EXAMINING THE RELATIONSHIP BETWEEN COGNITIVE CONTROL AND NONSUICIDAL SELF-INJURY

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ABSTRACT

Nonsuicidal self-injury (NSSI), the deliberate self-destruction of one's own body tissue engaged in without associated suicidal intent, is a prevalent behavior among adolescents and young adults. The current study examined whether one aspect of cognitive control, inhibitory control in response to negative emotional stimuli, is associated with repetitive engagement in NSSI. It further sought to examine whether sleep deficiency/irregularity, stress, and reward sensitivity moderate this relationship. A multi-method approach (self-report, behavioral measures, actigraphy) was employed to sensitively probe these relationships among 114 late adolescents with and without a history of repetitive NSSI. Findings suggested no relationship between inhibitory control in response to negative emotional stimuli and NSSI, as measured by a behavioral measure, but a significant positive relationship as measured by self-report. Stress and sleep irregularity, but not sleep deficiency or reward sensitivity, were associated with NSSI group status. Interaction analyses suggested that sleep irregularity and stress moderated the relationship between inhibitory control in response to negative emotional stimuli and NSSI. Results are discussed in terms of conceptual and clinical implications. Findings highlight the necessity of examining the temporal dynamics between the study's constructs and NSSI by employing an ecologically valid approach.

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CHAPTER 1

MANUSCRIPT IN JOURNAL ARTICLE FORM

Late adolescence is a period of normative social, biological, and psychological changes, many associated with increased risk for engagement in impulsive, and often self-destructive, behaviors, including nonsuicidal self-injury (NSSI). NSSI is the deliberate self-destruction of one's own body tissue engaged in without associated suicidal intent, and is a highly prevalent behavior among adolescents and young adults (Hamza, Stewart, & Willoughby, 2012). Furthermore, it is a major public health issue, as engagement in NSSI is associated with poor mental health outcomes and is a robust prospective predictor of suicidal behavior (Hamza et al., 2012). This study aims to attain a better understanding of developmental processes in late adolescence associated with heightened vulnerability for engagement in NSSI; it focuses specifically on clarifying the role of cognitive control in NSSI and in assessing sleep duration and regularity, stress, and reward sensitivity as moderators of this relationship.

Cognitive Control and Nonsuicidal Self-Injury

The functions of engagement in NSSI vary widely. However, perhaps the most well supported function of the behavior is affect regulation (Nock, 2009). Indeed, experimental and self-report findings consistently support that the majority of individuals engage in NSSI in order to regulate their affective experiences (Nock, 2009). In line with this, theory holds that those who self-injure may exhibit deficits in the cognitive control system, specifically in their ability to effectively modulate or inhibit behavior when experiencing intense negative emotions. This may be particularly true during adolescence when the cognitive control system normatively is still immature (Steinberg, 2010). Extant research is mixed regarding whether inhibitory control in response to neutral stimuli is associated with NSSI. Indeed, whereas numerous studies have found no such association between inhibitory control in response to neutral stimuli and NSSI (e.g., Allen & Hooley, 2015; Auerbach et al., 2014; Fikke et al., 2011; Glenn & Klonsky, 2010; Janis & Nock, 2009; Lengel, DeShong, & Mullins-Sweatt, 2016), one study did find that those with a history of self-injury evidenced degraded inhibitory control compared to those without a history (Meza, Owens, & Hinshaw, 2016).

However, more recent experimental research suggests that elevated cognitive control, *specifically in response to negative emotional stimuli*, serves as a protective factor against NSSI, whereas lower levels of cognitive control in response to negative emotional stimuli are a risk factor for greater engagement in NSSI (Allen & Hooley, 2015; Allen & Hooley, 2019). In line with these findings, a recent-meta analysis suggests that a corresponding self-report measure of reduced inhibitory control in response to negative emotion, the UPPS-P Negative Urgency subscale, is reliably associated with NSSI (UPPS-P: Urgency, Premeditation (lack of), Perseverance (lack of), Sensation Seeking, Positive Urgency; Lockwood, Daley, Townsend, & Sayal, 2017). Thus, it seems possible that although those who self-injure may not differ in their ability to inhibit prepotent motor responses (or, impulses) in general, they may differ in their ability to inhibit motor responses in the context of negative emotional cues. Additional research is needed to replicate these findings.

Research is also needed to determine whether other developmentally-relevant factors may serve to protect against or augment risk for NSSI in the context of low cognitive control in response to negative emotion (e.g., Lockwood et al., 2017). The current study examines sleep deficiency and irregularity, acute stress, and reward sensitivity, three factors that are in flux during the adolescent developmental stage, that are associated with self-injury, and that may theoretically modulate the relationship between cognitive control and NSSI.

Sleep/Wake Cycle in Adolescence

In addition to changes in the development of the cognitive control system, adolescence is also characterized by radical changes in timing and amounts of sleep. Many adolescents begin to delay bedtime, develop irregular sleep schedules, and experience low sleep quality and duration (Carskadon & Acebo, 2002; Knutson, 2005). Indeed, mounting evidence suggests that rates of insufficient sleep reach high levels during this developmental period (Johnson, 2006; Roberts, Roberts, & Duong, 2008). Moreover, both cross-sectional and prospective research suggests that NSSI is related to sleep problems during adolescence. For example, among a large community sample of adolescents, poor sleep quality and frequent nightmares were found to be independent cross-sectional associates of adolescent NSSI, after controlling for demographic characteristics and mental health variables (Liu, Chen, Bo, Fan, & Jia, 2017). Among a community clinic sample of adolescents, those reporting severe sleep complaints were significantly more likely to have engaged in NSSI than those with minimal sleep complaints (McGlinchey, Courtney-Seidler, German, & Miller, 2017). Among a large sample of adolescents, those who experienced greater divergence between their weekday and weekend sleep durations were significantly more likely to endorse engaging in a suicide attempt or NSSI over the prior year (Kang et al., 2014). Moreover, in the only longitudinal study to examine the relationship between sleep and NSSI, poor sleep quality predicted onset of repetitive NSSI among females over a one-year follow-up period (Lundh, Bjärehed, & Wångby-Lundh, 2013).

Despite the growing evidence suggesting that poor sleep quality is related to NSSI, very few studies have examined this relationship and only one has employed longitudinal methodology. Moreover, the extant studies exhibited important limitations, such as the use of a one-item self-report measure of sleep quality (Lundh et al., 2013), the use of a measure derived post-hoc from a diagnostic interview for depression (McGlinchey et al., 2017), and failing to differentiate between suicidal and nonsuicidal self-injurious behaviors (Kang et al., 2014). Most importantly, however, no studies have utilized objective measures of sleep when examining its relationship with NSSI. Notably, research has found poor to moderate correlations between self-reported sleep and objectively measured sleep (e.g., Girschik, Fritschi, Heyworth, & Waters, 2012; Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). Thus, studies using objective measures of sleep (i.e., actigraphy) are sorely needed within a longitudinal design to avoid the low reliability of self-report measures and to provide sounder evidence for determining whether there is a predictive relationship between sleep and NSSI.

Moreover, no studies to our knowledge have examined whether sleep deficiency or irregularity moderates the relationship between deficits in cognitive control in response to negative emotions and NSSI, despite mounting evidence that sleep problems affect cognitive control. Telzer and colleagues (2013) found that among adolescents, lack of sleep led to poorer response inhibition. Moreover, experimental research suggests that sleep deprivation results in poorer performance on a behavioral inhibition task in response to negative emotional stimuli, but does not affect performance in response to positive or neutral stimuli (Anderson & Platten, 2011). Thus, it is plausible that sleep deficiency and irregularity may tax the cognitive control system, particularly in the context of negative emotional stimuli. Given prior research suggesting that poorer cognitive control in response to negative emotional stimuli is associated with NSSI, it is hypothesized that heightened sleep deficiency and irregularity will augment this relationship.

Stress in Adolescence

Adolescence is also associated with increasing rates of exposure to stressful life events (e.g., Ge, Lorenz, Conger, Elder, & Simons, 1994) as well as increases in stress reactivity (Stroud et al., 2009). The experience of stress often precedes engagement in NSSI (Liu, Cheek, & Nestor, 2016), likely in part contributing to the surge in NSSI in adolescence. Indeed, empirical evidence suggests that many adolescents report engaging in NSSI as a means to cope with negative affect experienced due to acute stressors (Liu et al., 2016; Nock & Mendes, 2008). Cross-sectional research has suggested that compared to adolescents without a history of NSSI, those with a history of the behavior report a greater occurrence of lifetime stressful events (Cerutti, Manca, Presaghi, & Gratz, 2012) and past year stressful events (Baetens, Claes, Muehlenkamp, Grietens, & Onghena, 2011; Garrison et al., 1993; Tang et al., 2016). Moreover, recent longitudinal research has provided preliminary evidence of a predictive relationship between stress and NSSI. Using an idiographic approach, Liu and colleagues (2014) found that greater rates of negative life events predicted greater engagement in NSSI, after adjusting for both gender and concurrent depressive symptoms. Additionally, stressors may serve as proximal risk factors for engagement in NSSI (Hankin & Abela, 2011) and may predict the onset of

NSSI among adolescents (Voon, Hasking, & Martin, 2014). In line with these findings, a recent meta-analysis found a significant modest association between stressful life events and NSSI (Liu et al., 2016).

