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Emotional response inhibition to self-harm stimuli interacts with momentary negative affect to predict nonsuicidal self-injury urges

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ABSTRACT

The current study investigated whether impaired emotional response inhibition to self-harm stimuli is a risk factor for real-time nonsuicidal self-injury (NSSI) urges. Participants were 60 university students with a history of repetitive NSSI. At baseline, participants completed an emotional stop-signal task assessing response inhibition to self-harm stimuli. Participants subsequently completed an ecological momentary assessment protocol in which they reported negative affect, urgency, and NSSI urge intensity three times daily over a ten-day period. Impaired emotional response inhibition to self-harm stimuli did not evidence a main effect on the strength of momentary NSSI urges. However, emotional response inhibition to self-harm images interacted with momentary negative affect to predict the strength of real-time NSSI urges, after adjusting for emotional response inhibition to neutral images. Our findings suggest that emotional response inhibition deficits specifically to self-harm stimuli may pose vulnerability for increased NSSI urge intensity during real-time, state-level negative affect.

Nonsuicidal self-injury (NSSI) is defined as intentional damage to one's body without suicidal intent (Nock, 2010). These behaviors are highly prevalent among youth; estimates suggest that 17.2% of community adolescents and 13.4% of young adults have a history of NSSI (Swannell, Martin, Page, Hasking, & St John, 2014). NSSI is strongly associated with mental health, interpersonal, and academic problems (e.g., Kiekens et al., 2016). Furthermore, NSSI engagement prospectively predicts suicidal ideation and behaviors (Franklin et al., 2017), despite the lack of lethal intent that characterizes NSSI episodes. Understanding the etiology of self-injurious behaviors, as well as their proximal risk factors, therefore, is critical to enhance public health strategies aimed at reducing suicide rates, which continue to rise globally (WHO, 2018). NSSI urges, or the strong desire to engage in self-harm without suicidal intent, represent an understudied proximal risk factor for NSSI behavior. Past work has found that NSSI urges are associated with and/or prospectively predict NSSI behavior, both longitudinally and within everyday life (Ammerman, Olino, Coccaro, & McCloskey, 2017; Hepp, Carpenter, Störkel, et al., 2020; Nock, Prinstein, & Sterba, 2009; Turner, Baglole, Chapman, & Gratz, 2019; Washburn, Juzwin, Styer, & Aldridge, 2010).

In addition to the relevance of measuring NSSI urges given their associations with NSSI behavior, prior theoretical work suggests that the experience of NSSI urges itself may be cognitively taxing, depleting finite self-regulatory resources (Hepp, Carpenter, Freeman, Vebares, & Trull, 2020). Recent research using ecological momentary assessment (EMA) supports this idea; Fitzpatrick and colleagues (2020) report that the intensity of daily-life NSSI urges predicts subsequent engagement in more severe NSSI behaviors (e.g., using different methods). The authors propose that resisting intense NSSI urges over long periods therefore might involve sufficient inhibitory demand to impede some people's ability to control NSSI behaviors once they have begun (Fitzpatrick et al., 2020). Although a separate body of literature has established specific inhibitory control deficits in NSSI (e.g., Allen & Hooley, 2015, 2019), researchers have yet to fully explore the role of such deficits in the strength of NSSI urges, which may play a role in the link between NSSI thoughts and behaviors. Examining individual differences in

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cognitive control processes has begun to clarify pathogenetic mechanisms and clinical trajectories of potentially harmful behaviors and associated urges (e.g., alcohol cravings; Papachristou et al., 2012); the present study accordingly seeks to evaluate the role of such processes in NSSI.

Studies using EMA to evaluate NSSI remain relatively rare, and even fewer have examined real-time urges to engage in NSSI, resulting in calls for greater empirical evidence on their distal and proximal precipitants (for reviews, see Hepp, Carpenter, Störkel, et al., 2020; Rodríguez-Blanco, Carballo, & Baca-García, 2018). However, extant EMA findings support the notion that people often use NSSI for emotion regulation purposes, specifically to reduce negative affect (e.g., Armey, Crowther, & Miller, 2011; Rodríguez-Blanco et al., 2018). Such studies generally indicate that elevations in negative affect (NA) often precede episodes of NSSI urges and behaviors, and that engagement in NSSI typically is followed by decreases in NA (Andrewes, Hulbert, Cotton, Betts, & Chanen, 2017; Nock et al., 2009; Shingleton et al., 2013; Victor, Scott, Stepp, & Goldstein, 2019). This is consistent with findings that affect regulation (c.f., intrapersonal negative reinforcement; Nock, 2010) is the most commonly reported motivation for NSSI immediately following engagement in the behavior (Shingleton et al., 2013). Taken together, these EMA studies characterize NSSI as being accompanied by heightened daily and momentary NA, which may maintain nonsuicidal self-injurious thoughts and behaviors via negative reinforcement.

Research also has examined whether underlying person-level vulnerabilities influence the likelihood that negative emotions will lead to NSSI urges and acts. Impulsivity is hypothesized to be such an underlying vulnerability factor that may facilitate acting on impulses to regulate emotions in maladaptive ways (see Hamza, Willoughby, & Heffer, 2015). Research consistently implicates one particular facet of impulsivity, negative urgency, in the experience of NSSI urges and behavior (Berg, Latzman, Bliwise, & Lilienfeld, 2015; Bresin, Carter, & Gordon, 2013; Riley, Combs, Jordan, & Smith, 2015a). Negative urgency refers to the tendency to engage in rash action in response to aversive affective states (Cyders & Smith, 2008; Hamza et al., 2015; Whiteside & Lynam, 2001). Meta-analytic evidence supports the robustness of this association, which remains significant even after accounting for other impulsive traits, (e.g., sensation-seeking; Berg et al., 2015). Furthermore, one of the few longitudinal studies focused on risk factors for NSSI onset found that high levels of self-reported negative urgency predicts NSSI initiation among college students (Riley, Combs, Jordan, & Smith, 2015b).

