, Linköping, Sweden. LMM and MZ contributed equally to this work as joint first authors. MH and MZ contributed equally to this work as joint senior authors. Address correspondence to Leah Mayo, Ph.D., at leah.mayo@liu.se. Received Sep 1, 2020; revised Oct 26, 2020; accepted Nov 11, 2020. Supplementary material cited in this article is available online at https://doi.org/10.1016/j.jspsc.2020.11.004.

REFERENCES

Emotional Reactivity in NSSI