Like sleep deficiency and irregularity, a significant body of research suggests that the experience of stress similarly may tax cognitive processes (e.g., Mather & Lighthall, 2012; Porcelli & Delgado, 2009; Preston, Buchanan, Stansfield, & Bechara, 2007). Indeed, Rahdar and Galván (2014) found that greater experiences of daily stress measured in an ecological momentary assessment (EMA) design impaired response inhibition in adolescents and adults, and did so more strongly for adolescents as compared to adults. Moreover, among adolescents, experiencing high stress was associated with less recruitment of the dorsolateral prefrontal cortex (DLPFC), a brain region involved in cognitive control, during inhibition as compared to when they were experiencing low stress; this finding was not exhibited among adults (Rahdar & Galván, 2014). Experimental research also has found that acute stress impairs cognitive control processes underlying flexible task switching (Plessow, Kiesel, & Kirschbaum, 2012). In line with this finding, recent research also suggests that stress reduces attentional control and impairs functional connectivity in the frontoparietal network, which is responsible for attentional shifting (Liston, McEwen, & Casey, 2009). Despite a clear effect of stress on numerous aspects of cognitive control, including response inhibition, there is some mixed evidence regarding the effect of stress on response inhibition task performance (e.g., Galván & McGlennen, 2012). Moreover, no research to our knowledge has examined whether stress specifically impacts cognitive control in response to negative emotion. Thus, additional research is needed to clarify the relationship between stress and response inhibition, particularly in the context of negative emotion. It is hypothesized that experiencing high levels of acute stress also may tax cognitive control in response to negative emotion, and thus, strengthen its relationship with NSSI.

Reward Sensitivity in Adolescence

Reward sensitivity may be defined as one's reactivity and responsiveness to incentive. Reward sensitivity develops in a curvilinear manner throughout adolescence, peaking in mid-adolescence (e.g., Steinberg, 2010). Previous research has found that heightened reward sensitivity is associated with engagement in NSSI (Cerutti et al., 2012), frequency of NSSI (Burke et al., 2015; Cerutti et al., 2012; Jenkins, Seelbach, Conner, & Alloy, 2013), and number of NSSI methods employed (Jenkins et al., 2013). However, there is some mixed evidence regarding the relationship between reward sensitivity and NSSI (e.g., Ammerman, Kleiman, Jenkins, Berman, & McCloskey, 2017; Jenkins et al., 2013).

The Dual Systems model of adolescent neurodevelopment posits that risk-taking behavior peaks during adolescence as a result of an imbalance between two neural systems that have divergent patterns of development: the *affective system*, which is involved in reward sensitivity and develops in a curvilinear manner, peaking in mid-adolescence; and the aforementioned *cognitive control system*, which is involved in inhibitory control, and develops in a linear fashion over adolescent development, peaking in the mid-twenties (Steinberg, 2010). Although originally developed to explain the surge of risk-taking behavior in adolescence, it is possible that the Dual Systems model of adolescent neurodevelopment also may help to elucidate the surge in engagement in NSSI during this time period. NSSI shares important features of common health risk behaviors (e.g., risky sexual behavior, substance abuse). Indeed, engagement in NSSI inherently involves risk for significant bodily damage and is engaged in for a host of intra- and inter-personal rewards (Nock, 2009). Moreover, the behavior is often immediately reinforced (reduces negative affect, increases positive affect; Nock, 2009).

Thus, we posit that reward sensitivity may moderate the relationship between cognitive control in response to negative emotional stimuli and NSSI. Specifically, among late adolescents who have a low or moderately sensitive reward system, the cognitive control system may be sufficiently developed to override the reward system and inhibit NSSI. On the other hand, among adolescents and young adults who have a hypersensitive reward system, the cognitive control system may be insufficiently robust to override the reward system and inhibit NSSI.

An Integrated Developmentally Informed Model of the Relationship between Cognitive Control and NSSI

The current study evaluates whether individual differences in cognitive control in response to negative emotional stimuli are associated with NSSI, especially when considering cognitive control's interplay with other developmentally-informed vulnerabilities for the behavior: sleep deficiency/irregularity, stress, and reward sensitivity. Specifically, this study examines whether high levels of sleep deficiency and irregularity, stress, and reward sensitivity may tax the cognitive control system, thereby strengthening the relationship between cognitive control in the context of negative emotion and NSSI. Although extant research has evaluated each of the components of the proposed model separately, this body of work has been limited by single-method designs, and in most cases, studying each component in isolation. Therefore, the current study fills these gaps in the literature by utilizing a multi-method design in order to examine the dynamic relationships between each of these constructs.

Primary Study Hypotheses

First, in line with research suggesting poorer cognitive control in response to negative emotional stimuli is positively associated with NSSI (Allen & Hooley, 2015), it is hypothesized that both behavioral and questionnaire measures of cognitive control in response to negative emotional stimuli will be associated with NSSI history (Hypothesis 1). Second, based on evidence suggesting that diminished sleep quality, sleep disturbance, and irregular sleep/wake cycle is associated with engagement in NSSI (Kang et al., 2014; Lundh et al., 2013; McGlinchey et al., 2017), it is hypothesized that diminished time asleep, as measured by self-report and actigraphy, and irregular sleep/wake cycle, as measured by actigraphy, will be associated with NSSI history at baseline (Hypothesis 2a). Further, based on research suggesting that sleep deficiency and irregularity tax the cognitive control system (e.g., Anderson & Platten, 2011), it also is hypothesized that irregular sleep/wake cycle and diminished time asleep will affect cognitive control, thus moderating its association with baseline NSSI group status. Thus, it is posited that participants with high levels of sleep deficiency and irregularity and low levels of cognitive control will be most likely to endorse a positive NSSI history at baseline (Hypothesis 2b).

Third, given evidence suggesting that stressful life events predict NSSI (for a review, see Liu et al., 2016), it is hypothesized that number of recent stressful life events will be associated with NSSI history at baseline (Hypothesis 3a). And, based on research suggesting that stress may tax the cognitive control system (e.g., Rahdar & Galván, 2014), it is also hypothesized that the experience of recent stress will affect cognitive control, thus moderating its association with baseline NSSI group status, such that participants experiencing high levels of stress and low levels of cognitive control will be most likely to endorse a positive NSSI history at baseline (Hypothesis 3b).

Finally, in line with tenets of the Dual Systems model of adolescent neurodevelopment (Steinberg, 2008), as well as research suggesting that reward hypersensitivity and poorer cognitive control in response to negative emotional stimuli are positively associated with NSSI frequency (Burke et al., 2015 and Allen & Hooley, 2015, respectively), it is hypothesized that the relationship between behavioral and self-report measures of reward sensitivity and NSSI history at baseline will be moderated by behavioral and self-report measures, respectively, of cognitive control in response to negative emotional stimuli. Specifically, it is hypothesized that high reward sensitivity will be associated with a positive NSSI history (Hypothesis 4a) and that this relationship will be strongest when accompanied by low cognitive control (Hypothesis 4b).

Method

Participants

Participants in the current study were Temple University undergraduates. Two groups of participants were recruited: 57 with a history of repetitive NSSI and 57 without a history of NSSI. Inclusion criteria for both groups included being between the ages of 18 and 22, having normal or corrected vision, and reporting fluency in English. Additional inclusion criteria for the NSSI group included having a lifetime history of at least two distinct episodes of NSSI engagement, determined by a self-report measure of NSSI (Gratz, 2001) and an interview (Nock, Holmberg, Photos, & Michel, 2007).

Exclusion criteria for the control group included reporting a history of any engagement in NSSI or a history of a suicide attempt. Participants were not excluded from either group on the basis of any other clinical or demographic variables.

Procedure

Screening. Participants were recruited from Temple University introductory psychology classes through posting flyers around campus, and through the Temple Psychology Research Participation System (http://temple.sona-systems.com/default.asp), "Sona Systems." Undergraduates interested in the study had the opportunity to complete an online consent form and a brief online screener using Qualtrics, a secure and encrypted web data collection service, to determine their eligibility to complete the baseline in-person session and actigraphy follow-up period. The online screener inquired about demographic characteristics, reward sensitivity, cognitive control in the context of negative emotionality, symptoms of ADHD, suicide attempt history, and NSSI history. Participants were compensated with course credit for completing the online screener. Eligible participants were invited to schedule a baseline in-person session.