In the context of the intrapersonal negative reinforcement model of NSSI, negative urgency is proposed to augment the likelihood that an individual may experience and act on the urge to engage in NSSI when faced with NA (e.g., Hamza et al., 2015). In line with this conceptualization, an EMA study conducted among college students found that daily sadness predicted urges to self-injure most strongly among those reporting high trait levels of negative urgency (Bresin et al., 2013). Despite the robust association between negative urgency and NSSI, research investigating the neurocognitive underpinnings of emotion-related impulsivity in self-harm is sparse. Furthermore, no EMA investigations of NSSI have included objective, behavioral metrics of impulsivity (e.g., measures of *inhibitory control*). More broadly, extant EMA literature in clinical science has insufficiently addressed interactions between state-level, within-person processes (e.g., affect) and between-person factors (e.g., inhibitory control) in the proximal prediction of real-world psychopathology, particularly using methodology other than self-report.

A growing body of cross-sectional research has examined the nature and extent of behaviorally assessed response inhibition deficits associated with NSSI, given the putative relevance of impulsivity to these behaviors. In contrast to personality-based studies of impulsivity, most behavioral investigations find no performance differences between participants with a NSSI history and comparison groups on inhibitory control tasks (e.g., Allen & Hooley, 2017; Dahlgren et al., 2018; Fikke, Melinder, & Landrø, 2011; Glenn & Klonsky, 2010; Lengel, DeShong, & Mullins-Sweatt, 2016; Mc Closkey, Look, Chen, Pajoumand, & Berman, 2012). Less work, however, has addressed "hot" executive functioning (c.f., *affective control*) in NSSI, including response inhibition in *emotional* contexts, despite conceptual links between this construct and urgency (Allen, Bozzay, & Edenbaum, 2019; Hamza et al., 2015). The few studies evaluating emotional response inhibition in this population suggest that individuals with a history of NSSI may exhibit deficits in the ability to terminate ongoing motor impulses triggered by automatic reactions to negatively valenced stimuli (Allen & Hooley, 2015, 2019). These findings fit with negative reinforcement models of NSSI, indicating that inhibitory difficulties may manifest only during periods of heightened NA, leading to impulsive cognition and behavior associated with relief from unpleasant affect. Allen et al. (2019) provide a complementary explanation for impaired emotional response inhibition in NSSI, suggesting that such affective control deficits might represent latent psychopathology risk more broadly. The transdiagnostic nature of urgency, which is linked to a range of internalizing and externalizing disorders (e.g., Berg et al., 2015), supports this notion that poor emotional response inhibition might make it difficult to inhibit both cognitions (e.g., thoughts, urges) and behaviors. However, it remains unknown whether the degree of emotional response inhibition impairment is associated with increased NSSI *risk* (e.g., NSSI urges), given that previous studies compared those with a lifetime NSSI history to those without any history of NSSI (Allen & Hooley, 2015). Additionally, the cross-sectional nature of this research significantly limits inferences regarding the causal role of emotional response inhibition in NSSI risk and maintenance.

Taken together, the above literature provides evidence that those who engage in NSSI may have difficulty modulating or inhibiting behavior in the context of undesirable emotional states, and, as a result, may be prone to experiencing urges to self-harm during occurrences of elevated NA and urgency. Notably, prior studies have focused mainly on *trait-level* impulsivity in NSSI (for reviews, see Hamza et al., 2015; McHugh et al., 2019), whereas recent work suggests that *state-level* impulsivity – particularly in affective and/or interpersonally-challenging contexts – may be equally or more relevant to self-injurious behaviors (e.g., Griffin, Freeman, & Trull, 2020). Moreover, only one prior investigation has examined emotional response inhibition to *self-harm stimuli*, reflecting another important gap in this area of inquiry. Specifically, Allen and Hooley (2015) carried out a cross-sectional study comparing emotional response inhibition to self-harm images between young adults with and without a history of NSSI behavior. Contrary to study hypotheses, participants with lifetime NSSI history had *better* response inhibition than those without any previous NSSI when presented with self-harm images (Allen & Hooley, 2015). The authors proposed that this unexpected finding might be due to positive implicit associations with NSSI (see Cha, Wilson, Tezanos, DiVasto, & Tolchin, 2019) or desensitization through repeated exposure, despite finding that individuals with NSSI history generally categorized these images as "negative" in the behavioral task. This unexpected association may be attributable to study limitations, e.g., utilizing a cross-sectional design to compare participants without any history of NSSI to those with heterogeneous NSSI histories, a group with inherently greater familiarity with and exposure to NSSI (and its imagery). Thus, research is still needed to address whether the degree of emotional response inhibition deficits to self-harm stimuli impacts vulnerability to proximal contributors to NSSI risk (e.g., greater intensity NSSI urges; Nock et al., 2009). EMA methodology is particularly well-suited to evaluate how NSSI-specific response inhibition impairment might manifest in the "real world," by clarifying its relationship with hypothesized real-time precipitants of NSSI urges, namely, momentary NA and impulsive urges driven by heightened aversive affective arousal (i.e., feelings of *state* urgency in daily life).

