Beyond distress: a role for positive affect in nonsuicidal self-injury
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The ability to generate and regulate emotional experiences is critical to psychological well-being. Impairments in emotion regulatory processes have transdiagnostic associations with psychopathology. Nonsuicidal self-injury (NSSI) is prevalent in adolescent populations, especially clinical adolescent populations, and often linked to emotion regulatory deficits. Clinical observations propose a role for NSSI behaviors in regulating affect, suggesting that these behaviors may arise when other emotion regulatory strategies are insufficient or inaccessible. Experimental evidence has begun to explore the psychophysiological and neural underpinnings of emotion processing in NSSI populations. Thus far, a primary focus has been the role of NSSI in regulation of affect in response to stressful or negative states or stimuli, often suggesting enhanced reactivity in such situations. However, recent evidence suggests that NSSI populations may also display heightened reactivity to positive or rewarding stimuli. Here, we highlight this emerging data and how it may be integrated into existing NSSI framework.

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Introduction
Humans strive to avoid unpleasant experiences, and as a result, research has emphasized the role of negative emotional experiences, and the ability to effectively modulate these, in relation to psychopathology [1]. Here, we review the role of positive affect in nonsuicidal self-injury (NSSI) and argue for the importance of including the processing of positive emotional experiences into our understanding of NSSI. NSSI includes a constellation of behaviors deliberately performed to cause bodily harm, such as cutting, burning, or hitting oneself, without suicidal intent, and is often associated with dysregulated emotion processing [2,3]. NSSI is more common in females than males, especially in clinical samples [4]. It is particularly prevalent in adolescent populations, with rates of 17% in community samples and up to 60% in clinical populations [5]. Although a high prevalence of NSSI in young adult college samples has been found [6], the frequency of NSSI behaviors typically decreases from adolescence into adulthood [7]. Despite this, NSSI during adolescence is associated with higher levels of stress, anxiety, and difficulties in emotion regulation even a decade later [8]. In clinical samples, NSSI can occur together with several different psychiatric disorders [9,10]. NSSI can also occur on its own, without any comorbidities. Diagnostically, NSSI is currently considered a symptom of borderline personality disorder (BPD). However, NSSI has been proposed as a diagnostic entity in its own right and was included in Section III of the DSM-5 as a condition requiring further study [11,12]. As such, there is a critical need for innovative, mechanism-based investigations into the antecedents and consequences of NSSI behaviors.

Longitudinal data show that rates of NSSI peak during mid-adolescence [13]. Adolescence is a developmental period characterized by the maturation of cognitive and affective processes that mature along different timescales and under the control of partially distinct biological processes [14], including neurodevelopmental changes driven 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 [15]. Research on the neurobiology of NSSI in adolescents is only now emerging, but initial reports suggest that this population may indeed exhibit dysregulation of limbic and prefrontal connectivity [16]. Thus, understanding the neural contributions of emotion reactivity and regulation are key to identifying evidence-based treatment options for this population. Conceptually, emotion reactivity relates to how an emotion is experienced and includes the threshold, intensity, and duration of the emotional reaction, whereas emotion regulation is the process through which the emotion is modulated [17]. Underlying difficulties with emotion regulation have
consistently been found in NSSI, but the role of possible increased reactivity in relation to NSSI is somewhat more ambiguous, with results varying depending on methods used (self-report versus behavior) to assess this construct [18].

Self-reported affect in NSSI
How one reacts to affective experiences is related to both general well-being and psychopathology [19]. Difficulties regulating both negative and positive affect has been shown to be a risk factor for several psychopathologies, suggesting that positive affect is equally important to consider [20]. Negative affect can broadly be defined as subjective unpleasant experiences of mood and emotions, such as being afraid or sad, while positive affect refers to experiences on the pleasant side of the affect dimension (interest or joy, for example) [21]. Impairments in affective processing can result in maladaptive strategies, such as NSSI, used in effort to modulate affect [2]. Accordingly, individuals with NSSI report experiencing difficulties in the regulation of affect, as assessed via retrospective self-reports [3,22]. Higher levels of negative emotion reactivity have been reported consistently, whereas self-report data on positive affect reactivity is somewhat more ambiguous. One recent study showed no group differences on self-reported positive emotion reactivity in those with and without NSSI [23], while another study found less self-reported reactivity of positive emotion reactivity and response to an amusing film clip in those with NSSI [24]. There is thus a need of further studies examining self-reported versus in-vivo positive emotion reactivity.