Part 1. At the baseline in-person visit, participants completed a written consent. Participants completed the Life Events Scale to assess recent acute stress, the Self-Injurious Thoughts and Behaviors Interview (SITBI; Nock et al., 2007) to confirm correct group membership, and interviews to assess history of mood disorders and Borderline Personality Disorder (BPD). Participants completed the Effort-Cost Computational Task to evaluate reward sensitivity and an amended version of the Stop Signal Task (Allen & Hooley, 2015) to assess cognitive control to three conditions: neutral, positive, and negative stimuli. The reward sensitivity and cognitive control tasks were counterbalanced. Finally, participants received a brief training on properly wearing wrist Actiwatches, which measure activity levels to objectively and reliably capture sleep/wake cycles. Participants were trained in using their smartphones to complete the daily sleep diary portion of the study.

Part 2. During the 10-day sleep study period, participants were contacted via text message in the morning to prompt them to click a link, which directed them to Qualtrics (a secure and encrypted web data collection service) to fill out the daily sleep diary on their smart phones. At the end of the 10-day period, participants returned their Actiwatches, received compensation, and were debriefed.

Instruments

Self-Report Questionnaires.

Nonsuicidal self-injury history. The Deliberate Self Harm Inventory (DSHI; Gratz, 2001) assesses the frequency, duration, and forms of NSSI behaviors (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) _______ without the intent to die?” For each of the 17 types of NSSI behaviors endorsed, respondents are asked about age at onset, frequency over one’s lifetime, frequency over the previous one year, and if the behavior has ever resulted in a hospitalization or required medical treatment. Research has supported the DSHI’s test-retest reliability and construct, discriminant, and convergent validity in a university-student sample (Gratz, 2001; Fleige et al., 2006). In the current study, the internal consistency of the items assessing presence versus absence of 17 specific methods of NSSI behaviors was .57, which is in line with the reliability found for this measure in other studies (e.g., Armey, Crowther, & Miller, 2011, alpha = .75; Buckholdt et al., 2015, alpha = .63; Gratz & Tull, 2012, alpha = .67).

Reward sensitivity. The Behavioral Inhibition System/Behavioral Activation System (BIS/BAS Scale; Carver & White, 1994) has two scales, one of which assesses behavioral approach or reward sensitivity. Participants respond to 20 items using a 4-point Likert-type scale ranging from *strongly disagree* (1) to *strongly agree* (4). A BAS total score is calculated by summing all BAS items, with higher scores indicating higher reward sensitivity. The BIS/BAS scales have demonstrated good internal consistency and retest reliability (Carver & White, 1994). In the current study, the reliability of the BAS Total subscale was good (alpha = .86).

Cognitive control in response to negative emotional stimuli. The UPPS-P Impulsivity Scale (UPPS-P; Lynam, Smith, Whiteside, & Cyders, 2006) is a 59-item scale designed to assess five traits related to impulsive behavior: negative urgency, positive urgency, lack of perseverance, lack of planning, and sensation seeking. In the current study, we employed the negative urgency subscale (UPPS-NU) to assess cognitive control in the context of negative emotion. The negative urgency subscale includes 12 items assessing the tendency to act without thinking in response to distress. Example items include, "When I feel bad, I will often do things I later regret in order to make myself feel better now," and "I often make matters worse because I act without thinking when I am upset." The UPPS-NU has demonstrated good internal consistency in prior studies (e.g., Cyders & Smith, 2007; Liu & Kleiman, 2012). In the current study, the reliability of the UPPS Negative Urgency subscale was good (alpha = .89).

Stress. The Life Events Scale (LES) (Safford, Alloy, Abramson, & Crossfield,

2007) is an inventory of 100 major and minor life events in a variety of domains relevant to college students (e.g., school, finances, family, peer, and romantic relationships). The scale instructs participants to indicate which events occurred in their lives over a pre-defined period (2 weeks in this study).

Attention Deficit Hyperactivity Disorder symptoms. The Adult ADHD Self-Report Version 1.1 Screener (ASRS-V1.1; Kessler et al., 2005) is an 18-item questionnaire assessing symptoms of inattention and hyperactivity experienced over the past six months. Each symptom is rated on a 5-point, Likert-type scale with higher scores indicative of more severe symptomatology. ADHD symptoms served as a covariate in the analyses when associated with group status. The ASRS-V1.1 exhibits good internal consistency (Kessler et al., 2005). For this study, we employed the 6-item version of this screener, given that it has demonstrated superior sensitivity, specificity, and classification accuracy compared to the full version (Kessler et al., 2005). The reliability in the current study was good (alpha = .74).

Diagnostic Interviews.

Mood disorders. The Schedule for Affective Disorders and Schizophrenia-Lifetime (SADS-L; Endicott & Spitzer, 1978; Alloy et al., 2000) is a semi-structured diagnostic interview that was designed to assess lifetime and current Axis I disorders according to DSM-IV criteria. In the current study, only the mood disorder sections were administered to participants to assess lifetime and current mood episodes. Mood disorders served as covariates in the analyses when associated with group status. The SADS-L has demonstrated excellent inter-rater reliability in 80 jointly rated interviews (Alloy et al., 2000). SADS-L inter-rater reliability in the current study was calculated based on agreement between joint ratings of 20% of the interviews. Agreement for DSM-IV mood diagnoses was excellent. Diagnosis-specific agreement ranged from 96.65%-100%.

Borderline Personality Disorder. The Structured Interview for Diagnosis for Personality Disorders (SID-P; Pfohl, Blum, & Zimmerman, 1995) assesses personality psychopathology as defined by the 10 DSM-IV personality disorders. In the current study, the SID-P was used only to assess the presence of BPD. BPD diagnosis served as a covariate in the analyses when associated with group status. Research suggests that the interview has acceptable inter-rater reliability (Pfohl et al., 1995). SID-P inter-rater reliability in the current study was calculated based on agreement between joint ratings of 20% of the interviews. Agreement for BPD diagnosis was excellent (100%).

Nonsuicidal self injury. The Self-Injurious Thoughts and Behaviors Interview (SITB; 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. This interview has been used in various clinical and non-clinical settings and has demonstrated strong psychometric properties (Nock et al., 2007). The SITBI has demonstrated inter-rater reliability (K = 0.99), construct validity, and test–retest reliability (K = 0.70) (Nock et al., 2007). In the present study, the SITBI was employed to measure history of NSSI and suicide attempts to ensure correct group classification of study participants. SITBI reliability in the current study was calculated based on agreement between joint ratings of 20% of the interviews, specific to assessment of NSSI and suicide attempt history. The agreement between the joint ratings was excellent with both NSSI and suicide attempt history evidencing 100% agreement.

Behavioral Tasks.

Cognitive control in response to negative emotional stimuli. The Emotional Stop-Signal Task (ESST; Allen & Hooley, 2015) is a computer task paradigm employed to measure inhibitory control over behavioral responses (Verbruggen & Logan, 2008). The SST, in its original form, instructs participants to make fast-paced decisions about visual stimuli (left and right arrows) by pressing a left key when they see left arrows and a right key when they see right arrows on the screen. During this task, on approximately 25% of the trials, visual stimuli appear directing the participant to withhold their response (stop signals). The stop signals appear on the screen after a variable delay period. Participants are usually able to inhibit their behavioral responses when the stop signal appears shortly after the arrow appears. However, as the latency increases, participants evidence a more difficult time in inhibiting their control over prepotent responses. The stop signal delay (SSD) is the amount of time between displaying the main stimulus and the stop-signal. In the standard scoring, a stop signal reaction time (SSRT) is recorded for each participant, which is the maximum amount of time that can elapse between the imperative stimulus and stop-signal, such that a behavioral response can still be inhibited by that participant (Logan & Cowan, 1984). In the SST employed in this study, the SSD was adjusted after each stop trial so that approximately 50% of the trials result in commission errors (Allen & Hooley, 2015; Osman et al., 1990). In this adapted protocol, a successful response inhibition on one stop trial leads to an increase in the SSD on the subsequent stop trial, with each successive stop trial increasing in difficulty until the participant's inhibition fails. When a participant's inhibition fails, the SSD is then reduced. In the current protocol, the SSRT was calculated by subtracting the median stop signal delay time from the mean go-signal reaction time (GSRT) (Allen & Hooley, 2015). Thus, greater SSRTs denote greater inhibitory control.

The current SST was modified to be an auditory emotional SST (ESST) that assesses inhibitory control over affective judgments (Allen & Hooley, 2015). The task uses images from the International Affective Picture System (IAPS; Lang, Bradley, Cuthbert, 2008) that were matched for content intensity, in both target ("go") and inhibition ("stop") trials. Neutral, positive, and negative affective stimuli (12 of each) were included. Participants were instructed that they should indicate the valence of each image presented to them by clicking a smiling face or a frowning face on a keyboard. For trials designated as stop trials, images are followed by an auditory tone; participants were instructed that responses should be inhibited when they hear this tone. Participants were presented with similar numbers of stimuli from each of the types of trials (neutral, positive, negative stimuli). The dependent variables for each of these categories of trials are the proportion of commission errors engaged in relative to the total number of stop trials for each category. This proportion reflects inhibitory control failure rates for each type of stimulus.