Accordingly, the current study evaluated the associations of occasion-level (i.e., momentary) NA and urgency with individuals' urges to engage in NSSI. In line with the negative reinforcement framework of

NSSI maintenance, we expected that NSSI urges would be stronger at occasions characterized by high NA and high urgency. We further hypothesized that occasion-level NA would interact with occasion-level urgency to predict NSSI urge intensity, such that intensity of NSSI urges would be highest at moments characterized by both high NA and urgency.

We then examined whether greater deficits in emotional response inhibition to self-harm stimuli strengthen the associations of NA and urgency with NSSI urges, given theoretical and empirical background suggesting that impaired emotional response inhibition may reflect a risk factor for future NSSI among those with a history of these behaviors. Following Allen and Hooley's (2015) original hypothesis, we predicted that individuals with worse emotional response inhibition to self-harm stimuli at baseline generally would report greater NSSI urge intensity over the EMA period. We also hypothesized that emotional response inhibition deficits to self-harm stimuli would moderate the associations of NA and urgency with NSSI urges, strengthening associations between occasion-level NA and NSSI urge intensity and between occasion-level urgency and NSSI urge intensity.

1. Method

1.1. Participants

Participants in the current study were drawn from a sample of 123 undergraduate students at Temple University who completed an EMA study. Approximately half of the sample was recruited for a lifetime history of repetitive NSSI ($n = 64$) and half of the sample for a history of no engagement in NSSI ($n = 59$). Inclusion criteria for the NSSI + group included a minimum of two lifetime NSSI acts determined by self-report and a clinician-rated interview. Additional inclusion criteria stipulated that participants possessed normal or corrected vision, access to a smartphone, and endorsed fluency in English. The current study's primary analyses employ 60 participants drawn from the NSSI + group (1 participant was excluded due to non-completion of the Emotional Stop-Signal Task (ESST) and 3 participants were excluded due to less than 75% accuracy of valence judgments on the ESST; see Allen & Hooley, 2019). Participants were between the ages of 18–26 ($M = 20.13$ years; $SD = 2.06$) and the majority identified as female ($n = 55$; 91.7%). The racial composition of the sample was White ($n = 41$; 68.3%), Asian ($n = 12$; 20%), Black ($n = 0$; 0%), Biracial ($n = 4$; 6.7%), other ($n = 2$; 3.3%), and one participant preferred not to answer (1.7%). Approximately 10% ($n = 6$) of the sample identified as Hispanic. Participants identified as heterosexual (n = 28, 63.3%), bisexual (n = 15, 25%), lesbian, gay, or homosexual (n = 2, 3.3%) and other (n = 5, 8.3%).

1.2. Procedure

Participants were recruited from psychology classes and through posting flyers on campus. Participants completed a brief online screener to determine eligibility for the study. The screener included questions related to history of NSSI, as measured by the Deliberate Self-Harm Inventory (Gratz, 2001). Participants received course credit for completing the screener. Those eligible were invited to schedule an in-person session to complete two parts of the study. This research was approved by Temple University's Institutional Review Board.

Part 1. At the baseline in-person visit, participants completed an interview to confirm repetitive NSSI history (SITBI; Nock, Holmberg, Photos, & Michel, 2007) and the Emotional Stop Signal Task (ESST; Allen & Hooley, 2015).

Part 2. At the conclusion of the in-person visit, participants were trained on the EMA procedures and completed a sample EMA prompt during the session to ensure that they understood all terminology employed in the presented questions. Particular attention was paid to ensuring that participants understood the definition of NSSI, as well as NSSI urges. The next day, participants began to receive text messages including a link to a Qualtrics questionnaire. Participants received four questionnaire links per day for a total of 10 days. The first questionnaire of the day was pre-programmed to align with participants' typical wake-time and assessed sleep indices; these data were not analyzed in the current study. Participants also completed three identical signal-contingent questionnaires within a 12-h window of their choosing (e.g., 10am-10pm). The timing of alerts for these three signal-contingent questionnaires were randomized, such that participants received one alert within a morning, afternoon, and evening block. Each of these three alerts was randomized such that no two alerts were less than 90 min apart. Participants were instructed to complete the survey as soon as possible after receiving the alert and were informed that they would only receive credit for surveys completed within 30 min of receiving the alert in order to encourage swift responding. Participants received course credit for completing the EMA study protocol. To increase adherence to the EMA protocol, participants were granted the option of an additional course credit or $15 for completion of at least 85% of the surveys during the ten-day period within the allotted 30 min. The signal-contingent questionnaires prompted participants to report on a range of experiences, emotions, and behaviors. In the current study, only the questions pertaining to NA, urgency, and NSSI urge level were analyzed. Each signal-contingent questionnaire took an average of 2.8 min to complete.

Inclusive of all signal-contingent alerts (3x daily surveys), participants completed 88.93% of the 30 alerts over the 10-day period (M = 26.68; SD = 3.49; total completed alerts ~ 1600). Participants completed 71.60% (M = 21.48; SD = 5.27) of the 30 randomized signal-contingent surveys within a 30-min period after receiving the alert and 78.67% (M = 23.60; SD = 4.62) within a 60-min period after receiving the alert. Including prompts responded to by participants within 60 min of receiving the alert allowed us to include approximately 90% of the available data (completed signal-contingent survey alerts), and thus, all alerts completed within 60 min (n = 1427 alerts) were included in the current analyses in order to augment power.

