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Assessing Non-Suicidal Self-Injury in the Laboratory

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Abstract

Objectives: The majority of non-suicidal self-injury (NSSI) research has used self- or clinician-rated measures of behavior which (a) are subject to reporting biases, or (b) have limited use in experimental designs which could illuminate causal relationships. Laboratory-based behavioral tasks have therefore been developed to assess NSSI-related behaviors more directly.

Methods: We reviewed the behavioral methods that have been developed to assess NSSI tendencies or behaviors over the past thirty-years.

Results: Several categories of laboratory analogues were identified: NSSI-related stimuli (e.g., NSSI pictures, implicit association tasks, guided imagery), experimenter administered pain stimuli (e.g., cold, heat, pressure, shock, and blade), and self-selected pain stimuli (e.g., cold and shock).

Conclusion: These behavioral methods assess various aspects of NSSI and all have distinct advantages and shortcomings. Overall, these approaches have made significant contributions to the field complementing self- and clinician-ratings.

Keywords

NSSI; self-injury; laboratory methods; behavioral analogues; behavioral tasks

Introduction

Non-suicidal self-injury (NSSI) is the direct, intentional destruction of one's own body tissue without the intent to die (Nock, 2009). This behavior occurs in 4–6% of adults (Klonsky, 2011; Swannell, Martin, Page, et al., 2014) and 12%–18% of adolescents and young adults (Claes, Luyckx, & Bijttebier, 2014; Taliaferro & Muehlenkamp, 2015). The influence of NSSI on individual functioning is widespread, including increased interpersonal difficulties (Adrian, Zeman, Erdley, et al., 2011; Tatnell, Kelada, Hasking, et al., 2014), difficulty regulating their emotions (Andover & Morris, 2014; Bresin, 2014), emotional distress / arousal (Nock & Mendes, 2008; Plener, Schumacher, Munz, et al., 2015), and

comorbid psychopathology (Bentley, Cassiello-Robbins, Vittorio, Saur-Zavala, et al., 2015; Braga & Gonçalves, 2014). Individuals who engage in NSSI are also at a heightened risk for suicide attempts (Klonsky, May, & Glenn, 2013; Whitlock, Muehlenkamp, Eckenrode, et al., 2013).

Studies examining NSSI have relied almost exclusively on non-experimental research using self-report measures or interviews, and, more recently, ecological momentary assessment (EMA). These methods have provided valuable foundational knowledge about NSSI, such as who engages in NSSI and antecedents of the behavior (e.g., Bentley, et al., 2015; Somer, Bildek, Kabukcu-Basay, Gungo, et al., 2015; Swannell et al., 2014), in addition to a more nuanced, day-to-day understanding of those who engage in NSSI (e.g., Nock, Prinstein, Sterba, 2009). These methods, though valuable, are limited by recall bias, impression management, motivation, adoption of response sets, and so on.

Behavioral tasks have been used to assess constructs thought to be associated with NSSI, such as impulsivity (Glenn & Klonsky, 2010; McCloskey, Look, Chen, et al., 2012), problem solving abilities (Nock & Mendes, 2008), and pain tolerance and threshold (Hooley, Ho, Slater, et al., 2010; Germain & Hooley, 2013). These methods have provided objective data about the characteristics of people who engage in NSSI, but are not intended to assess behaviors representative of NSSI specifically nor do they allow for examination of risk factors (see Kraemer, Kazdin, Offord, et al., 1997 for discussion of risk) specific to NSSI.

Behavioral analogues, which allow for the direct assessment of a behavior through a proxy or another strongly related behavior, have long been used to study various human behaviors, such as aggression (e.g., Taylor, 1967), altruism (Milgram, Mann, & Harter, 1965), and group processes (Asch, 1952; 1956). There is now a growing body of literature in which researchers have developed and tested a variety of laboratory approaches to studying NSSI. Research using these laboratory-based methods has greatly added to the field as they allow a much closer representation of the experience of NSSI by attempting to mimic the behavior in the laboratory, without actual injury. In contrast to self- and clinician ratings of NSSI and self-harm considered more broadly (including suicide; e.g., Fliege, Lee, Grimm, et al., 2009; Gratz, 2003 Klonsky, 2007; Nock, 2009), these analogues as a whole have yet to be critically reviewed.

Current Review

Although several reviews have been published on NSSI research, including those on NSSI functions, common correlates, and treatment (e.g., Bentley, Nock, & Barlow, 2014; Nock & Prinstein 2004; 2005), to our knowledge, no previous review has focused solely on the use of laboratory-based behavioral methods used in the study of NSSI. The current paper aimed to fill this gap by providing a systematic review of NSSI analogue studies. In addition to providing this comprehensive review, research findings using these techniques are discussed in the context of the broader NSSI literature.

Method

Search Strategy and Study Eligibility

The search targeted published papers between July 1984 and November 2016. An electronic search on the following databases was carried out: PsycINFO, PsycARTICLES, ERIC, CINAHL, and MEDLINE. The following search terms were included: (a) self-injury or self-injurious behavior or non-suicidal self-injury or self-harm or deliberate self-harm or self-mutilation or self-aggression, and (b) experimental or laboratory or behavioral or real-time. Studies had to be in English and meet the following three inclusion criteria: (1) included a task that was an analogue of intentional self-injury (e.g., directly assessing a NSSI-proxy behavior). Examples of tasks that did not meet the proxy for self-injury criterion included EMA/daily diary designs, behavioral measures of impulsivity, and assessments of *only* pain tolerance; (2) the study was conducted in a controlled laboratory setting (e.g., no case studies); and (3) the sample was not specific to those with intellectual disabilities, autism spectrum disorder, or traumatic brain injury.

Results

Data Extraction

Of the 2,104 studies produced by the search, 61 papers were shortlisted for detailed analyses based on the abstracts. Thirty-seven of studies did not fit initial search criteria. The reference sections of the remaining 24 papers were examined, as was seminal papers in the literature, for additional, potentially relevant studies that were not included in the initial electronic search. An additional 32 papers were retrieved for a more detailed evaluation; of these 24 were included. Thus, a total of 48 studies were included in the review (See Figure 1). The final sample was further evaluated for type of laboratory task employed and grouped by three main task categories: NSSI-related (non-pain) stimuli [NSSI pictures (2 studies), implicit associations (6 studies), and guided-imagery (5 studies)]; experimenter administered pain stimuli [cold, hot, pressure, shock, and blade stimuli (23 studies)]; and self-selected pain stimuli [cold and shock stimuli (12 studies)]. See Table 1 for an overview and description of these behavioral methods and Table 2 for the included studies. Given the limited number of studies examining each laboratory task, a meta-analysis of the findings was not appropriate; however, effect sizes when available have been included in Table 2.