Reward sensitivity. The Effort-Cost Computational Task (ECCT; Gold et al., 2013) is a computerized task that tests the impact of reward value and probability on making low and high effort decisions. Participants are instructed to make a decision between two response alternatives displayed on the screen: (a) an easy option (10 key presses) with a lower reward value (i.e., $1) and (b) a difficult option (50 key presses) with a higher reward value (i.e., $3–7). The effortful task requires inflating a virtual balloon by pressing alternating left-right keys on a keyboard until it pops. Participants are free to select either the easy or difficult option on a given trial. For each trial, there is a 100% probability of receiving the reward (we did not include the 50% probability trials used in some prior studies employing this task, based on recommendations from the task developer given results finding that these trials did not add to predictive validity of the task). The task is composed of 30 trials, with 6 trials of each type ($1 vs. $3, $1 vs. $4, $1 vs. $5, $1 vs. $6, $1 vs. $7). High reward sensitivity is characterized by pursuing difficult, high value options when outcomes are certain (i.e., 100%). The main score was the difference between % hard choices during the highest reward condition and % hard choices during the lowest reward condition (Horan et al., 2015). We also examined the main effects of percent of hard choices at each of the five reward levels, in line with prior literature (Reddy et al., 2015).

Sleep/wake cycle.

Actigraphy. Actigraphy was employed to objectively and reliably assess sleep deficiency and irregularity. Actiwatches sample data in one-minute epochs and store the data digitally in the device. Research suggests that actigraphy is highly correlated with the field's gold standard measure of sleep, polysomnography (Marino et al., 2013). Furthermore, it has been found to perform significantly better than self-report sleep measures (e.g., Girschik et al., 2012; Lauderdale et al., 2008). Participants were instructed to wear an Actiwatch (Philips Healthcare, Bend, OR) on their non-dominant wrist for the entirety of a period of 10-days following the baseline assessment period (removing it only when it would get wet; e.g., during bathing). The current study utilized the following sleep variables generated by the Actiwatch software: sleep duration (duration of time between participants' main period of sleep onset and offset, after subtracting wake time after sleep onset (WASO)). Moreover, sleep/wake cycle regularity statistics were calculated from actigraphy variables (i.e., standard deviation of duration of time asleep after subtracting WASO; standard deviation of daily time of participants' main sleep onset and wake time).

Daily Sleep Diary. Participants were sent a sleep diary survey every morning over the course of the 10 days that they wore Actiwatches. The sleep diary inquired about sleep information from the day and night prior. The sleep diary asked participants what time they got into bed to go to sleep, what time they fell asleep, what time they woke up in the morning, and what time they got out of bed. The sleep diary also asked participants to estimate how many minutes they were awake between the time that they fell asleep and woke up, otherwise referred to as WASO. The current study utilized the following self-report sleep variables: sleep duration (i.e., duration of time between sleep onset and offset, after subtracting WASO) and sleep/wake cycle regularity (i.e., standard deviation of duration of time asleep after subtracting WASO; standard deviation of daily time of sleep onset and wake time).

Analytic Strategy

Sample Size and Power Analysis. Power analyses were conducted using G*Power 3.1.9.2 (Faul, Erdfelder, Lang, & Buchner, 2007) to examine all primary hypotheses predicting NSSI group membership. Research examining the relationship between a behavioral measure of cognitive control in response to negative emotional stimuli and NSSI suggests a medium to large effect size (Allen & Hooley, 2015). No research has examined the effect of objectively measured sleep over a short-term duration in differentiating between those with and without NSSI. However, self-report research suggests that sleep deficiency is associated with NSSI with a medium effect size (Lundh et al., 2013). A recent meta-analysis suggests a small to medium relationship between stressful life events and NSSI (pooled OR = 1.81 [95% CI=1.49–2.21]) (Liu et al., 2016). No research has examined the relationship between a behavioral measure of reward sensitivity and NSSI. However, self-report research has suggested a moderate effect size of elements of reward sensitivity predicting NSSI presence (Cerutti et al., 2012) and frequency (Burke et al., 2015). Given the general findings of moderate effect sizes between the constructs of interest and NSSI status, we estimated that in order to detect significant two-way interactions between cognitive control and sleep, stress, and reward sensitivity in predicting group status of a moderate effect size with Power = .80 and α = .05, a sample size of 50 in each group would be required. Thus, we were well powered in the current study to detect moderate effect sizes for interaction effects.

Analyses. To test the hypotheses of this study (direct associations, 2-way interactions) for predicting a categorical outcome (group membership: NSSI+ versus NSSI-), hierarchical logistic regressions were carried out in M*plus* Version 8 (Muthén & Muthén, 2019), with and without controlling for covariates (psychoactive medication use, history of mood disorders, BPD, and ADHD symptoms), only for those covariates that were significantly associated with the outcome.

Results

Preliminary Analyses

Participants (*N* = 114) ranged in age from 18-22 (mean 19.50 years; SD = 1.22). In regards to gender, 87.7% (n = 100) identified as female. Approximately 62.4% identified as White, 15.8% as Asian, 7.0% as Black, 6.1% as more than one race, 0.0% as

Native Hawaiian or Pacific Islander, and 0.9% expressed that they would prefer not to answer; 9.6% identified as Hispanic or Latino. No differences were found in demographics between the NSSI+ and NSSI- groups (see Table 1).

Table 1

Participant demographic characteristics by NSSI group status

	NSSI- (N = 57)	NSSI+ (N = 57)	*t or chi-square*
Age	19.51 (1.51)	19.49 (1.30)	0.08
Sex	82.50% female	93.00% female	2.93
Race	54.40% White 14.00% Other 12.30% Asian 14.00% Black 0.0% Native Hawaiian or Pacific Islander 5.3% More than one race 0.0% Prefer not to answer	70.20% White 1.80% Other 19.30% Asian 1.80% Black 0.0% Native Hawaiian or Pacific Islander 7.0% More than one race 1.8% Prefer not to answer	3.03[+]
Hispanic	12.3%	7.0%	1.51
UPPS NU	25.81 (7.34)	31.36 (7.07)	-3.96***
Stress	7.12 (4.80)	9.35 (5.15)	-2.40*
BAS Tot	24.14 (5.60)	25.86 (5.83)	-1.61
ADHD Sx	8.93 (3.96)	11.86 (3.87)	-4.00***
BPD	0.0%	3.6%	2.11
DSM-Curr Dep	1.8%	12.5%	4.96*
DSM-Past Dep	15.8%	66.7%	30.45***
Bipolar-Curr/Past	5.3%	12.3%	1.75
Psychoactive Med Use	7.1%	40.4%	17.13***

*$p < .05$; ** $p < .01$; *** $p < .001$.
Note: [+]Due to small group sizes in Race, chi-square test carried out on White versus non-White categorization. Standard deviations are in parentheses. UPPS NU = Negative Urgency; Stress = Life Events Scale – Total Negative Events; BAS Tot = Reward Sensitivity; BPD = Borderline Personality Disorder; DSM-Curr Dep = Current DSM Depressive Disorder; DSM-Past Dep = DSM Past Depressive Disorder; Bipolar-Curr/Past = Current or Past Bipolar Disorder; Med = Medication.

Of the NSSI+ group, the average number of NSSI acts was 46.47 (*SD* = 96.68; Range = 2-588); 43.9% of the NSSI+ group endorsed engaging in NSSI in the past one year, 21.1% in the past month, and 5.3% in the past week. The average age of onset of NSSI was 13.51 (*SD* = 3.06). Of the NSSI methods queried by the SITBI, participants engaged in an average of 1.96 methods (*SD* = 1.03), with the following methods endorsed: self-cutting (73.7%), self-burning (19.3%), inserting sharp objects into self (5.3%), picking skin to the point of drawing blood (17.5%), hitting self (24.6%), giving self a tattoo (1.8%), scraping skin to point of drawing blood (28.1%), and other (26.3%).

We observed excellent participant compliance in actigraphy and sleep diary procedures. Participants wore their Actiwatch an average of 9.47 out of 10 days; 94.60% wore their Actiwatch over 80% of the 10 days. Participants completed an average of 9.35 of 10 sleep diaries; 92.90% completed over 80% of the 10 morning sleep diaries. The NSSI+ and NSSI- groups did not differ significantly in their compliance in wearing the Actiwatch ($t(111) = 0.25$, $p > .05$) or in completing the sleep diaries ($t(108) = -1.17$, $p > .05$).