1.3. Measures

1.3.1. Screener

Lifetime History of NSSI. The Deliberate Self Harm Inventory (DSHI; Gratz, 2001) assesses the frequency, duration, and forms of NSSI (e.g., cutting, carving, burning, biting, head-banging). The DSHI asks how often the participant has engaged in each of 17 types of NSSI behaviors with the prompt, "Have you ever intentionally (i.e., on purpose) _____?" For each of the 17 types of NSSI behaviors endorsed, respondents are asked about age at onset, frequency, recency, years of engagement, and whether the behavior has ever resulted in a hospitalization or required medical treatment. Research has supported the DSHI's internal consistency, test-retest reliability, and construct, discriminant, and convergent validity in a university-student sample (Fliege et al., 2006; Gratz, 2001).

1.3.2. In-person session

Lifetime History of NSSI. The Self-Injurious Thoughts and Behaviors Interview (SITBI; Nock et al., 2007) is a structured interview that assesses the presence, frequency, and characteristics of a wide range of self-injurious thoughts and behaviors, including NSSI, suicidal ideation, suicide plans, suicide gestures, and suicide attempts. In the present study, the SITBI measure of lifetime history of NSSI was used to confirm lifetime engagement in repetitive NSSI. This interview has demonstrated strong psychometric properties and has been used in various clinical and non-clinical settings (Nock et al., 2007). The SITBI has demonstrated inter-rater reliability ($\kappa = 0.99$), construct validity, and test–retest reliability ($\kappa = 0.70$) (Nock et al., 2007).

Response Inhibition to Self-Harm Stimuli. The Emotional Stop-Signal Task (ESST; Allen & Hooley, 2015) paradigm is a measurement of motor impulse control in response to affective stimuli. Stimuli consisted of randomly presented neutral, negative, and positive images from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) in addition to a separate category of stimuli depicting various stages of self-cutting.

Participants were given two main instructions. First, participants were asked to indicate the valence of each image as positive or negative "as quickly and accurately as possible" by pressing corresponding keys on a computer keyboard. Second, participants were informed that a subset of trials include an auditory "stop-signal" tone that accompanied some images after a brief, variable delay (50-1150 ms). If the stop-signal was present, participants were directed to refrain from responding to stimulus valence and to not press a key, i.e., to inhibit prepotent motor responses accompanying emotional reactions to the images. Commission errors ("false alarms") occur when participants fail to inhibit their keyboard response to an image during stop-signal trials. The stop-signal delay begins at 250 ms post-stimulus onset and is dynamically adjusted using a 50 ms staircase tracking procedure, such that the delay is increased by 50 ms following each successful inhibition and conversely decreased by 50 ms after each false alarm. This staircase function is used to ensure that participants achieve a 50% total commission error rate (approximately) across all stimulus categories; if we predicted no differences in emotional response inhibition as a function of image content, we would expect that about half of stop trials would accordingly produce false alarms, regardless of the presented stimulus. Deviations from this 50% commission error rate *within* each specific stimulus category thus indicate the relative ease or difficulty of inhibiting emotional reactions to the content in that particular type of image (e.g., self-cutting). Akin to prior research (e.g., Allen & Hooley, 2015), in the present study, inhibitory control over emotional reactions to self-harm stimuli was operationalized as the percentage of commission errors made during stop-signal trials with NSSI images relative to the total number of stop-signal trials during which NSSI images were presented, while controlling for the rate of false alarms to neutral stimuli (as an index of general response inhibition). Thus, a higher NSSI commission error rate represents poorer emotional response inhibition *specifically* to stimuli depicting self-harm.

While commission error rates are not traditionally used to index response inhibition, accumulating evidence supports the validity of this approach (Allen & Hooley, 2015, 2019; Allen, Sammon, Fox, & Stewart, 2020). Provided that participants achieve an overall commission error rate of approximately 50% across all stimulus categories (which is the goal of the delay algorithm), we should not observe stimulus-specific deviations from this baseline rate *unless* there are actual differences in the ability to inhibit responses to different types of stimuli. Past work has consistently found image valence effects on ESST false alarm rates across stimulus categories, suggesting an appreciable signal-to-noise ratio for stimulus-specific commission error rates as a metric of within-person differences in emotional response inhibition.

1.3.3. Ecological momentary assessment

Urgency. In the current study, three items were adapted from the negative urgency subscale of the UPPS-P Impulsivity Scale (UPPS–P; Lynam, Smith, Whiteside, & Cyders, 2006) and included in the EMA signal contingent surveys to examine momentary urgency. The UPPS-P is a 59-item scale that assesses five traits related to impulsive behaviors: negative urgency, positive urgency, lack of perseverance, lack of planning, and sensation seeking. The UPPS-P has demonstrated good internal consistency in prior studies (e.g., Cyders & Smith, 2007; Liu & Kleiman, 2012). The three items consisted of, "Right now, I feel like doing something I will later regret in order to make myself feel better now," "Right now, it feels hard to resist acting on my feelings," and "Right now, it feels hard to keep my feelings under control." Items were rated on a Likert scale from 0 (*not at all)* to 9 (*very much*) with higher scores indicating greater momentary urgency. The mean of the three items generated a total score. In addition to this momentary average, we calculated daily averages within each person and a person average. Reliability estimates indicated excellent reliability for average person urgency ratings across the EMA period ($R_{KF} = 0.99$), adequate reliability at the day level ($R_{1R} = 0.68$) and fair reliability at the occasion level ($R_{1R} = 0.56$).