NSSI-Related (Non-Pain) Stimuli

NSSI Pictures.—To better understand what individuals may experience when viewing NSSI-related content, researchers have used NSSI-related picture stimuli (e.g., sharp objects pressed against bare skin; lacerated arms) in the laboratory, most often presented amongst neutral, positive, and negative valenced images from the International Affective Picture System (Lang, Bradley & Cuthbert, 2008). This technique is an important analogue of exposure to an expanding number of NSSI focused websites and online videos (Lewis & Baker, 2011) and might also provide insight into the reactions among self-injurers as they re-examine their own NSSI wounds/scars.

Research in this area has largely focused on inhibitory control in reactions to NSSI-related images. For example, NSSI history is associated with poor inhibition to negative emotional images and enhanced inhibition to NSSI-related images. Control participants, on the other hand, show impaired inhibition to NSSI-related images (Allen & Hooley, 2015). Thus, those who engage in NSSI showed impaired negative emotional arousal inhibition, and may have a conditioned response associating NSSI with relief or reward (Allen & Hooley, 2015). Using similar images, those with a history of NSSI reported NSSI-related photos to be more arousing and showed increased activation in the limbic system and prefrontal cortex for NSSI-related (vs. neutral) pictures (Plener, Bubalo, Fladung, et al., 2012).

Plener et al. (2012) postulated that hyper-reactivity of limbic structures (e.g., amygdala) among those with NSSI may be indicative of increased distress when viewing the images, with increased activity in the frontal cortex representing attempts to compensate for the limbic hyper-arousal. NSSI participants also rated NSSI-related images to be more arousing, but also demonstrated increased control over responses related to these images, suggesting a potential disconnect in how individuals view their NSSI behavior (e.g., explicitly negative) and their automatic response to the behavior (e.g., implicitly rewarding), which may be attributed to neural activity in response to NSSI images (Plener et al., 2012). Taken together, these findings support the notion that NSSI serve to regulate emotions through processes outside of an individual's direct awareness.

Implicit Association Tasks.—NSSI engagement is often associated with feelings of shame, guilt, and regret, (Leibenfult, Gardner & Cowdry, 1987; Schoenleber, Berenbaum & Motl, 2014) and may elicit negative reactions in others (Linehan, 1993). Consequently, those who engage in NSSI may be hesitant to discuss this behavior. IATs have been adapted to study NSSI in the laboratory. Through these reaction-time measures, an individual's implicit associations about self-injury (via self-injury images) are examined; one version of this task measures individuals' implicit identity with self-injury (i.e., associations of self-injury with themselves) and another version measures individual's implicit attitudes about self-injury (i.e., associations of self-injury as favorable vs. unfavorable). IATs may be particularly well-suited for the assessment of psychopathology (Palfai & Wagner, 2002), and thus self-injury, given that they may be resistant to attempts to “fake good” (Banse, Seise, & Zerba, 2001), may offer better predictive validity for socially sensitive topics (Greenwald, Poehlman, Uhlmann, et al., 2009), and have strong psychometrics (e.g., Cunningham, Preacher, & Banaji, 2001; Lane, Banaji, Nosek, et al., 2007).

Using the Self-Injury IAT (SI-IAT; Nock & Banaji, 2007a; 2007b), self-injurers demonstrated a positive identification with NSSI (Glenn & Klonsky, 2011; Nock & Banaji, 2007b), whereas control participants showed a negative identification (Nock & Banaji, 2007b). Further, individuals with a NSSI history and no suicide attempts more strongly identified with NSSI than those with only suicide attempt history or no history of self-harm (Dickstein, Puzia, Cushman, et al., 2015).

Although there is strong evidence for implicit NSSI identity, the findings related to NSSI attitudes are less consistent. For example, non-self-injuring adolescents have been shown to demonstrate a stronger, positive association between “cutting” and “bad” as compared to

those with a history of NSSI (Nock & Banaji, 2007b), but this has not been replicated in other samples (Glenn & Klonsky, 2011; Knowles & Townsend, 2012). Finally, responses related to both NSSI identification and attitudes on the SI-IAT independently and significantly predicted concurrent NSSI status above and beyond demographic information and psychiatric factors (Nock & Banaji, 2007b); however, performance on the tasks did not predict future NSSI behavior in college (Glenn & Klonsky, 2011) or adolescent inpatient (Dickstein et al., 2015) samples.

It is possible that inconsistent findings regarding implicit NSSI cognitive biases could be due to the potential influence of the function of NSSI on one's unconscious cognitions. Specifically, one may consider NSSI more or less favorable depending on their reason for engaging in the behavior. Using a similar IAT measure (e.g., Go-No-Go Association Task) examining implicit NSSI functions (Knowles & Townsend, 2012) individuals with a history of NSSI endorsed a stronger "self-harm" – "arousal" association (Knowles & Townsend, 2012). Furthermore, internal or automatic NSSI functions (e.g., "to escape", "to get relief...") were significantly related to a "self-harm" – "sedation" association, whereas interpersonal functions (e.g., "to punish someone", "to find out if someone cared") were associated with a positive "self-harm" – "good" association (Knowles & Townsend, 2012). Overall, these findings suggest that although NSSI is associated with higher arousal, those who report engaging in NSSI for affective relief may also view the act as calming.

The use of IAT behavior to predict future NSSI is just beginning to be tested but holds promise. For example, among adolescent inpatients, SI-IAT scores differentiated self-injurers from non-injurers at baseline, in addition to predicting subsequent cutting behavior during the hospital stay, even after controlling for NSSI history and prospective risk factors. Further, when participants explicitly reported low NSSI likelihood their SI-IAT performance still predicted cutting during the hospital stay (Cha, Augenstein, Frost, et al., 2016). Important in the use of the self-injury IATs moving forward, particularly among high-risk samples, the presentation of the stimuli in NSSI-related IATs does not increase participants' self-reported desire to self-injure, regardless of NSSI history or psychiatric functioning (e.g., community sample, psychiatric inpatient; Cha, Glenn, Deming, et al., 2016). Thus, IATs hold great promise as a measurement tool, both to better understand the characteristic of those who engage in NSSI and as a potential predictor of NSSI.

Guided Imagery.—Guided imagery has been used to assess individual reactions to an imagined act of NSSI. An NSSI scenario has four stages: 1) scene / context of the NSSI act; 2) events immediately preceding NSSI; 3) details of the actual NSSI act; and 4) events immediately following NSSI (Haines et al., 1995). The presentations of these NSSI-specific scripts have the advantage of allowing the examination of emotional, psychophysiological, and neuropsychological responses to all stages of an NSSI act (albeit imagined) in a "low-risk" task. Subjective and psychophysiological responses during NSSI guided imagery support the notion that NSSI may serve to provide relief from negative affect (Brain, Haines, & Williams, 1998; 2002; Haines, Brain & Williams, 1995; Welch, Linehan, Sylvers, et al., 2008). Specifically, individuals with a history of NSSI show an overall increase in subjective and physiological when imagining an NSSI-triggering event and a subsequent decrease in arousal immediately after imagining the NSSI act (Brain et al., 1998; 2002; Haines et al.,

1995). Current and past self-injurers did not differ in their pattern of arousal during imagery (Brain et al., 1998.)