Of the potential covariates, current depressive disorder, past depressive disorder, level of ADHD symptoms, and current psychoactive medication use were significantly different between groups (Table 1). Thus, all analyses were run with and without adjusting for this set of covariates. Bivariate correlations between study variables can be found in Table 2.

Table 2

Bivariate correlations between study variables

	1	2	3	4	5	6	7	8	9	10	11	12
1. Act Slp Duration	---											
2. Act Slp Duration SD	.002	---										
3. SR Slp Duration	.746***	-.036	---									
4. SR Slp Duration SD	.039	.857***	-.026	---								
5. Act Time Asleep SD	-.162	.525***	-.120	.497**	---							
6. Act Time Awake SD	-.244*	.538***	-.102	.534***	.462***	---						
7. SR Time Asleep SD	-.076	.465***	-.088	.541***	.820***	.334***	---					
8. SR Time Awake SD	-.123	.568***	.008	.606***	.346***	.899***	.293**	---				
9. ESST	.049	.077	-.117	.040	-.070	-.034	-.017	.003	---			
10. UPPS NU	-.045	.264**	-.097	.306**	.217*	.196*	.158	.220*	.082	---		
11. ECCT	.033	.078	.086	.042	.070	.039	-.064	.049	.019	-.035	---	
12. BAS	.006	-.006	-.077	-.021	.055	-.147	-.003	-.090	-.004	-.116	-.045	---

* $p < .05$, ** $p < .01$, *** $p < .001$.

Note. Act = Actigraphy; SR = Self-report; Slp Duration = sleep duration; SD = standard deviation (measure of regularity); ESST = Emotional Stop Signal Task; UPPS NU = Negative Urgency subscale of the UPPS-P Impulsivity Scale; ECCT = Effort-Cost Computational Task; BAS = Behavioral Approach System subscale of the BIS/BAS scale.

Hypothesis Testing Analyses

Hypothesis 1: Is cognitive control in response to negative emotional stimuli associated with history of engagement in NSSI? Overall stop-signal reaction time, omission errors, and commission errors were inspected for normality and did not meet assumptions. Nor did they meet assumptions upon applying a log transformation. Thus, we conducted a Mann-Whitney U test to examine whether there were group differences and found no differences between groups in overall stop-signal reaction time (U(110) = 1510.00, $p > .05$), omission errors (U(110) = 1397.50, $p > .05$), or commission errors (U(110) = -1273.50, $p > .05$)[1].

A 2 x 3 within-subjects analysis of variance (ANOVA) was conducted to examine the effects of group (NSSI+ vs. NSSI-) and image valence (neutral, positive, negative) on the proportion of commission errors committed, a measure of inhibitory control. The outcome variables were inspected for normality. Due to violations of normality in the proportion of commission errors committed for neutral (kurtosis = 3.80; Kolmogorov-Smirnov statistic = 0.11, $p < .01$) and negative (Kolmogorov-Smirnov statistic = 0.09, $p = .02$) stimuli, a natural log transformation was applied to both of these outcome variables. However, the pattern of results did not differ between the use of raw values or natural log values. Thus, for ease of interpretation, results using the raw values of all outcome variables are presented. We found a significant main effect of image valence, $F(2, 109) =$

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[1] These findings were in line with analyses conducted using independent samples t-tests, which suggested no differences between groups in overall stop-signal reaction time ($t(110) = -0.17$, $p > .05$), omission errors ($t(110) = -0.19$, $p > .05$), or commission errors ($t(110) = -0.48$, $p > .05$).

38.17, $p < .001$, partial $\eta^2 = .258$. Post-hoc tests revealed that participants exhibited the poorest inhibitory control in response to positive images, followed closely by negative images, and the strongest inhibitory control in response to neutral images . However, there was no significant group main effect, $F(1, 110) = 0.88$, $p > .05$, partial $\eta^2 = .008$, and no interaction effect between group and image valence, $F(1, 110) = 0.87$, $p > .05$, partial $\eta^2 = .008$, indicating that both groups had a similar pattern of inhibitory control across image valence.

A corresponding self-report measure of reduced inhibitory control in response to negative emotion (UPPS-P negative urgency), however, was significantly associated with group status (B = 0.10, Wald = 12.51, OR = 1.11, 95% CI [1.05,1.17], $p < .001$). This result did not hold after controlling for covariates (B = .02, Wald = 0.18, OR = 1.02, 95% CI [0.93,1.11], $p > .05$).

Hypothesis 2a: Are sleep duration and sleep/wake cycle regularity associated with history of engagement in NSSI? A series of binary logistic regressions was conducted to examine whether sleep duration and regularity were associated with NSSI group status (see Table 3). Our findings indicated that sleep duration, measured by both actigraphy and self-report, was not associated with NSSI group status (see Table 3). Regularity of sleep duration as measured by actigraphy and self-report, however, was significantly associated with NSSI group status, such that NSSI+ members evidenced significantly greater variation in their sleep duration across the 10 days of study. Of note, when controlling for covariates, only regularity of sleep duration as measured by actigraphy remained significant (B = .02, Wald = 5.18; OR = 1.02, 95% CI [1.00,1.04], $p = .023$). Regularity of time of sleep onset as measured by actigraphy and self-report was not associated with NSSI group status. Regularity of wake onset as measured by actigraphy was not associated with NSSI group status; however, self-reported wake onset was associated with NSSI group status (Table 3), but this finding did not hold when controlling for covariates.

Table 3

Logistic regressions evaluating sleep predictors of NSSI group status

Predictor	B	Wald	*OR*	95% CI	*p*	ΔR^2
Act Slp Duration	0.00	0.05	1.00	1.00-1.01	.494	0.006
SR Slp Duration	0.00	0.03	1.00	1.00-1.01	.825	0.000
Act Slp Duration SD	0.02	8.34	1.02	1.01-1.04	.004**	0.118
SR Slp Duration SD	0.01	6.95	1.01	1.00-1.03	.008**	0.100
Act Time Asleep SD	0.50	1.80	1.65	0.80-3.41	.179	0.023
SR Time Asleep SD	0.27	0.51	1.31	0.63-2.71	.474	0.006
Act Time Awake SD	0.55	2.59	1.74	0.89-3.42	.108	0.035
SR Time Awake SD	0.91	5.49	2.49	1.16-5.33	.019*	0.073

* $p < .05$, ** $p < .01$, *** $p < .001$.

Note. Logistic regressions presented have not adjusted for covariates. Act = Actigraphy; SR = Self-report; Slp Duration = sleep duration; SD = standard deviation (measure of regularity).

Hypothesis 2b: Do lower sleep duration and less sleep/wake cycle regularity increase the likelihood that a lower level of response inhibition in response to negative emotional stimuli is associated with NSSI? Results suggested that sleep duration (as measured by both actigraphy and self-report) did not moderate the relationship between cognitive control in response to negative stimuli (as measured by both behavioral task and self-report) and NSSI (Table 4).

Table 4

Two-way interactions between sleep and cognitive control in the context of negative emotionality predicting NSSI group status

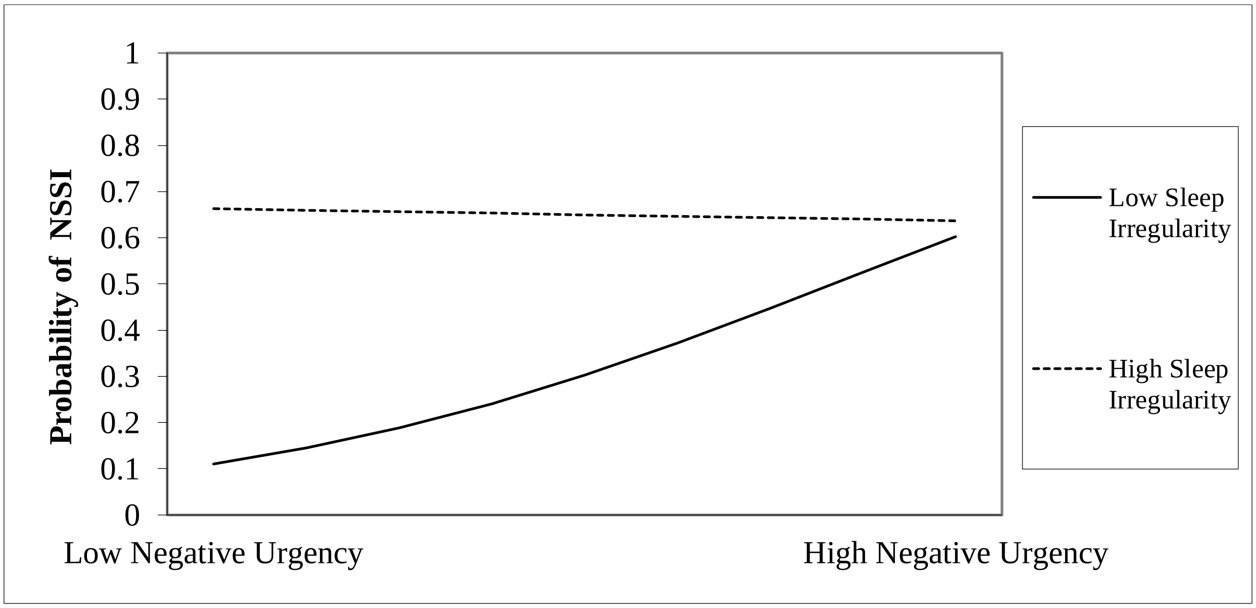
Predictor	β	*OR*	OR 95% CI	*p*
SR Slp Duration x UPPS NU	0.001	1.00	1.00-1.00	.244
SR Slp Duration SD x UPPS NU	-0.002	1.00	1.00-1.00	.041*
SR Time Asleep SD x UPPS NU	-0.073	0.93	0.84-1.03	.169
SR Time Awake SD x UPPS NU	-0.100	0.91	0.80-1.02	.101
Act Slp Duration x ESST	0.005	1.01	0.96-1.06	.829
Act Slp Duration SD x ESST	0.025	1.03	0.93-1.14	.624
Act Time Asleep SD x ESST	-0.398	0.68	0.00-796.65	.914
Act Time Awake SD x ESST	1.173	3.23	0.04-274.15	.605