Negative Affect. To measure NA, the signal contingent survey asked participants to respond to the prompt, "Right now, to what extent are you feeling …" in the context of three NA-related states: "sad," "lonely," and "hopeless." Participants rated each item on a Likert scale from 0 (*not at all)* to 9 (*very much*) with higher scores indicating greater levels of NA. The mean of the three items generated a total score. In addition to this momentary average, we additionally calculated daily averages within each person and a person average. Reliability estimates indicated excellent reliability for average person NA ratings across the EMA period ($R_{KF} = 0.99$), and adequate reliability at the day level ($R_{1R} = 0.74$) and at the occasion level ($R_{1R} = 0.63$).

NSSI Urge. To measure NSSI Urge, the signal contingent survey included the prompt, "Right now, how intense is your urge to engage in non-suicidal self-injury?" Participants rated this item on a Likert scale from 0 (*not at all)* to 9 (*very much*), with higher scores indicating greater momentary urge to engage in NSSI.

NSSI Behavior. To measure NSSI behavior, the signal contingent survey included the prompt, "Since the last alert, have you engaged in non-suicidal self-injury?" Participants responded yes or no. This question was included to provide descriptive statistics about our sample; we were not powered to examine NSSI behavior in this study.

1.3.4. Analytic strategy

Generalized linear multi-level models (MLM) with restricted maximum likelihood estimation accounted for the nesting of the EMA data (i.e., observations nested within days nested within persons) and uneven spacing of observations across episodes and persons. Models had three levels (occasion, day, and person) and included a random intercept at the person-level. NSSI urge was the criterion, which we treated as a count variable due to the relative sparsity of urge ratings above '1'. We present results from models using a Poisson distribution. Overdispersion can occur with the Poisson distribution and can lead to the inflation of significance estimates. Examination of the ratio of the sum of squared Pearson residuals and the residual degrees of freedom, an estimation of overdispersion, revealed no evidence for overdispersion (range = 0.47 - 0.66; Bolker, 2019; Gelman & Hill, 2007). The ratio of observed to predicted number of zeros for NSSI urges was close to 1 (0.96), indicating that NSSI urges was not zero inflated beyond what is appropriate for the Poisson distribution (Lüdecke, Makowski, Waggoner & Patil, 2020). Analyses were performed in R using the glmer function from the package lme4 (Bates, Mächler, Bolker, & Walker, 2015). Models included 1427 observations over 577 days across 60 participants.

The primary predictors of interest were occasion-level NA and urgency (measured at the same occasion as NSSI urge intensity), and person-level emotional response inhibition to self-harm stimuli. We additionally included in models day- (i.e., the day average of occasion-level estimates) and person-level (i.e., the person average of day-level estimates) NA and urgency to adjust for these effects. Indicators were centered on the cluster mean at the next level, with person-level estimates centered within the sample mean. This was done to disaggregate effects at these different levels (Curran & Bauer, 2011).

We conducted main effect models, followed by two sets of interaction models. In the first interaction model, we examined the interaction between occasion-level NA and urgency, and person-level emotional response inhibition to self-harm stimuli. We then conducted these same models, while adjusting for the effects of person-level emotional response inhibition to neutral stimuli. Emotional response inhibition to self-harm stimuli and neutral stimuli were sample-centered. Reflecting our primary interest in the occasion-level and for parsimony, we only included in models the interactions for occasion-level NA and urgency with emotional response inhibition to self-harm and neutral stimuli.

2. Results

2.1. Descriptives

The sample reported an average of 57 lifetime NSSI acts (Range: 2–720; SD = 128.47) and 7.7 past-year NSSI acts (Range: 0–180; SD = 26.53). Retrospectively, at baseline, approximately 45% (n = 27) of the sample endorsed engaging in NSSI over the past year, 20% (n = 12) over the past month, and 5% (n = 3) over the past week. Also at baseline, approximately 50% (n = 29) of the sample endorsed experiencing an NSSI urge over the past year, 31.7% (n = 19) over the past month, and 15% (n = 9) over the past week. Participants reported engaging in an average of two NSSI methods over their lifetimes (SD = 1.10). The majority of participants endorsed cutting/carving skin (76.7%; n = 46). Approximately 18.3% reported burning skin (n = 11), 6.7% (n = 4) inserting sharp objects underneath skin/nails, 20% (n = 12) picking areas of the body to the point of drawing blood, 23.3% (n = 14) hitting self, 1.7% (n = 1) giving self a tattoo, and 26.7% (n = 16) other methods.

Findings suggested that ESST response inhibition to self-harm stimuli did not differ between participants with versus without a history of NSSI ($t(116) = -0.08$, $p = .938$). Within the NSSI group, the mean ESST response inhibition to self-harm stimuli was 0.56 (SD = 0.20).[1] The no-signal reaction time (i.e., mean reaction time on trials without a stop-signal) was 755.14 ms (SD = 103.97), the stop-signal reaction time (i.e., an index of overall emotional response inhibition) was 289.56 ms (SD = 67.66), the total omission errors across stimulus categories was 4.74 (SD = 4.81), and the total commission errors across stimulus categories was 0.47 (SD = 0.08).