Given the high co-occurrence of NSSI among individuals with borderline personality disorder (BPD; Clarkin, Widiger, Frances, et al., 1983; Soloff, Lis, Kelly, et al., 1994), differences in neural activity during imagined NSSI have been examined among those with both BPD and a history of NSSI (Kraus, Valerius, Seifritz, et al., 2010). NSSI/BPD participants demonstrated significant activation in the left medial temporal gyrus and deactivation in the middle frontal gyrus in the early preparation stages of imagining an NSSI act (Kraus et al., 2010), with a subsequent decrease in mid-cingulate activation when imagining the actual NSSI act. This pattern may relate to failure to inhibit or modulate emotional or cognitive reactivity during “approach” behavior, and enhanced emotional involvement and reduced pain sensitivity during the actual act. Furthermore, these neural processes occur even in the absence of subjective changes in affect (Kraus et al., 2010).

Overall, studies using guided imagery have provided support for an increase in arousal leading up to NSSI and a decrease in this arousal following a (imagined) NSSI act among both past and current self-injurers. This effect was also found to be stronger among those with infrequent NSSI behavior, suggesting NSSI may be particularly reinforcing at onset. Despite findings potentially being confounded with the presence of BPD, the use of guided imagery has consistently suggested that NSSI may be used as a way to reduce tension.

Experimenter Administered Pain Stimuli

Methods discussed thus far have focused on NSSI-related images, words, and scripts. However, researchers have also used tasks that attempt to recreate the experience of NSSI in the laboratory by administering an aversive (painful) stimulus, thus providing insight into how individuals experience an analogue of NSSI. These approaches are discussed below.

Cold stimuli.—A common method of assessing pain tolerance or experiences during the administration of pain is the Cold Pressor Test (CPT; Sadler, Welland, Mefferd, et al., 1967; Lovallo, 1975; Stam, Petrusic & Spanos, 1981). In the CPT, the participant immerses one (or both) arms in an ice bath, typically maintained at 1–4 degrees Celsius. Participants are instructed to keep their arm(s) in the water until it is too painful to do so, or until the maximum time is reached (e.g., 2 minutes); time in the bath and verbal pain intensity ratings are used to assess participant’s pain perception.

Early research showed that NSSI/BPD participants who deny subjective pain during NSSI also report less pain during the CPT compared to those NSSI/BPD participants who report pain during NSSI and to healthy volunteers, who did not differ from each other (Russ, Roth, Lerman, et al., 1992; Russ, Roth, Kakuma, et al., 1994). This pattern of results persists even after an opiate antagonist naloxone is administered (Russ et al., 1994), suggesting that NSSI pain analgesia may not be linked to the endogenous opioid system as once hypothesized. In contrast, lack of pain during NSSI was associated with greater affective relief immediately afterward (Russ et al., 1992; Russ et al., 1994). Another factor influencing pain during NSSI is the reported function of the behavior. Endorsement of a self-punishment function was associated with lower pain ratings on the CPT (Hamza, Willoughby, & Armiento, 2014),

suggesting that individuals who report pain analgesia during NSSI may be more likely to use NSSI as a form of self-punishment.

The CPT has also been used to show psychophysiological and neurophysiological differences to pain experience among those with NSSI (Chen, Dworkin, Haug, et al., 1989; Franklin, Hessel, Aaron, et al., 2010; Russ, Campbell, Kakuma, et al., 1999). Two psychophysiological measures used in this research are startle-alone reactivity (e.g., an involuntary response in reaction to a sudden sound), thought to be a measure of affective valence, and prepulse inhibition (e.g., when a weaker pre-stimulus inhibits the reaction to a subsequent stronger startling stimulus), as an indicator of information processing.

Those with a history of NSSI, compared to two non-NSSI groups (one matched to the NSSI group on affect dysregulation and the other a healthy control group), reported decreases in their startle-alone reactivity following the CPT. Further, participants with a history of NSSI demonstrated an increase in prepulse inhibition after the CPT whereas both comparison groups showed a decrease. Overall, results indicate that NSSI (via the pain-proxy) may not only serve an affect regulation, but also a cognitive regulation function (Franklin et al., 2010).

Electroencephalograms (EEG) have also been used during the CPT to measure neurophysiological underpinnings during the painful stimuli. In implementing this method, however, inconsistent findings have emerged. For example, pain sensitive (tolerating pain for a shorter duration) healthy participants, as opposed to pain tolerant participants, demonstrated higher delta levels (power densities) during the CPT (Chen et al., 1989). On the other hand, individuals with BPD who do not experience pain during NSSI (e.g., pain tolerant) demonstrated significantly higher theta, but not delta, levels during the CPT when compared to non-injuring clinical and non-clinical controls (Russ et al., 1999). In evaluating the latter finding, it was hypothesized that higher theta levels among pain absent participants may be linked to dissociative states during pain (Russ et al., 1999), and thus supporting an 'anti-dissociation' function (Nock & Prinstein 2004) of NSSI for this subgroup of self-injurers. However, it is possible that such discordant findings could be an artifact of sample characteristics (e.g., non-clinical vs. clinical) or variability in CPT procedures (e.g., differing temperatures of the water bath), as opposed to representing true group differences.

Overall, CPT studies provide further support for the emotional and cognitive regulation (Franklin et al., 2010) functions of NSSI. These studies have largely focused on the absence of pain during NSSI, suggesting those with aberrant pain perceptions during NSSI may represent a specific class of self-injurers, supported through both subjective (Russ et al., 1992; Russ et al., 1994) and objective (Russ et al., 1999) measures. Although it is unclear if driven by NSSI or BPD presence, it appears self-injurers not experiencing pain during NSSI may disconnect from the momentary pain (Russ et al., 1999), but still experience the subsequent affective relief. As such, this group may be at particular risk for chronic NSSI.

Heat stimuli.—Heat as an aversive stimulus is most commonly administered through a heat thermode, or via laser radiant heat, and is often applied to the hand (i.e., back of hand or fingers). It is possible this method may better represent pain experienced during NSSI as

burning is a more common form of NSSI relative to exposure to extreme cold (Whitlock, Muehlenkamp, Eckenrode, 2008).