* $p < .05$, ** $p < .01$, *** $p < .001$.
Note. Logistic regressions presented have not adjusted for covariates. Act = actigraphy; SR = self-report; Slp Duration = sleep duration; SD = standard deviation (measure of regularity); UPPS NU = Negative Urgency subscale of the UPPS-P Impulsivity Scale; ESST = Emotional Stop Signal Task.

Sleep/wake cycle regularity (as measured by both actigraphy and self-report) did not moderate the relationship between cognitive control in response to negative stimuli (as measured by behavioral task) and NSSI. However, there were mixed findings when considering sleep/wake cycle regularity (as measured by both actigraphy and self-report) moderating the relationship between self-reported cognitive control in response to negative stimuli (UPPS-P negative urgency) and NSSI. A significant interaction was found such that self-report sleep duration regularity moderated the relationship between cognitive control in the context of negative emotionality (as measured by self-report) and NSSI (Table 4). The relationship between cognitive control in the context of negative emotionality and NSSI probability was strongest at the lowest levels of sleep irregularity (Figure 1; Table 4). Indeed, those evidencing high sleep irregularity had a strong likelihood of NSSI at both low and high levels of cognitive control in the context of negative emotionality. However, those evidencing low sleep irregularity exhibited low probability of NSSI when high on cognitive control in the context of negative emotionality (i.e., low levels of negative urgency) and high probability of NSSI when low on cognitive control in the context of negative emotionality (i.e., high levels of negative urgency). When controlling for covariates, this relationship was no longer significant, but was trending towards significance (B = -0.002; SE=.001; OR = 1.00, 95% CI [1.00, 1.00], *p* = .07). Bed time and wake time regularity did not moderate the relationship between cognitive control and NSSI (Table 4).

Figure 1

Two-way interaction between cognitive control in the context of negative emotionality and sleep duration irregularity in predicting NSSI group status



<u>Hypothesis 3a: Is the experience of psychosocial stress associated with history of engagement in NSSI?</u> Recent experience of psychosocial stress was associated with NSSI group, such that participants with greater levels of stress were more likely to belong to the NSSI+ group (B = 0.09, Wald = 5.69, OR = 1.10, 95% CI [1.02,1.17], *p* = .017). This association did not persist when controlling for covariates.

Hypothesis 3b: Does psychosocial stress moderate the association between cognitive control in the context of negative emotionality and NSSI? Total negative life events trended towards significance in moderating the relationship between cognitive control in response to negative stimuli (as measured by a behavioral task) and NSSI (Figure 2; Table 5). When controlling for covariates, this relationship was maintained and reached statistical significance (OR = 2.04; $p = .035$). The relationship between cognitive control in the context of negative emotionality and NSSI probability was strongest at the highest levels of recent psychosocial stress (Table 5; Figure 2). At high levels of stress and low levels of cognitive control in the context of negative emotionality (i.e., high rate of commission errors in response to negative emotional stimuli), participants exhibited the greatest probability of belonging to the NSSI group. Total negative life events did not moderate the relationship between cognitive control in response to negative stimuli (as measured by self-report) and NSSI (Table 5).

Table 5

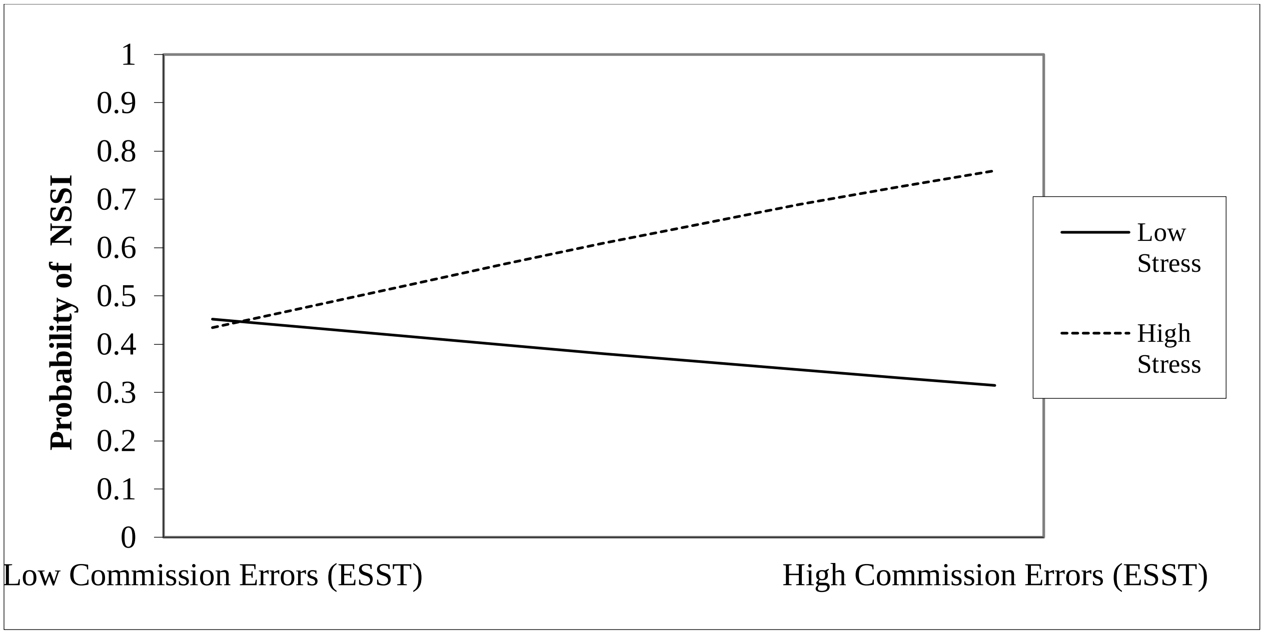
Two-way interactions between stress and cognitive control in the context of negative emotionality predicting NSSI group status

Predictor	β	*OR*	OR 95% CI	*p*
Stress x UPPS NU	-0.007	0.99	0.98-1.00	.199
Stress x ESST	0.559	1.75	0.98-3.12	.058

* $p < .05$, ** $p < .01$, *** $p < .001$.
Note. Logistic regressions presented have not adjusted for covariates. Stress = acute stress experienced over prior two weeks; UPPS NU = Negative Urgency subscale of the UPPS-P Impulsivity Scale; ESST = Emotional Stop Signal Task

Figure 2

Two-way interaction between cognitive control in the context of negative emotionality and total stressful life events in predicting NSSI group status



Hypothesis 4a: Is reward sensitivity associated with history of engagement in NSSI? Reward sensitivity, as measured by the BAS, was not significantly related to NSSI group status (B = 0.05; Wald = 2.51; OR = 1.06, 95% CI [.987-1.127], $p > .05$). This finding held when adjusting for covariates. Similarly, a task-based measure of reward sensitivity, the ECCT, did not evidence a significant direct relationship with NSSI group status (Table 6). These associations remained non-significant when accounting for covariates.

Table 6

Logistic regressions evaluating reward sensitivity task predictors of NSSI group status

Predictor	β	Wald	*OR*	95% CI	*p*	ΔR^2
% Chosen – Level 3	0.12	0.05	1.13	0.38-3.35	.822	.001
% Chosen – Level 4	0.73	1.95	2.08	0.74-5.80	.163	.023
% Chosen – Level 5	0.44	0.74	1.56	0.58-4.26	.391	.009
% Chosen – Level 6	0.26	0.16	1.30	0.36-4.68	.689	.002
% Chosen – Level 7	-0.24	0.10	0.79	0.18-3.51	.753	.001
% Chosen High-Low	-0.23	0.19	0.79	0.28-2.25	.664	.002

* $p < .05$, ** $p < .01$, *** $p < .001$.
Note. Logistic regressions presented have not adjusted for covariates. % Chosen – Level 3-7 = Percent of hard choices at each of the five reward levels.