Over the EMA period, 41.7% (n = 25) of the sample reported an NSSI urge. Participants reported an NSSI urge on 8.2% of prompts (n = 117). On prompts with an NSSI urge, mean intensity rating of urge was 2.66 (SD = 2.09). Approximately 13.33% (n = 8) of participants reported NSSI behavior on 0.6% of the total prompts (n = 9 reported NSSI acts). Across the EMA period, mean NA was 1.84 (SD = 2.03) and mean urgency was 0.96 (SD = 1.58). Prior to centering, NA and urgency were correlated ($r[1425] = 0.622$, $p < .001$). NSSI urge intensity was correlated with both NA ($r[1425] = 0.385$, $p < .001$) and urgency ($r[1425] = 0.407$, $p < .001$). After centering, occasion-level ($r[1425] = 0.227$, $p < .001$), day-level ($r[1425] = 0.176$, $p < .001$), and person-level NA and urgency ($r[1425] = 0.725$, $p < .001$) continued to be correlated. There was sufficient variance at the level of occasion, day, and person for negative affect (ICCs = 27%, 15%, 58% respectively) and urgency (ICCs = 37%, 17%, 46% respectively), which justified our three-level approach to analysis.

2.2. Occasion-level negative affect and urgency with NSSI urges

In separate models, we examined the association of NA with NSSI urges, and the association of urgency with NSSI urges. Results are presented in Table 1. Moment-, day- and person-level NA were associated with reporting a stronger NSSI urge when modeled simultaneously. Similarly, moment-, day-, and person-level urgency also were associated with reporting a stronger NSSI urge. Finally, we examined a model that included NA, urgency, and their interaction. There were no changes to main effects, except that person-level NA was no longer significant. The interactions of NA and urgency at occasion-, day-, and person-level all were not significant.

Table 1
Associations of negative affect and urgency with NSSI urge.

	IV: Negative Affect			IV: Urgency		
	Est.	95% CI	*p*	Est.	95% CI	*p*
Predictors						
Intercept	−2.06	[-8.98, 4.86]	.559	−0.88	[-7.36, 5.6]	.790
Occasion-level	0.44	[0.34, 0.54]	<.001	0.41	[0.35, 0.48]	<.001
Day-level	0.59	[0.49, 0.69]	<.001	0.66	[0.58, 0.74]	<.001
Person-level	0.80	[0.35, 1.26]	.001	1.39	[0.78, 2.00]	<.001
Covariates						
Study day	−0.05	[-0.1, −0.01]	.020	−0.02	[-0.07, 0.02]	.329
Age	−0.11	[-0.45, 0.24]	.539	−0.16	[-0.48, 0.17]	.345

Note. N = 60 individuals, 1427 observations. CI = confidence interval. Results presented are from Poisson models.

2.3. Cross-level interactions with emotional response inhibition to self-harm stimuli

Prior to examining interactions, we first conducted a model for the main effect of emotional response inhibition to self-harm stimuli. In this model, emotional response inhibition to self-harm stimuli was not associated with NSSI urge intensity (Est. = 1.79, 95% CI = [-2.62, 6.20], $p = .427$). To examine interactions with emotional response inhibition to self-harm stimuli, we created separate models for NA and urgency. For these models, the interactions of occasion-level NA and urgency, respectively, with emotional response inhibition to self-harm stimuli were of primary interest, while day- and person-level main effects were included to adjust for their effects. Results are presented in Table 2. For NA, there was a significant interaction between occasion-level NA and emotional response inhibition to self-harm stimuli. To understand this interaction, we calculated simple slopes and found that the association of NA and NSSI urge intensity was significant at both 1 SD above (Est. = 0.58, 95% CI = [0.44, 0.71], $p < .001$) and below (Est. = 0.26, 95% CI = [0.10, 0.41], $p = .001$) the mean for emotional response inhibition, but was stronger at 1 SD above the mean. This indicates that participants who exhibited greater deficits in emotional response inhibition to self-

Table 2
Interactions of negative affect and urgency with ESST NSSI response inhibition to self-harm stimuli predicting NSSI urge.

	IV: Negative Affect			IV: Urgency		
	Est.	95% CI	*p*	Est.	95% CI	*p*
Predictors						
Intercept	−1.85	[-8.35, 4.66]	.581	−0.72	[-7.06, 5.61]	.822
Occasion-level	0.42	[-0.32, 0.52]	<.001	0.39	[0.32, 0.46]	<.001
Day-level	0.60	[0.50, 0.70]	<.001	0.67	[0.58, 0.75]	<.001
Person-level	0.74	[0.32, 1.17]	.001	1.37	[0.76, 1.97]	<.001
ESST NSSI RI	0.25	[-3.11, 3.61]	.881	−0.37	[-3.66, 2.92]	.827
Occasion-level x ESST NSSI RI	0.83	[0.24, 1.43]	.011	0.40	[0.07, 0.73]	.016
Covariates						
Study day	−0.05	[-0.10, −0.004]	.031	−0.02	[-0.06, 0.02]	.349
Age	−0.11	[-0.44, 0.21]	.501	−0.16	[-0.48, 0.16]	.320

Note. N = 60 individuals, 1427 observations. CI = confidence interval. ESST = Emotional Stop-Signal Task, RI = Response Inhibition. Results presented are from Poisson models.

[1] Emotional response inhibition variables from the ESST are reported as proportions, i.e., commission error (or "false alarm") rates during stop trials within each stimulus category (Neutral, Positive, Negative, & NSSI images).

harm stimuli and who reported higher NA in a given moment reported a stronger NSSI urge at that same moment. When we conducted the same model, adjusting for person-level response inhibition to neutral stimuli, this interaction remained significant. Results are presented in Table 3.