Early work supporting the use of heat stimuli demonstrated that those with BPD and NSSI rated the heat as less painful than healthy volunteers did, independent of attentional focus (Schmahl, Greffrath, Baumgärtner, et al., 2004). Relatedly, among healthy volunteers the offset of heat stimuli was rated as more pleasant among those who found the heat to be more painful and physiologically arousing (Leknes, Brooks, Weich, et al., 2008). Furthermore, participants with a history of NSSI reported larger decreases in negative affect following painful heat stimuli as compared to non-painful stimuli than those without a history of NSSI, whereas the opposite pattern was found for non-painful warmth (Bresin & Gordon, 2013). These studies support the idea that pain analgesia and affective relief following pain among those with NSSI are related.

Heat stimuli has been used to examine neural activation among those with BPD and NSSI history at both fixed and idiographic heat levels (Schmahl, Bohus, Esposito, et al., 2006). Upon exposure to the fixed temperature, NSSI/BPD relative to no-NSSI/non-BPD participants perceived the stimuli as more painful and demonstrated lower activity in the right posterior parietal cortex (Schmahl et al., 2006); both groups, however, revealed a pattern of activity in the lateral and medial pain pathways. When presented with heat stimuli based on individual pain thresholds, greater differences emerged. The NSSI/BPD group showed lower activity in the parietal cortex, greater activity in the left dorsolateral prefrontal cortex, and deactivation in the right amygdala and perigenual portion of the anterior cingulate cortex, which are areas thought to evaluate pain intensity and be involved in the affective evaluation of pain (Schmahl et al., 2006). It is possible NSSI/BPD individuals have a neural circuit of pathologically reduced pain perception, where pain is primarily modulated through the down-regulation of emotional components of pain (Schmahl et al., 2006).

The use of heat as a NSSI-proxy supports and extends the cold stimuli findings. Initial evidence for a link between pain offset and reward has been substantiated among healthy participants, which may ultimately generalize to those with a history of NSSI. Further, research has differentiated between painful and non-painful stimuli. In the wake of a negative mood, self-injurers derived greater emotional relief from painful versus non-painful heat stimuli, which was not true for non-injurers. Therefore, a more intense pain experience may be imperative for those who engage in NSSI to experience the same degree of affective relief. Self-injurers also show some evidence of altered neural activation in pain and affective circuits in response to heat stimuli, but only after controlling for pain threshold differences between groups. However, the inclusion of co-morbid BPD or non-self-injuring, non-pathological participants limits the specificity of these findings. Despite these limitations, the findings provide preliminary evidence of differential processing of painful heat stimuli among self-injurers.

Pressure stimuli.—Another aversive stimulus used in the laboratory is tactile pressure. Two main methods of pressure have been used in pain research: The pressure algometer (Forgione & Barber, 1971), which is applied to the finger and knuckle to create an “aching” pain; and the Tourniquet Pain Test (Sternbach, Murphy, Timmermans, et al., 1974), which

induces an ischemic muscular pain via blood pressure cuff while participants contract their hand.

Work using the pressure algometer has supported previous findings that individuals with a history of NSSI report the experience of physical pain as less intense than those without a history of NSSI (McCoy, Fremouw, & McNeil, 2010). However, the limited research on emotion regulation is less clear. Following physical pain via the pressure algometer, both those with and without a history of NSSI reported decreases in shame (Schoenleber et al., 2014) suggesting the use of pain to lessen feelings of shame does not differ across individuals. It is possible, however, that group differences did not emerge as shame reduction is not a predominant function of NSSI (Klonsky, 2007).

Electric shock.—Another method by which pain has been used to mimic the experience of self-injury is electric shock. In this approach, an electrode is placed on the finger, hand, or arm, which induces a tingling/stinging sensation of increasing intensity.

Adding to the limited literature on pain offset, startle response has been used as an implicit measure of negative valence in association with the experience of electric shock (Andreatta, Mühlberger, Yarali, et al., 2010). The presentation of the shock was paired with a geometric shape at varied intervals (e.g., before, after, delayed). Results indicated that the stimuli associated with pain-relief (e.g., delay after the shape) acquired positive implicit valence (attenuated startle response), but were explicitly rated as aversive (Andreatta et al., 2010). These findings provide information as to why some individuals may be attracted to a conditioned stimulus (e.g., NSSI), even if they explicitly judge it as negative. Additional studies also used psychophysiological indices of positive affect (startle postauricular reactivity) and negative affect (startle eye blink reactivity) to examine pain offset following electric shock (Franklin, Lee, Hanna, et al., 2013; Franklin, Puzia, Lee, et al., 2013). Among those with and without NSSI history, pain offset simultaneously increased positive affect and decreased negative affect (Franklin, Lee, et al., 2013; Franklin, Puzia et al., 2013). However, there were no differences in strength of pain offset reactions between those with and with a history of NSSI (Franklin, Puzia, et al., 2013). Findings suggest repeated episodes of NSSI do not generate heightened offset pain relief, and, as such, heightened pain relief may not be a major risk factor for NSSI. Additional studies using shock stimuli on non-NSSI participants suggest that trait anxiety levels do not play a role in shock perception (Arntz et al., 1991). It is less clear if focus on the painful stimuli has an effect (Arntz et al., 1991, Duker et al., 1991, Duker et al., 1999). Taken together these finding suggest that NSSI may be an automatic, or learned, rewarding experience, which has important implication for the utilization of explicit NSSI attitudes in future research and treatment.

Blade stimuli.—The last category of pain paradigms includes both incisions made on the participant's forearm and a procedure developed to replicate the pain experienced via incision without actual tissue damage. In both of these approaches, the experimenter administers the stimuli.

Two studies have used a standardized surgical procedure (Kawamata, Watanabe, Nishikawa, et al., 2002; Pogatzki-Zhan, Wagner, Meinhardt-Renner, et al., 2010) to replicate the

experience of NSSI in the lab by creating an incision on participant's forearm, allowing for the direct examination of the influence of tissue damage on stress regulation. Focusing on subjective (aversive tension) and objective (heart rate) indexes of stress, these studies recruited individuals with BPD and NSSI histories, along with healthy controls, to undergo a stress induction followed by an incision. There was support for both short- and long-term effects of the tissue damage on stress regulation. In the NSSI/BPD group, heart rate decreased following the incision and lower subjective tension ratings were found for up to 30 minutes following the incision (Rietz, Krause-Utz, Pogatzki-Zhan, et al., 2012). Extending these findings via fMRI use, the NSSI/BPD group also demonstrated greater decreased amygdala activity and a normalized functional connectivity with the superior frontal gyrus following the incision (Rietz, Kluetsch & Niedtfeld, 2015). Taken together, these studies support the notion that NSSI may be used as an attempt to cope with dysregulated affect, and that the subjective relief of this behavior may be more than momentary.