Hypothesis 4b: Does reward sensitivity moderate the association between cognitive control and history of engagement in NSSI? Reward sensitivity (as measured by self-report and behavioral task) did not moderate the relationship between cognitive control in response to negative stimuli (as measured by self-report and behavioral task) and NSSI (Table 7).

Table 7

Two-way interactions between reward sensitivity and cognitive control in the context of negative emotionality predicting NSSI group status

Predictor	β	*OR*	OR 95% CI	*p*
BAS x UPPS NU	0.004	1.00	0.99-1.01	.424
ECCT x ESST	1.173	3.23	0.01-980.95	.687

* $p < .05$, ** $p < .01$, *** $p < .001$.
Note. Logistic regressions presented have not adjusted for covariates. BAS = Behavioral Approach System subscale of the BIS/BAS scale; UPPS NU = Negative Urgency subscale of the UPPS-P Impulsivity Scale; ECCT = Effort-Cost Computational Task; ESST = Emotional Stop Signal Task.

Discussion

The current study investigated whether cognitive control in the context of negative emotion is associated with repetitive NSSI. It further examined three moderators of this proposed association. Findings were mixed. Contrary to study hypotheses and findings of prior literature (i.e., Allen & Hooley, 2015; Allen & Hooley, 2019), poorer cognitive control in response to negative emotional stimuli, as measured by an Emotional Stop Signal Task, was not associated with repetitive NSSI history. However, a self-report measure of cognitive control in the context of negative emotion, the Negative Urgency subscale of the UPPS-P, was significantly associated with repetitive NSSI history. Of note, however, this finding did not hold after controlling for covariates.

We found minimal evidence to support the relationship between behaviorally-measured cognitive control of negative emotional impulses and NSSI history. Our findings using the Emotional Stop Signal Task did not replicate two prior studies finding that those with a history of NSSI exhibit impaired inhibitory control over negative emotional impulses using this task, as compared to controls (Allen & Hooley, 2015; Allen & Hooley, 2019). However, our findings are in line with prior research suggesting that NSSI is not associated with general cognitive control deficits (Janis & Nock, 2009; McCloskey, Look, Chen, Pajoumand, & Berman, 2012) or with cognitive control under conditions that require inhibiting emotional interference (e.g., response inhibition post negative mood induction) (Allen & Hooley, 2017; Lengel et al., 2016).

Our self-report measure of cognitive control over negative emotional impulses was significantly associated with repetitive NSSI history in the expected direction. Negative urgency has been found to be cross-sectionally and longitudinally predictive of

NSSI in a number of studies (e.g., Bresin, Carter, & Gordon, 2013; Riley, Combs, Jordan, & Smith, 2015; Peterson, Davis-Becker, & Fischer, 2014; You, Deng, Lin, & Leung, 2016). The divergence between our findings for the self-report and behavioral measure of cognitive control is in line with a substantial body of research that has noted weak relationships between behavioral task and self-report measures of impulsivity (e.g., Aichert et al., 2012; MacKillop et al., 2016; Sharma, Markon, & Clark, 2014). Indeed, the current study suggests that the self-report measure of cognitive control in the context of negative emotional impulses (Negative Urgency subscale of the UPPS-P) and the ESST were not correlated with one another (Table 1). This might suggest that self-reported negative urgency and the ESST are tapping separate constructs, which is not in line with prior findings that found a small but statistically significant correlation between the two measures (Allen & Hooley, 2019). The mixed findings of the current study as compared to previous studies using the ESST in relation to NSSI suggest the need for additional research. Given that each of the three studies examining this relationship were cross-sectional, an additional research priority is to examine this relationship within a longitudinal design in order to clarify whether cognitive control in response to negative emotional impulses may be a risk factor for subsequent NSSI or simply a correlate.

We hypothesized that the relationship between cognitive control in the context of negative emotion and NSSI may be particularly strong under conditions of deficient and irregular sleep, high levels of acute stress, and high reward sensitivity. We discuss each of these proposed moderators' simple associations with NSSI history as well as their interaction with behaviorally measured and self-reported cognitive control in the context of negative emotion.

Sleep

The pattern of associations between sleep deficiency and irregularity and NSSI was notable. Interestingly, and in line with prior research with an undergraduate sample (Phillips et al., 2017), we found no statistical correlation between average daily sleep duration and sleep irregularity (Table 1), suggesting that sleep irregularity is a distinct construct that may offer salient information about individual differences in sleep/wake cycle. We found that average sleep duration was not associated with a history of repetitive NSSI. However, sleep duration irregularity, as measured by both actigraphy and self-report daily diaries, was significantly related to NSSI history, such that greater irregularity over the course of the 10-day period of sleep measurement was positively associated with a history of repetitive NSSI. In line with this finding, irregularity of self-reported time of awakening also was associated with NSSI history.

Thus, our findings seem to suggest that average sleep duration may not be related to NSSI, but rather that it is the *irregularity* of one's sleep/wake cycle that may put individuals at greater risk. This is consistent with the one study that has examined sleep/wake cycle irregularity in relation to self-injurious behaviors; this prior study found that the retrospective reporting of greater divergence between weekday and weekend sleep duration was associated with a broad class of self-injury, both with and without suicidal intent (Kang et al., 2014). The current study extends these findings by examining irregularity using both objective and self-report methods over the course of a ten-day period, and by examining its relationship specifically to NSSI.

Recent research illuminates the association of sleep irregularity with circadian rhythm disturbance. Phillips and colleagues (2017) found that among undergraduates, sleep irregularity is significantly related to circadian phase delay as assessed by endogenous melatonin rhythm and by sleep propensity rhythm. This study similarly found that sleep irregularity, and not average sleep duration, was associated with poor functioning (e.g., academic performance). Sleep irregularity therefore may be a very important metric, as it may correlate with an underlying vulnerability to poor functioning.

With regard to whether sleep indices moderate the association between cognitive control in the context of negative emotion and NSSI, a significant interaction emerged between self-reported sleep duration regularity and cognitive control in the context of negative emotionality (i.e., Negative Urgency subscale) and NSSI. Findings were partially in line with our hypotheses. We found that participants who self-reported high sleep duration irregularity had a strong likelihood of NSSI at all levels of self-reported cognitive control in the context of negative emotion. Participants who reported low sleep irregularity varied in their NSSI probability based on levels of cognitive control in the context of negative emotion; these individuals evidenced low NSSI probability when high on cognitive control and high probability of NSSI when low on cognitive control in the context of negative emotionality. Thus, consistent with our hypotheses, the lowest probability of NSSI is observed among those reporting low irregularity in sleep duration and high cognitive control. However, among those with high sleep irregularity, cognitive control did not have an effect on NSSI probability.

Importantly, sleep deficiency did not moderate the associations between cognitive control in the context of negative emotionality and NSSI, considering both behavioral and self-report measures of both constructs. This strengthens our finding that sleep duration may not be associated with NSSI when considering average time asleep during the main sleep period.

Interestingly, correlations indicate that sleep irregularity, as measured by self-report and actigraphy, and not sleep duration, is associated with self-reported cognitive control in the context of negative emotionality. Assessing the direction of this relationship will be an important research endeavor. So too will assessing whether sleep irregularity (via irregularity calculated over the prior one-week or via utilizing nightly sleep duration, after controlling for one's average sleep), moderates the relationship between cognitive control in the context of negative emotionality and NSSI urges/behavior in real time using EMA methodology.

Stress

We found that recent acute stress did differentiate between those with and without a history of repetitive NSSI. This finding is in line with much research suggesting that adolescents report engaging in NSSI as an emotion regulation strategy in response to acute stressors (e.g., Liu et al., 2016; Nock & Mendes, 2008). Furthermore, our finding is consistent with research suggesting that stress may be a predictor of both the onset and maintenance of NSSI among adolescents (e.g., Hankin & Abela, 2011; Voon et al., 2014). Moreover, it is consistent with meta-analytic evidence that there is a significant, modest association between stressful life events and NSSI (Liu et al., 2016). Future longitudinal research is needed in order to examine the extent to which stress is a proximal predictor of NSSI engagement (Liu et al., 2016). Nevertheless, although the present findings are cross-sectional in nature, they suggest that those with a history of repetitive NSSI, including many who have ceased engagement in NSSI, are still prone to greater levels of stressful life events than their non-self-injuring counterparts.