For urgency, there was a similar interaction between occasion-level urgency and emotional response inhibition to self-harm stimuli (Table 2). We again calculated simple slopes and found that the association of urgency and NSSI urge intensity was significant at both 1 SD above (Est. = 0.46, 95% CI = [0.39, 0.54], $p < .001$) and below (Est. = 0.32, 95% CI = [0.22, 0.42], $p < .001$) the mean for emotional response inhibition, but was stronger at 1 SD above the mean.[2] When we conducted the same model, adjusting for person-level response inhibition to neutral stimuli, this interaction was no longer significant (Table 3). There were no significant main effects for response inhibition to self-harm nor to neutral stimuli in either model.[3]

Table 3
Interactions of negative affect and urgency with ESST NSSI response inhibition to self-harm stimuli predicting NSSI urge, adjusting for neutral response inhibition.

	IV: Negative Affect			IV: Urgency		
	Est.	95% CI	*p*	Est.	95% CI	*p*
Predictors						
Intercept	−2.58	[-9.61, 4.45]	.472	−1.18	[-8.00, 5.64]	.735
Occasion-level	0.40	[0.19, 0.61]	<.001	0.30	[0.16, 0.44]	<.001
Day-level	0.60	[0.50, 0.70]	<.001	0.66	[0.58, 0.74]	<.001
Person-level	0.73	[0.31, 1.16]	.001	1.33	[0.73, 1.93]	<.001
ESST NSSI RI	−0.24	[-3.70, 3.21]	.890	−0.38	[-3.73, 2.96]	.822
Occasion-level x ESST NSSI-RI	0.85	[0.20, 1.5]	.010	0.24	[-0.14, 0.62]	.211
Covariates						
ESST Neutral-RI	1.56	[-2.79, 5.90]	.482	0.13	[-4.10, 4.37]	.951
Occasion-level x ESST Neutral-RI	0.06	[-0.56, 0.69]	.842	0.29	[-0.10, 0.67]	.142
Study day	−0.05	[-0.1, −0.004]	.033	−0.02	[-0.07, 0.02]	.334
Age	−0.10	[-0.43, 0.23]	.548	−0.14	[-0.46, 0.18]	.393

Note. $N = 60$ individuals, 1427 observations. CI = confidence interval. ESST = Emotional Stop-Signal Task, RI = Response Inhibition. Results presented are from Poisson models.

3. Discussion

The current study found evidence for main effects associations of occasion-level NA and urgency with NSSI urge intensity, providing greater corroboration that elevated NA and the impulsive urge to alter affective experiences are concomitants of NSSI urges (Rodríguez-Blanco et al., 2018). However, contrary to hypotheses, there was no interaction between occasion-level NA and urgency in predicting NSSI urge intensity. Additionally, we did not observe a direct association of emotional response inhibition to self-harm stimuli with occasion-level NSSI urge intensity. We did, however, find evidence that the degree of impaired emotional response inhibition to self-harm stimuli impacts the relationship between momentary NA and NSSI urge intensity, even when adjusting for emotional response inhibition to neutral stimuli.

Our findings highlight that, among individuals with a history of repetitive NSSI, occasion-level NA is associated with NSSI urge intensity. In line with a large body of literature suggesting that the most prevalent function of NSSI is to reduce aversive affective experiences (Rodríguez-Blanco et al., 2018), we found that occasions, as well as days and people, characterized by higher NA were associated with stronger NSSI urges. We similarly found that occasions, as well as days and people, characterized by higher urgency were associated with stronger NSSI urges. Cross-sectional (e.g., Hamza et al., 2015) and longitudinal (Riley et al., 2015b) evidence suggests that negative urgency is related to and predictive of NSSI. Our results extend this literature to the natural environment, where individuals experience NSSI urges in their daily lives, and validate prior work suggesting that day-level general impulsivity is associated with NSSI acts (Ammerman et al., 2017). To our knowledge, this is the first EMA study examining the relationship between occasion-level urgency and NSSI urge intensity. Our hypothesis that the greatest NSSI urges would be expected at high levels of both NA and urgency was not supported. Rather, our findings suggest that self-reported occasion-level NA and urgency may be conceptualized best as having independent associations with NSSI urge intensity.

Our preliminary analyses suggest that emotional response inhibition to self-harm stimuli did not differ between participants with and without a history of repetitive NSSI. In line with this null finding, we did not find evidence supporting a main effect association of emotional response inhibition to self-harm stimuli with the momentary strength of the NSSI urges. However, our results demonstrate that performance on this task independently moderated associations between occasion-level NA and the intensity of NSSI urges. Specifically, our findings suggest that emotional response inhibition deficits to self-harm stimuli may pose vulnerability for increased NSSI urge intensity during real-time states of elevated NA. Given that this association remained after adjusting for response inhibition to neutral stimuli, our results offer evidence that this association is specific to response inhibition to self-harm stimuli. It is possible that individuals with this deficit might have difficulty inhibiting their self-injury urge impulses in the context of negative affective risk states, thus facilitating stronger urges. The results complement previous daily diary work that found that greater baseline self-report negative urgency strengthened the association between daily sadness and NSSI urges (Bresin et al., 2013). Our findings and those of Bresin et al. (2013) together indicate that trait-level negative urgency may augment the association between occasion-level negative emotions and NSSI urge intensity.