Following this, researchers sought to develop and test a new paradigm using a blade stimulus, but without actual tissue damage (Shabes, Schloss, Megeri, et al., 2016). Through a series of experiments comparing several pain stimuli models (including the afore discussed incision procedure) with the new method, which resembled the blade used in the incision procedures but blunted to prevent tissue damage, participants reported similar maximum pain ratings for the blade stimuli as the incision (Shabes et al., 2016). The authors considered this as evidence supporting the use of the blade stimuli as a noninvasive model for pain that closely represents the experience of an actual incision (Shabes et al., 2016). Applying this method, researchers examined the impact of seeing blood during NSSI on stress regulation among those with BPD and NSSI histories. It was found that seeing blood (compared to seeing no blood) during the pain stimuli lead to a greater decrease in urges for NSSI for the NSSI/BPD group, however, it did not lead to a decrease in heart rate (Naoum, Reitz, Krause-Utz, et al., 2016).

Research using blade stimuli has allowed for a more ecologically valid way of examining the pain experienced during an act of NSSI. These studies support the role of NSSI as a form of affect regulation, particularly as measured by subjective experience, and neuroimaging findings are in line with these propositions. Additionally, results have highlighted the potentially important role of seeing blood in NSSI. Although these findings are confounded with the comorbid diagnosis of BPD, these methodologies have provided an avenue for a significant advancement of understating the experience of NSSI.

Multiple pain stimuli.—Several studies have compared reactions to different categories of pain. In response to both pressure and heat stimuli, for example, healthy participants experienced significant decreases in both positive and negative affect following pain, with women and those higher in emotion reactivity reporting larger decreases in negative affect following the painful stimuli (Bresin, Gordon, Bender, et al., 2010). These findings support negative affect reduction following pain and that this effect is not specific to type of pain stimuli, which is important to consider given the numerous NSSI methods self-injurers can use. Similarly, NSSI/BPD individuals with pain analgesia during self-injury reported reduced pain intensity during both the CPT and Tourniquet Pain Test (TPT) in comparison to

healthy participants, a difference that was further enhanced when in a self-reported state of distress (vs. calmness; Bohus et al., 2000). Although reduced pain intensity was found among all self-injurers, those in distress exhibited greater reductions in pain intensity, potentially reflecting a state dependent increased pain threshold. Of note, however, a greater number of NSSI/BPD participants reported pain analgesia during the TPT (characterized as a deep or “ischemic” pain) than during the CPT, viewed as more “superficial” pain (Bohus, Limberger, Ebner, et al., 2000). These discrepancies suggest that individuals with a history of NSSI may perceive superficial pain differently due to its similarity to the pain experienced during NSSI, and have potential implications for the future assessment of pain as a NSSI-proxy.

Self-Selected Pain Stimuli

To better replicate the in vivo experience of NSSI, participants have also been allowed to choose if and when they receive an aversive stimulus (and its intensity), increasing the ecological validity of pain tasks by better representing the self-inflicted pain during NSSI. Further, it allows researchers to draw conclusions regarding cause-and-effect relationships. Among studies using this approach, the majority used electric shock as the pain stimulus.

Shock stimuli.—The Self-Aggressive Paradigm (SAP; Berman & Walley, 2003; McCloskey & Berman, 2003) is an analogue of self-harm guised as a reaction time task in which participants self-select the shock level. Studies using the SAP found those with a history of NSSI administered higher mean shock levels compared to healthy participants, and (at a trend level) non-injuring psychiatric controls, supporting the criterion validity of the task (McCloskey, Ben-Zeev, Lee, et al., 2012). The SAP has examined both intrapersonal and external factors that putative influence NSSI-proxy behaviors, such as impulsivity. Level of shock administered by those with a NSSI history was related to both behavioral and self-reported impulsivity measures whereas actual NSSI behavior was only related to self-reported impulsivity (McCloskey et al., 2012). Although results may have been confounded by method invariance, they indicate that self-injurers are indeed more behaviorally impulsive. Another intrapersonal (e.g., biological) factor was examined by experimentally altering 5-HT activity via tryptophan depletion (McCloskey, Ben-Zeev, Lee, et al., 2009). Individuals in both high and low risk groups who consumed the tryptophan depletion (vs. placebo) drink were more self-aggressive on the SAP (McCloskey et al., 2009), suggesting that lowered 5-HT may enhance self-injurious behaviors above and beyond psychiatric predisposition.

The SAP has also been used to experimentally test potential causal relationships with NSSI correlates. The use of mood altering substances such as alcohol and benzodiazepines are associated with NSSI. In a college sample of men, acute intoxication (vs. placebo drink) resulted in higher mean self-shock and a four-fold increase in extreme self-shock on the SAP (McCloskey & Berman, 2003). A later study showed that the effect of alcohol on self-harm was associated with decreased self-awareness (Berman, Bradley, Fanning, et al., 2009). The benzodiazepine diazepam (5 mg and 10 mg) were also found have a dose dependent facilitatory effect on SAP self-shock (Berman, Jones, & McCloskey, 2005). This is not unexpected as benzodiazepines have been thought to be a risk factor for self-harm.

The presence of one or more self-aggressive models has been associated with increased self-aggression on the SAP (Berman & Walley, 2003; Sloan, Berman, Zeigler-Hill, et al., 2006). It was also shown that this effect could be reversed by observing a dissenter amongst a self-harming group, especially among women (Sloan, Berman, Zeigler-Hill, et al., 2009). Taken together, these results suggest that both acute substance impairment or the presence of a self-aggressive model can have a direct effect on non-suicidal self-harm.

Researchers have further adapted previous painful stimuli procedures to not only allow participants to choose their level of electric shock but to also permit them to initiate the shock (Bracken, Berman, McCloskey, et al., 2008; Weinberg & Klonsky, 2012). In an examination of the relationship between self-selected shock and state dissociation, participants were assigned to either a self-harm (high shock) or control (mild shock) condition. Women expecting to experience the high shock reported greater dissociation than men, but only after they administered the shock (Bracken et al., 2008); this may be suggestive of women experiencing greater relief following pain, represented as a mild dissociative state.

Using a similar method among those with and without a history of NSSI, self-injurers set higher levels of maximum shock but did not report significantly greater subjective levels of pain, indicating greater pain analgesia. Further, higher shock levels led to greater arousal reduction for NSSI participants, whereas higher subjective ratings of pain predicted smaller reductions in negative arousal (Weinberg & Klonsky, 2012). These findings suggest that more intense self-inflicted pain may facilitate greater reduction of negative arousal, but only if the subjective experience is not judged as highly aversive. Affective relief from self-selected shock has also been examined under differing mood conditions (Inbar, Pizarro, Gilovich, et al., 2013). Participants in a guilt condition initiated stronger shocks than those in a sad or neutral condition, and participants had greater relief from feelings of guilt following stronger shocks (Inbar et al., 2013). Supporting the aforementioned findings, more intense self-inflicted pain appears to lead to greater relief, and further, this effect may be stronger when an individual is experiencing high levels of guilt.