Stress moderated the relationship between our behavioral task measure of cognitive control in response to negative emotional stimuli and NSSI. At greater levels of stress, cognitive control was more strongly related to NSSI. In line with our hypotheses, participants reporting high levels of recent acute stress and who evidenced low cognitive control in response to negative emotional stimuli evidenced the greatest probability of belonging to the NSSI group. Findings suggest that greater levels of stress may amplify the risk of being unable to inhibit behavioral impulses in response to negative stimuli, resulting in greater NSSI likelihood. It remains to be seen whether stress indeed deteriorates response inhibition to emotional stimuli, as it has been evidenced to deteriorate other executive functioning processes, including general response inhibition (e.g., Mather & Lighthall; Porcelli & Delgado, 2009; Preston et al., 2007; Rahdar & Galván, 2014). However, if it does, this may explain why high levels of stress may be a key ingredient in the relationship between cognitive control and NSSI. Future research should employ ambulatory cognitive control tasks in conjunction with EMA so that the effect of stress on cognitive control in response to negative emotional stimuli can be examined in real time to assess whether there is a possible causal relationship at play.

Recent acute stress did not, however, moderate the relationship between self-reported cognitive control in the context of negative emotionality (i.e., Negative Urgency subscale) and NSSI. This further suggests that the self-report and behavioral measures of cognitive control of responses to negative emotional urges are tapping separate constructs.

Reward Sensitivity

Contrary to study hypotheses, reward sensitivity, as measured by the BAS subscale of the BIS/BAS scale, was not related to history of repetitive NSSI. Similarly, a behavioral paradigm that assesses reward sensitivity, the Effort Cost Computational Task (ECCT; Gold et al., 2013), also was unrelated to history of repetitive NSSI. Furthermore, reward sensitivity did not moderate the relationship between cognitive control in response to negative emotional stimuli and NSSI. These findings add to the mixed literature on the reward system's influence on NSSI.

Indeed, a body of literature suggests that reward sensitivity is positively associated with engagement in NSSI (Cerutti et al., 2012), frequency of NSSI (Burke et al., 2015; Cerutti et al., 2012; Jenkins et al., 2013; Robertson, Miskey, Mitchell, & Nelson-Gray, 2013), and number of NSSI methods employed (Jenkins et al., 2013). On the other hand, there is some contradictory evidence regarding the relationship between reward sensitivity and NSSI (e.g., Ammerman et al. 2017; Jenkins et al., 2013). Indeed, Jenkins and colleagues (2013) found no significant differences between those with and without a history of NSSI on any of the BAS subscales nor on a distinct measure of reward sensitivity (Torrubia, Avila, Molto, & Caseras, 2001). Moreover, Jenkins and colleagues (2013) found that the reward responsivity subscale of the BAS predicted *fewer* lifetime acts of NSSI. A more recent study suggests that it may be that mutual correlates of reward sensitivity and NSSI account for their relationship. Indeed, Ammerman and colleagues (2017) found that prior to adjusting for covariates, reward sensitivity was positively related to a history of NSSI. However, after using propensity scores to match propensity for NSSI based on both demographic factors and BAS and NSSI-related risk factors (e.g., anxiety, depressive symptomology, impulsivity, substance use), these differences were no longer significant. Based on these recent findings, it is plausible that reward sensitivity is, in fact, not implicated in the etiology of NSSI, but rather only associated with co-occurring personality traits and comorbidities (Ammerman et al., 2017).

The current study focused on cognitive control *in the context of negative emotion* given theory and research about the context in which individuals engage in NSSI. Perhaps this lack of association is due to evaluating *general* reward sensitivity rather than reward sensitivity in the context of negative emotion (e.g., employing stimuli that elicit negative affect as a manipulation to assess reward sensitivity). We had proposed that incentive sensitivity in general may be associated with NSSI, given that those who engage in the behavior are likely motivated by the associated emotional rewards. Thus, to go a step further, another direction may be to develop a measure of *emotional reward sensitivity*. Indeed, perhaps the way in which we measured reward sensitivity, in which rewards were presented as monetary in nature, does not permit the measurement of individual differences in incentive sensitivity to emotional rewards, specifically (e.g., reduction of negative affect, expansion of positive affect). Indeed, perhaps reward sensitivity in general does not interact with cognitive control in response to negative emotional stimuli, but rather an emotional reward sensitivity questionnaire or task, specifically, may capture what influences the relationship between the cognitive control system and NSSI.

Clinical Implications

If the current study's findings are replicated in a longitudinal design, there are potential implications for the treatment of NSSI. Our findings suggest that individuals with a history of NSSI consider themselves to act more rashly when they are experiencing negative emotions. Interventions aimed at augmenting control over one's impulses when experiencing negative emotions therefore may be helpful. One component of Dialectical Behavior Therapy, distress tolerance skills, in particular, may be helpful in this regard (Linehan et al., 2006). Distress tolerance skills aim to increase the use of adaptive skills specifically designed to be employed during extreme distress to reduce the likelihood that individuals engage in impulsive harmful behaviors (Linehan et al., 2006). Acceptance-based skills, such as those central to Acceptance and Commitment Therapy (Hayes, Strosahl, & Wilson, 2009), also may be useful in teaching individuals that even extremely aversive emotions are not inherently harmful and that they will pass. These skills promote conscious awareness and acceptance of negative emotions, rather than taking rash measures to facilitate avoidance (Hayes et al., 2009).

The current findings suggest that those with a history of repetitive NSSI are more likely to have experienced higher levels of recent life stress. Findings further suggest that high levels of recent life stress, in combination with low levels of cognitive control, may increase NSSI likelihood. Thus, interventions aimed at reducing life stress may be useful as a means to buffer against the possible risk of low cognitive control, thus reducing NSSI risk. Some research suggests that those who engage in NSSI may possess qualities or engage in behaviors that lead to the generation of stressful life events (Burke et al., 2015); future research should investigate this further to better understand whether this process is maintaining heightened levels of stress among those with a past history of NSSI. Such research may facilitate the identification of treatment targets.

The majority of research on the relationship between NSSI and sleep has focused on self-report measures of sleep quality or insomnia symptoms and no studies prior to the current study have utilized objective measures of sleep when examining its relationship with NSSI, despite poor to moderate correlations between self-reported and objectively measured sleep (e.g., Girschik et al., 2012; Lauderdale et al., 2008). Thus, the current findings suggesting a significant relationship between sleep irregularity and NSSI, if replicated in a longitudinal design, have important implications for novel and low-burden interventions. Indeed, sleep hygiene protocols with psychoeducation highlighting the importance of sleep regularity paired with light interventions to correct delayed circadian rhythm (Phillips et al., 2017) may aid individuals at risk for NSSI. Research using objective measures of sleep (i.e., actigraphy) is sorely needed within a longitudinal design to avoid the low reliability of self-report measures and to provide sounder evidence for determining whether there is a predictive relationship between sleep indices and NSSI.

Strengths and Limitations

This study had numerous strengths. First, it employed both self-report and behavioral measures of the majority of constructs investigated, including cognitive control in the context of negative emotion, reward sensitivity, and sleep/wake cycle. The wrist Actiwatches employed in this study to capture sleep/wake cycle are gold standard wearable devices and have been validated by polysomnography (Marino et al., 2013). Participant compliance in completing sleep diaries and wearing the Actiwatches over the

10-day period of assessment were notably high. Moreover, for the most part, self-report and actigraphy-rated sleep indices were correlated, augmenting our confidence in our measures of sleep. Finally, we employed gold-standard interview measures to ensure correct group classification and to adjust for the effects of current and prior mood disorder history.

Despite this study's strengths, it is important to consider the impact of its weaknesses. First and foremost, this study was limited by its cross-sectional design. Thus, causal conclusions may not be drawn. Second, recency and frequency of NSSI varied widely in this sample. Indeed, whereas the average number of NSSI acts in this sample was 46.47, it ranged from 2-588. Moreover, whereas 44% of the NSSI+ group engaged in NSSI in the past one year, the majority engaged in NSSI over one year ago. Thus, it is possible that some of the null findings may be explained by both lack of recency and severity of NSSI engagement in this sample. Future studies may consider employing a clinical sample with more recent and severe NSSI in order to elucidate whether the pattern of findings observed in this study generalize to more severe presentations of NSSI among those currently engaging in the behavior. Third, our self-report measure of stress was unable to be corroborated by an additional unit of analysis. Although the self-report questionnaire assessing recent stress in this study was based on a well-established inventory of over one hundred events, life events were not also assessed using an interview, the combination of which is considered gold-standard in the field of life event reporting (e.g., Hammen, 2005).

Future Directions

Our results support the need for longitudinal research to better understand the temporal dynamics between cognitive control in the context of negative emotions, sleep/wake patterns, stress, reward sensitivity, and engagement in NSSI. A longitudinal study is the logical next step in further clarifying the associations between the constructs. Such a study also should measure sleep, reward sensitivity, and stress prospectively, so as to clarify whether they are predictive and moderate the relationship between cognitive control and NSSI in real time. An EMA study paired with actigraphy would be well positioned to be able to examine said associations. Such a multi-method design would allow for the examination of the dynamic relationships between each of these constructs.

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