People engage in NSSI for many different reasons. The most commonly reported motive for NSSI is to reduce or escape unwanted negative states [25]. The proposed diagnostic criteria for an NSSI disorder diagnosis include expectancies that NSSI will result in relief from a negative feeling or cognitive state; resolution of an interpersonal difficulty; or a positive feeling state [11]. Recent research has emphasized the need to take both negative and positive affect in account in models of NSSI [26]. Common self-reported reasons for engaging in NSSI behaviors thus include attempts to reduce negative affect or to increase positive affect [27–29]. In particular, positive valenced low-arousal affective states (e.g. relaxation) increase and negative valenced high-arousal states (e.g. anxiety) decrease following NSSI [30]. There are, however, some uncertainties concerning the construct of the intrapersonal positive reinforcer, which needs more precise understanding and definition [28]. For instance, which specific emotions are included in the construct [31]; whether states of relaxation and relief, for example, are positive affects per se, or rather an effect that follows after a high-arousal negative affective state has been reduced (negative reinforcement); and is therefore a possible rise in positive affect a secondary rather than a primary maintaining factor [28,32].

Evidence from ecological momentary assessment (EMA) studies suggest that affect regulation plays a key role in facilitating NSSI behaviors [33]. In particular, individuals report increases in negative affect immediately before an NSSI act [32–34]. There is also some support for a decrease in positive affect before performing NSSI and an increase in positive affect following NSSI [32,35]. Results from EMA are however somewhat inconclusive, with one study not finding support for an increase in positive affect after NSSI [36] and others supporting a reduction in negative affect as well as an increase in positive affect following NSSI [32,33,37]. Jenkins and Schmitz [37], for example, found that negative affect decreases after engaging in an NSSI event, while positive affect increases, with the increases in positive affect more pronounced in women than men [37]. Evidence from self-report and EMA studies generally support the notion that NSSI may be used to modulate affect when other affect regulation strategies are insufficient or inaccessible. Self-report measures, however, have well-known limitations. In this case, antecedents and consequences of behavior are not always within conscious awareness and difficulties identifying motives for NSSI can be more or less pronounced [32]. Experimental studies have begun to explore these ideas using psychophysiology (e.g. facial electromyography, skin conductance) and neuroimaging in an effort to elucidate mechanisms underlying these reported impairments in affective reactivity and regulation.

Psychophysiology of affective processing in NSSI
Conceptually, NSSI is often associated with reactions to a negative or distressing state. As a consequence, experimental work has primarily focused on determining how individuals with NSSI react in tasks used to induce a negative affective state. For instance, a task designed to induce frustration resulted in increased physiological arousal (e.g. skin conductance) in NSSI participants as compared to control participants [17]. In response to a psychosocial stress task, adolescents with NSSI demonstrated attenuated cortisol reactivity, but no differences in heart rate or self-reported stress [38]. Following exposure the same laboratory stress challenge in a separate study, NSSI participants showed less autonomic reactivity to positive images, while this response was increased in control participants [39]. Thus, stress responding appears to be dysregulated in NSSI participants, which has downstream effects on affective reactivity.

Comparatively less attention has been given to the processing of positively valenced stimuli in NSSI populations. However, recent evidence suggests that deficits in affective processing in NSSI participants may be more
general, and not specific to negative states or stimuli. In particular, we have recently shown that a clinical sample of adolescent NSSI participants demonstrate greater emotional reactivity to both positive and negative affective images, as assessed via facial electromyography, in the absence of any stressor [22**]. Facial electromyography is a non-invasive and sensitive measure used to assess affective reactions [40]. NSSI participants demonstrated greater negative affect, indexed by activity of the corrugator or ‘frown’ muscle in response to negative emotional stimuli, as compared to healthy controls participants. In addition, they also demonstrated greater positive affect, indicated by greater activity of the zygomatic or ‘smile’ muscle in response to positive images. Although adolescents with NSSI show enhanced emotional reactivity via EMG as compared to their age-match counterparts, there is no differences in their self-reported ratings of image valence or arousal, which is assessed immediately following each stimulus presentation. Thus, results from this study suggest that emotional overreactivity is not specific to negative affective processing, but appears to be a general phenomenon that also applies to the processing of positive affective information. Our results are congruent with recent studies of positive emotion reactivity [23,24] that show no self-reported group differences between those with and without NSSI, further strengthening the need for future studies of perceived versus actual positive emotion reactivity. These findings are an important contribution to the psychophysiological literature of positive reactivity in adolescent NSSI, which is scarce [18,26].