The present findings support the theory that skills training to develop alternative ways of regulating aversive affect and affect-driven states such as urgency, may be an effective clinical approach for reducing NSSI

[2] As described in the analytic strategy, models used a Poisson distribution, which we believe to be the most appropriate model to run, due to the absence of evidence for overdispersion. However, we also conducted models using normal, negative binomial, and zero-inflated Poisson (ZIP) distributions. Results from models using a normal distribution did not differ from models using a Poisson distribution. For the negative binomial models, the interactions for ESST response inhibition and negative affect (*Est.* = 0.74, 95% CI = −0.21, 1.69, p = .126) and urgency (*Est.* = 0.53, 95% CI = −0.14, 1.19, p = .119) were not significant, though the estimates were of similar magnitude and in the same direction as those reported in Table 2. This, however, is not particularly surprising as the difference between Poisson and negative binomial models is that the latter include a parameter to account for overdispersion. In the absence of overdispersion, this could lead to an overestimation of the variance in NSSI Urges, resulting in incorrectly higher standard errors and decreased significance. For the ZIP models, similar to negative binomial models, the interactions for ESST response inhibition and negative affect (*Est.* = 0.56, 95% CI = −0.07, 1.18, p = .082) and urgency (*Est.* = 0.30, 95% CI = −0.20, 0.81, p = .235) were not significant, though the estimates were of similar magnitude and in the same direction. However, the zero-inflation portion was not significant and there was no evidence of zero inflation of NSSI urges, indicating that the Poisson distribution is more appropriate.

[3] Findings held when the sample was restricted to only participants with a history of 5 or more NSSI acts (n = 46) (See Supplementary Tables 1–3).

urges and therefore NSSI behaviors. Dialectical Behavior Therapy (Linehan et al., 2006) emotion regulation and distress tolerance skills may be particularly relevant skills. Our findings indicate that these types of interventions may be especially effective for individuals who present with deficits in cognitive control, specifically related to difficulties regulating negative emotional reactions and behavioral responses to negative emotions in the presence of NSSI-related stimuli.

3.1. Limitations

It is essential to consider study limitations when interpreting the findings. First, although a strength of the current study was its focus on the clinically relevant but understudied topic of NSSI urges, it was not designed to assess predictors of NSSI acts. Urges are more frequent, facilitating the assessment of their strength in the moment, repeatedly across time. Additionally, it is arguable that urges are less constrained by situation or context. In contrast, individuals may only be able to engage in NSSI under somewhat more restricted circumstances (e.g., at home, when alone; Glenn & Klonsky, 2009). As a result, examining urges allowed us to examine more fully the proximal roles of NA and urgency in NSSI maintenance. Nevertheless, the generalizability of findings to engagement in NSSI is unclear and warrants investigation in future work. Indeed, it has been postulated within the craving literature that urges may occur *only* under circumstances when engagement in a behavior is thwarted, and further, that urges may not be necessary for behavior engagement (Tiffany, 1990). Such assertions may point to an important distinction between the psychological state of experiencing an urge to engage in NSSI versus actually engaging in NSSI. Further, examining whether these findings are generalizable is essential, as poor response inhibition may very well have a stronger relationship with action (engagement in NSSI) than urges, particularly in the context of negative affect and urgency. Second, the number of reported NSSI urges was also relatively low (41.7% of participants; 8.2% of prompts; n = 117), but comparable to previous EMA examinations of NSSI urges in undergraduates (e.g., Bresin et al., 2013). Third, participants only completed three assessments per day. This precluded us from examining lagged effects over time *within days*, as such analyses would be limited to only two assessments per day, greatly reducing power which would have limited our ability to carry out the cross-level interaction analyses. We strongly encourage future research to examine these within-day lagged effects in order to shed light on the directionality of the proposed relations. Fourth, the majority of the sample was female, and it is unknown whether findings generalize to males, as well as to non-college samples.

Fifth, the present findings' interpretability is somewhat constrained by the design of the ESST version we used in this study. For example, this ESST uses a single staircase tracking algorithm to adjust stop-signal delay. This design feature allows us to efficiently capture varying capacities for emotional response inhibition *within individuals* as a function of image content (by examining patterns of commission errors across stimulus categories) but precludes estimation of stimulus-specific stop-signal reaction time, the most commonly derived metric of response inhibition in this type of task. Finally, we were likely underpowered to detect cross-level interactions (i.e., interactions of occasion-level variables and emotional response inhibition). Interactions that include predictors at the person-level require significant numbers of participants to have power to detect medium to small effect sizes in two-level models (Arend & Schäfer, 2019). However, this power-related limitation does not apply to effects that were solely at the occasion-level. Future investigations employing larger sample sizes and with samples with a more recent and severe history of NSSI are warranted in order to examine whether the present cross-level effect will replicate, and extend, to NSSI behavior.

4. Conclusion

The present study builds on limited prior EMA research examining the association between NA and NSSI urge intensity in that it is the first EMA study to examine the relationship between occasion-level urgency and NSSI. Our findings present initial evidence that *between-person* emotional response inhibition deficits to self-harm stimuli may increase the strength of NSSI urges *within person,* during real-time heightened NA. Importantly, the broader field of clinical science has yet to regularly incorporate objective metrics derived from behavioral tasks into EMA studies of psychopathology (Schatten, Allen, & Armey, 2019), particularly to examine the interplay of trait-level factors with state (i.e., occasion-level) affect. This is the first study to our knowledge to examine a theoretically relevant between-person behavioral measure of cognitive control as a moderator of a hypothesized state-level precipitant of NSSI urges, thus offering a unique contribution.

CRediT authorship contribution statement

Taylor A. Burke: contributed to the study design, data collection, analyses, and manuscript preparation. **Kenneth J.D. Allen:** and. **Ryan W. Carpenter:** contributed to the study design, analyses, and manuscript preparation. **David M. Siegel:** and. **Marin M. Kautz:** contributed to the study design, data collection, and manuscript preparation. **Richard T. Liu:** contributed to manuscript preparation. **Lauren B. Alloy:** contributed to the study design, data collection, and manuscript preparation.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

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