Cold stimuli.—Using procedures similar to the CPT, modified to be implemented in the fMRI scanner (e.g., sealed flexible plastic bag filled with ice and water applied to the forearm), research has compared self-administered stimuli to experimenter-administered stimuli. Interestingly, both those with and without NSSI reported that experimenter administered cold was more painful than the self-administered cold. On the other hand, the NSSI group reported more relief than those without NSSI for the self-administered cold (Osuch, Ford, Wrath, et al., 2014). This study contributes two unique findings to the literature on NSSI. First, by matching groups on demographic and psychiatric symptom reports it presents findings that may be distinct to self-injurers. Second, it suggests that self-administered pain stimuli, allowing for the active self-initiated component of the behavior, may better represent the experience of NSSI.

As noted, the use of self-selected pain has provided nuanced information about the experience of pain, and subsequent relief, when the participant initiates the stimulus, more closely representing an act of NSSI (Osuch et al., 2014). Through the use of this

methodology, several risk factors of self-injurious behavior (and assumedly NSSI) have been identified, including self-injurious group behavior, gender, and substance use, with particularly strong evidence for the impact of alcohol. Higher levels of self-selected shock also led to greater reductions in arousal, which may be informative in considering the progression from non-severe NSSI behavior to more medically-severe NSSI and potentially suicidal behavior. These methods have also provided insight on potential NSSI mechanisms, suggesting that pain relief may be greater after experiencing higher levels of dissociation or guilt.

Examination of the effect sizes produced by each method reviewed also provides insight into their utility (see Table 2). Despite a considerable number of studies not reporting sufficient data to calculate effect sizes, each method had an average Cohen's *d* of around 0.5, or higher, suggesting each type of stimuli is producing at least a medium effect; however, missing information prevents direct comparison of the different NSSI-related and pain stimuli, representing an area of future research. Overall, given these significant methodological benefits and evidence of meaningful effects, the reviewed laboratory-based NSSI methods have provided support for, and greatly expanded upon, the largely correlational NSSI literature through the testing of causal hypotheses.

Discussion

This systematic review of laboratory analogues of NSSI included findings from 48 articles published over the last 30 years featuring three main types of laboratory-based methods: NSSI-related (non-pain) stimuli, experimenter administered pain stimuli, and self-selected pain stimuli. Despite a recent increase in their use, these methods are still limited in their implementation compared to the NSSI literature as a whole.

With regard to NSSI-related non-painful stimuli, multiple studies show increased arousal to such stimuli (Brain et al., 1998; 2002; Haines et al., 1995; Nock & Banaji, 2007b; Plener et al., 2012), supporting their utility in assessing NSSI reactions. Furthermore, these methods allow researchers to examine responses to NSSI from unique perspectives: reactions to NSSI content (as potentially seen online), understanding all stages of NSSI behavior, and providing a snapshot of NSSI attitudes or cognitions that one might not be willing or able to discuss.

The use of actual pain stimuli (e.g., cold, heat, pressure, shock, and blade) provides the ability to more directly examine factors associated with the willingness to self-harm as well as how pain is processed among self-injurers. Further, the ecological validity of these techniques has been increased by allowing participants to select, and even initiate, the pain they experience within the behavioral methods, better emulating NSSI.

NSSI research has focused on self-report to assess reasons, or functions, for engaging in NSSI. This work has found relief from negative affect to be the most common reason for NSSI (Klonsky, 2007; Nock & Prinstein, 2004; 2005). For example, the urge to engage in NSSI typically occurs within the context of negative thoughts or feelings (e.g., anger, frustration; Klonsky, 2009; Muehlenkamp, Williams, Gutierrez, et al., 2009; Nock 2009).

The use of laboratory behavioral methods has both supported and expanded upon these self-reported functions. Self-injurers have explicitly rated NSSI images as more arousing (Plener et al., 2012) and also demonstrated associations of NSSI with “sedation”, or decreasing arousal (Knowles & Townsend, 2012). Furthermore, those with NSSI demonstrated increased arousal leading up to an imagined NSSI act and decreases following (Brain et al., 1998; 2002; Haines et al., 1995).

Self-injurers response to direct physical pain has also supported an affect regulation role in NSSI. Self-injurers showed significant reductions in negative affect following painful stimuli (Franklin et al., 2010), which was further strengthened in the presence of negative mood (Bresin & Gordon, 2013). Moreover, reductions in both subjective and objective measures of stress were found following forearm incision, in addition to changes in neurological activation (Rietz et al., 2012; Rietz et al., 2015). Building off strong correlational evidence, testing hypotheses related to affect regulation via NSSI behavioral analogues has supported affective relief as a reinforcing property of NSSI behavior, and therefore, a target for intervention, especially because such affective relief has likely resulted in NSSI being a learned, rewarding behavior (Leknes et al., 2008).

Although more limited in scope, correlational and experimental studies have examined additional, non-affect regulatory NSSI functions, such as self-punishment, to “feel something”, and to influence the social environment (Lloyd-Richardson, Perrine, Dierker, et al., 2007). Supported through the use of laboratory methods, the affect regulation function was related to associating NSSI with sedation qualities whereas interpersonal / social functions were related to associating NSSI as being good or positive (Knowles & Townsend, 2012), supporting at least two separate categories of NSSI functions explicitly and implicitly. Findings have also highlighted specific NSSI functions. Those who reported NSSI as self-punishment reported pain as less aversive than those with other motivations (Hamza et al., 2014) and the experience of physical pain reduced specific feelings of guilt (Inbar et al., 2013), a common antecedent to self-punishment. Further, the anti-dissociation function (i.e., “to feel something”) (Nock & Prinstein, 2004) may be particularly reinforcing as pain relief has been found to be greater after experiencing higher levels of dissociation (Bracken et al., 2008). Despite the general focus on affect regulation as a motive for NSSI, the use of NSSI-proxies has indicated these additional functions may be equally reinforcing for NSSI behavior.

Given the self-identified relief experienced after NSSI, it has been proposed that those who engage in NSSI experience pain differently than those who do not harm themselves. This notion has received preliminary support through quasi-experimental research, demonstrating that self-injurers have a higher pain threshold and tolerance compared to those without a NSSI history (Germain & Hooley, 2013; Hooley et al., 2010). Adding to this literature, self-injurers, compared to non-injurers, reported the physical pain experienced in the laboratory as less intense. Further, those indicating an absence of pain during NSSI also reported significantly lower subjective pain ratings in the laboratory (McCoy et al., 2010). These findings support and extend pain threshold research by demonstrating that even when experiencing similar pain, self-injurers do not view the pain as aversive, which may significantly impact the natural pain barrier of NSSI behavior (Franklin et al., 2013).