It is worth noting that adolescents with NSSI do not show impairments in the sensitivity or accuracy of identifying emotions in the faces of others [41,42]. This remains true following induction of positive or negative mood [41], and even when tested in the same adolescent NSSI participants who displayed greater affective reactivity in the above study [42]. This potentially precludes the notion that NSSI participants may be more or less sensitive in detecting emotions generally, or that they cannot label emotions in others. Instead, it suggests that the impairments may be in their own introspective ability to identify and label emotions and interoceptive signals generated within themselves.

**Brain correlates of affective reactivity in NSSI**

Insights into the neural correlates of affective processing in NSSI are sparse but tend to suggest dysregulated emotion processing in NSSI cohorts. A preliminary neuroimaging investigation reported greater amygdala reactivity to emotional images, regardless of valence, in adolescents who engage in NSSI behavior [43]. However, in an older sample of young adults (ages 18–31), NSSI was associated with attenuated amygdala reactivity to negative images and greater amygdala reactivity to positive stimuli [44]. Thus, it is possible that NSSI behavior is associated with general affective hyper-reactivity in adolescence, but this may change throughout development. However, these results should be interpreted with caution, as both included relatively small sample sizes (i.e. \( N = 9 \) per group, \( N = 15 \) per group, respectively) and thus require replication in larger samples.

There is also evidence of dysregulated reward processing in NSSI populations, which varies according to the phase of reward processing, that is, anticipation versus receipt of reward. Adolescents who have engaged in NSSI demonstrate attenuated reward *anticipation* within the putamen, OFC, and amygdala [45]. However, adolescents with NSSI also show greater bilateral putamen activation following *receipt* of reward [46**]. Similarly, adults who engaged in NSSI demonstrate enhanced activation of the orbitofrontal cortex following *receipt* of an unexpected reward [47]. This greater reactivity exists not only in comparison to control subjects, but also to BPD patients without NSSI behavior. As such, enhanced neural reactivity to the receipt of reward appears to be specific to NSSI and further suggests that NSSI in particular may be associated with an inability to regulate both positive and negative emotional reactions.

Recently, we have combined psychophysiological and neural data to uncover unique brain-behavior associations that exist only in the NSSI cohort. We find that the enhanced emotional reactivity previously mentioned is associated with neural activity in the right anterior insula [22**]. Specifically, enhanced emotional reactivity assessed via facial EMG correlates with activity within the anterior insula in NSSI participants, but this association is absent in age-matched control participants (Figure 1). Critically, this association holds regardless of whether we assess insula activity in relation to positive affect (zygomatic activity), negative affect (corrugator activity), or both combined as a general measure of affect. Our neural and psychophysiological data point towards a potential valence-independent relationship that may be reflective of enhanced arousal. However, we found no significant difference between NSSI participants and controls in self-reported ratings of either valence or arousal, suggesting potential impairments in interoceptive awareness.

The insula is a highly integrative region, activated by a variety of processes and behaviors, including attention, language production, and autonomic processing [48]. The heterogeneity of the insular cortex is supported by extensive evidence of a rostrocaudal gradient in terms of architecture and functional connectivity in monkeys [49], and by functional imaging studies [50] and probabilistic tractography maps [51] in humans. The posterior territory of the insula receives bodily information via ascending small-diameter afferents, which innervate body tissues [52], and is connected to sensorimotor, parietal, and posterior temporal regions, whereas the
Consistently, adolescents with NSSI demonstrate greater emotional reactivity to positive and negative emotional images, as measured via facial electromyography (EMG). Compared to age-matched control participants, adolescent females with NSSI show greater activity of the corrugator muscle, which activates as the brow furrows in a frown, in response to negative emotional images. The NSSI population also demonstrated enhanced positive affect in response to positive emotional stimuli as indexed from activity of the zygomatic muscle, which pulls the corners of the mouth up into a smile. The enhanced emotional reactivity correlated with activation in the right anterior insula in the NSSI population, but not in the control sample suggestive of greater affect-related arousal in the NSSI population. There was no difference between the NSSI and control participants in self-reported ratings in response to emotional images (based on findings from Ref. [22**]).

Enhanced emotional reactivity in NSSI. Adolescents with NSSI demonstrate greater emotional reactivity to positive and negative emotional images, as measured via facial electromyography (EMG). Compared to age-matched control participants, adolescent females with NSSI show greater activity of the corrugator muscle, which activates as the brow furrows in a frown, in response to negative emotional images. The NSSI population also demonstrated enhanced positive affect in response to positive emotional stimuli as indexed from activity of the zygomatic muscle, which pulls the corners of the mouth up into a smile. The enhanced emotional reactivity correlated with activation in the right anterior insula in the NSSI population, but not in the control sample suggestive of greater affect-related arousal in the NSSI population. There was no difference between the NSSI and control participants in self-reported ratings in response to emotional images (based on findings from Ref. [22**]).