Prior to the use of laboratory behavioral methods, there was a dearth of research investigating how NSSI is experienced on a biological level. Using laboratory measures, those with a history of NSSI displayed differing neural activity (e.g., increased activation in the limbic system and prefrontal cortex) when viewing NSSI-related images (Plener et al., 2012), as well as when imagining NSSI-triggering acts (Kraus et al., 2010) and experiencing physical pain (Rietz et al., 2015; Schmahl et al., 2006). Overall, findings from laboratory harm behavioral methods suggest that individuals who engage in NSSI have differing subjective and neurological responses to pain, potentially a pattern related to failure to regulate emotional or cognitive reactivity, further supporting the notion of NSSI as a regulatory behavior (Kraus et al., 2010).

The use of laboratory tasks provides another method to test the association between intrapersonal factors, such as emotion regulation (discussed above), anxiety and impulsivity, and NSSI. Despite findings that over half of those who engage in NSSI report significant anxiety symptoms (Nock, 2009), the use of a NSSI-proxy has indicated that anxiety may not be a prominent or maintaining factor of NSSI (Artanz et al., 1991). Self-reported impulsivity has also been found to be higher among self-injurers (Glenn & Klonsky, 2010); however, conflicting with this relationship is the finding that self-injurers demonstrated decreased cognitive control over responses related to negative emotions and increased control NSSI-related images (Allen & Hooley, 2015). Conversely, self-selected shock levels were related to self-reported and behavioral impulsivity (McCloskey et al., 2012). These findings may shed light on differences between the experience during an act of NSSI (e.g., experiencing physical pain) as opposed to viewing NSSI related stimuli (e.g., NSSI images).

Finally, laboratory measures have also been used to test causal hypotheses related to putative external influences on NSSI. Cross-sectional research has suggested that individuals may be more likely to act on thoughts of self-harm when they are using alcohol or drugs (Klonsky, 2011; Nock, 2009). NSSI-proxies have allowed the directionality of the intoxication – NSSI relationship to be directly tested, showing that acute intoxication increases willingness to engage in self-harming behavior (Berman et al., 2009; McCloskey & Berman, 2003). Another hypothesized risk factor for NSSI behavior is NSSI contagion, which suggests that the risk of engaging in NSSI increases through peer NSSI engagement (Jarvi, Jackson, Swenson, et al., 2013; Prinstein, Heilbron, Guerry, et al., 2010). Supporting this, those who were exposed to group norms of increased self-injurious behavior also demonstrated increases in their own self-injurious behavior through the selection of higher-self shock (Berman & Walley, 2003; Sloan et al., 2006). The use of laboratory-based methods has allowed researchers to examine causal relationships of NSSI, and to identify prominent NSSI risk factors, in addition to delineating those factors that may not serve to maintain NSSI (e.g., anxiety). In summary, studies implementing laboratory analogues of NSSI have supported numerous hypotheses put forth based on correlational and quasi-experimental work. Furthermore, these studies have led to the identification of potential explanatory mechanisms of NSSI and, consequently, have significantly advanced the field.

Limitations and Future Directions

As with most new behavioral methodologies, issues of validity and reliability have to be considered. As mentioned, there has been support for the validity of included methods: self-injurers showed increased arousal to NSSI stimuli (Brain et al., 1998; 2002; Haines et al., 1995; Plener et al., 2012), greater implicit identification with NSSI (Nock & Banaji, 2007b), and differences in responses to pain (Bresin & Gordon, 2013; Franklin et al., 2010; McCloskey et al., 2012; McCoy et al., 2010). However, there is still a limited understanding of how standardized stimuli, particularly pain stimuli, relate to the actual experience of NSSI. Moving forward, the use of idiographic or self-selected stimuli should be further explored to improve the ecological validity of these methodologies.

Relatedly, there is a dearth of literature examining the reliability of these behavioral tasks. It has been found that slight variations in administration procedures may influence the experience of pain. For example, changing the cuff width used during the Tourniquet Pain Test alters responses to the experience of pain (Estebe, Le Naoues, Chemaly, et al., 2001). Although slight variations in administration can be expected (i.e., measurement error), more substantial differences may have adverse impacts on overall knowledge of NSSI. If physical/pain stimuli are initially introduced as too painful or too intense, all participants may experience significant pain too quickly, negating any group variation in responses to the stimuli. Conversely, it is also possible that presented stimuli may not be extreme enough to elicit pain, or accurately represent the pain experienced during NSSI. The extent to which each methodology may represent a more dispositional or state responding style is also unclear due to a lack of test-retest reliability. Given this, there is a need for more rigorous psychometric evaluations of behavioral methods of NSSI to improve the measurement and understanding of this behavior.

To date, there are no known iatrogenic effects of laboratory NSSI paradigms. For example, it has been demonstrated that participants (including self-injurers) reported no increase in urges to self-injure after seeing pictures of NSSI (Cha et al., 2016) or participating in the self-administered pain stimuli paradigm (Osuch et al., 2014), despite the increased ecological validity of real-world NSSI. Although the latter study did include a stress induction prior to the pain paradigm, it will be important for future research to replicate these findings within designs that aim to more accurately represent both the preceding events and consequences of NSSI behavior, as discussed below.

The inclusion of NSSI-proxy laboratory methods has significantly contributed to our knowledge of NSSI. However, it will be necessary to replicate current NSSI-proxy findings across various laboratory methods (e.g., cold vs. heat stimuli; experimenter vs. self-administered), settings, and populations. Of equal importance, more research is needed to better understand potential contrasts between current and past self-injurers. Although initial research has found these two groups do not differ in their arousal during imagined acts of NSSI (Brain et al., 1998), other findings have suggested that even past self-injurers experience physical pain differently than those who have never injured (Ludäscher, Greffrath, Schmahl, et al., 2009). Expanding on these findings would help better understand the long-term effects of NSSI and recovery from NSSI.

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Figure 1.
Flow chart showing the article-identification process