Figure 1

Enhanced emotional reactivity in NSSI. Adolescents with NSSI demonstrate greater emotional reactivity to positive and negative emotional images, as measured via facial electromyography (EMG). Compared to age-matched control participants, adolescent females with NSSI show greater activity of the corrugator muscle, which activates as the brow furrows in a frown, in response to negative emotional images. The NSSI population also demonstrated enhanced positive affect in response to positive emotional stimuli as indexed from activity of the zygomatic muscle, which pulls the corners of the mouth up into a smile. The enhanced emotional reactivity correlated with activation in the right anterior insula in the NSSI population, but not in the control sample suggestive of greater affect-related arousal in the NSSI population. There was no difference between the NSSI and control participants in self-reported ratings in response to emotional images (based on findings from Ref. [22**]).

Consistently, together with the midcingulate cortex, the anterior insula is considered a key node of the ‘salience’ network, a domain-general network which modulates attention and behavior at the present [54,55]. In our study, we identified a correlation between enhanced emotional reactivity, as measured by facial corrugator and zygomatic muscles, and the right anterior insula [22**]. Based on evidence on general forebrain asymmetry associated with energy optimization, it is proposed that activity in the right side of the insula is more related to the energy-expenditure, sympathetic activity, and arousal, whereas the left portion is more related to parasympathetic activity [53] but see also [56]. Thus, the observed enhanced emotional reactivity associated with increased right insula activity in the NSSI group might reflect generally increased physiological arousal to affective stimuli regardless of valence. Further studies should address the potential association between facial muscle reactivity and physiological arousal measures while processing positive and negative images in NSSI.

Conclusion: is there a role for positive affect in NSSI? The role of positive affect in NSSI has typically been conceptualized as a consequence of NSSI behaviors, with individuals engaging in NSSI to reduce negative affect
and subsequently increase positive affect [25]. Experimental studies have often focused on exploring proposed hyper-reactivity to negative emotional states and stimuli, but emerging evidence suggests that this enhanced reactivity may apply more broadly [22**]. The Cognitive Emotional Model [26] of NSSI, for example, emphasizes emotional intensity and emotion regulation difficulties, and argues for the need to include positive affect in the understanding of NSSI.

Though the experimental literature is somewhat mixed, it appears that NSSI could be associated with dysregulation of negative and positive affective reactivity. Retrospective self-reports consistently suggest a relationship between NSSI and impairments in affect regulation. Interestingly, there appears to be a dissociation between self-report and experimental (e.g. fMRI, EMG) assessments of affect processing that has a temporal influence. Although NSSI patients are able to identify deficits in emotion regulation retrospectively, they do not report deficits in emotion processing in real-time. NSSI participants do not differ from age-matched controls in valence and arousal ratings of emotional images [22**,43,57]. This is true even when NSSI individuals display greater psychophysiological reactivity (e.g. facial EMG) to both positive and negative emotional images, associated with right anterior insula activity, possibly reflecting increased salience and arousal (Figure 1) [22**]. Future work will be critical in replicating and extending this work in this population.

The role of positive affect in NSSI has important clinical implications. Traditionally, clinical focus has been given to the regulation of negative emotional experiences. If there is a heightened reactivity also to positive stimuli and insufficient ability to regulate it, this too may drive NSSI behaviors. In particular, high arousal contexts can drive urgency, conceptualized as impulsive responses to positive and negative emotions [20]. Negative urgency has been linked to impairments in emotion regulation and subsequent NSSI behaviors [58,59]. Based on our data and clinical experience, we argue that for individuals who also experience high intensity and reactivity to positive stimuli and have difficulties regulating their strong reaction, the response, albeit positive, can be perceived as problematic and overwhelming, potentially leading to NSSI to modulate the intensity of the emotional reaction. Greater understanding of the neural and physiological processes underlying urgency and its relation to psychopathology, including NSSI, is needed [20]. Continued insight into the neural and physiological markers of emotion regulation impairments can highlight targets for enhancing treatment outcomes. For instance, including bio-feedback or neuro-feedback may facilitate greater efficacy in clinical efforts to improve emotion regulation strategies and thus provide novel, evidence-based treatment approaches for this population.

Conflict of interest statement
Nothing declared.

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- of special interest
- of outstanding interest

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