Table 1

Overview of NSSI Behavioral Methods

Behavioral Method	Development	Description
NSSI Pictures	N/A	Images of razors, knives, and/or a lacerated arm
Self-Injury Implicit Association Task	Nock & Banaji, 2007a	Assesses NSSI identity (e.g., “cutting / me”; “cutting / not me”) and NSSI attitudes (e.g., “cutting / good”, where good is defined as pleasure and relief; “cutting / bad”, where bad is defined as painful and ineffective) by comparing time taken to classify concepts
Go-No-Go Association Task	Knowles & Townsend, 2012	Assesses NSSI arousal (e.g., “self-harm / arousal”; “self-harm / sedation”) by comparing time taken to classify concepts
Self-Injury Guided Imagery	Haines et al., 1995	Verbal script describing NSSI scenario in 4 distinct stages: setting the scene, approach to the behavior, the incident, and the consequence
Cold Pressor Task	Sadler et al., 1967; Lavallo, 1975; Stam, Petrusic & Spanoes, 1981	Immerse arm(s) in ice bath (typically at 32.5 degrees Fahrenheit (0.3 degrees Celsius)) for a maximum of three minutes, or until intolerable
Heat Thermode	N/A	Heat thermode placed on hand, ranging in temperature from 104–122 degrees Fahrenheit (increasing at a rate of 2–4 degrees per second) until maximum heat is reached or rated as painful
Pressure Algometer	Forgione & Barber, 1971	Algometer placed on fingers and knuckles and then lowered onto skin for a maximum of five minute or until painful
Tourniquet Pain Test	Sterbech, Murphy, Timmermans, et al., 1974	A blood pressure cuff is affixed to the upper arm and rapidly pumped up to a value of 30 mmHg above the previously determined highest measurement (e.g., maximum strength of dominant hand). Simultaneously, participants use half of their hand strength to depress a vigormeter at a rate of 40 times per minute.
Electric Shock	N/A	Electrode placed on hand or arm, which produces tingling/stinging (shock) sensation (used as both experimenter- and self- selected)
Self-Aggressive Paradigm	Berman & Walley, 2003; McCloskey & Berman, 2003	Repeated (typically 28–32) reaction time trials are presented, and after each trial the participants loses they are asked to select a shock level ranging from 0 (no shock) to 10 (the subjects predetermined threshold), or a 20 (believed to be twice their predetermined threshold).
Surgical Incision	Kawamata, Watanabe, Nishikawa, et al., 2002; Pogatzki-Zhan, Wagner, Meinhardt-Renner, et al., 2010	After disinfection with 70% alcohol, a 4-mm-long and 5–7 mm deep cut using a sterile scalpel is made through the skin, fascia, and muscle of the anterior aspect of the volar forearm.
Blade Stimuli	Shabes, Schloss, Mergi, et al., 2016	A blunted blade, with a tip size of 4 mm by 0.1 mm, is pressed against the right, volar forearm for seven seconds.

Note: N/A = No specific development paper

Table 2

Overview of Included Studies

Authors	Participants (NSSI+)	Study Design	Laboratory Task	Effect Size (Cohen's <i>d</i>)	Main Findings
NSSI Related (Non-Pain) Stimuli					
<u>NSSI-Related Images</u>					
Allen & Hooley, 2015	67 (33)	Between-Subjects (NSSI vs. no NSSI)	NSSI Pictures	0.73 ¹ ; 0.59 ²	NSSI+ showed poorer inhibition to negative emotion images ¹ and enhanced inhibition to NSSI images ²
Plener et al., 2012	18 (9)	Between-Subjects (NSSI vs. no NSSI)	NSSI Pictures	0.14 ²	NSSI+ rated NSSI images as more arousing ² and showed increased activity in middle orbitofrontal cortex and inferior and middle frontal cortex when viewing NSSI images
<u>Implicit Association Tests</u>					
Cha et al., 2016	123 (68)	Between-Subjects (NSSI vs. no NSSI); Within-Subjects	SI-IAT	0.73 ¹ ; 1.16 ²	NSSI+ had stronger implicit identification with NSSI than noninjured ¹ and SI-IAT scores predicted hospital-based cutting, even after controlling for age, NSSI history, and number of NSSI methods ²
Cha et al., 2016	3304 (°); 100 (°); 89 (°)	All studies: 2 (gender) x 2(pre-post desire to self-injure); x2(pre-post desire to die); x2 (pre-post mood); 2 (self-harm history vs. no) x 2(pre-post desire to self-injure); x 2(pre-post desire to die); x2 (pre-post mood);	SI-IAT	.02 ¹ ; -.06 ² ; .02 ³ ; -.38 ⁴ ; .54 ⁵ ; -.06 ⁶ ; .16 ⁷	S1: slight increase in a desire to self-injure ¹ , slight decrease in desire to die ² , and no change in mood post-IAT; slight mood decline among females ³ ; self-harm status had little to no effect on outcomes; S2: no changes in desire to self-injure or die post-IAT; decrease in mood post-IAT ⁴ ; slight mood decline among females ⁵ ; self-harm status had little to no effect on outcomes; S3: slight decrease in desire to die post-IAT ⁶ ; no changes in desire to self-injure or mood post-IAT; slight mood decline among females ⁷ ; self-harm status had little to no effect on outcomes
Dickstein et al., 2015	136 (46)	Between-Subjects (NSSI vs. suicide attempts / no NSSI vs. no NSSI)	SI-IAT	1.06 ¹ ; 1.13 ²	NSSI+ identified more with cutting vs. no cutting than those with a suicide attempt ¹ and control ² participants
Glenn & Klonsky, 2011	167 (81)	Longitudinal, Between-Subjects (NSSI vs. no NSSI)	SI-IAT	0.48 ¹	NSSI+ identified more with NSSI at baseline ¹ , but identification with NSSI at baseline did not predict NSSI behavior at 1-year follow-up
Knowles & Townsend, 2012	72 (24); 69 (21)	S1 and S2 Between-Subjects (NSSI vs. no NSSI)	Go – No-Go Association Task	S1: 0.79 ¹ ; 0.51 ² ; S2: 0.75 ³	S1: NSSI+ ¹ and controls showed a dislike (vs. like) association toward NSSI; NSSI+ ² showed an association between arousal (vs. sedation) and NSSI; explicit (vs. implicit) attitudes better predicted NSSI status; S2: NSSI+ showed a stronger NSSI-arousal association ³ ; among

Authors	Participants (NSSI+)	Study Design	Laboratory Task	Effect Size (Cohen's <i>d</i>)	Main Findings
Nock & Banaji, 2007	89 (53)	Between-Subjects (NSSI vs. no NSSI)	SI-IAT	1.23 ¹ ; 1.04 ²	NSSI+ automatic functions were related to NSSI-sedation association and interpersonal functions to NSSI-good association NSSI+ more strongly identified with cutting ¹ and the control group demonstrated a stronger association between cutting and bad ² ; performance in both areas predicted NSSI status
<u>Guided-Imagery</u> Brain, Haines, & Williams, 1998	70 (35)	3 (Current NSSI vs. Past NSSI vs. no NSSI) x 3 (event: accidental injury, anger, neutral)	Guided-imagery script	<i>a</i>	NSSI+ demonstrated decreased psychophysiological arousal when imagining cutting themselves, but only after the cutting; response differed from control participants, but did not differ between current and past NSSI+
Brain, Haines, & Williams, 2002	43 (43)	Between-Subjects (Frequent NSSI vs. Infrequent NSSI)	Guided-imagery script	<i>a</i>	Frequent and infrequent NSSI+ did not differ in psychophysiological responses, but infrequent NSSI+ reported being more anxious and uptight after the imagined NSSI act
Haines, Brain, & Wilson, 1995	38 (15)	3 (prison NSSI vs. no NSSI vs. non-prison control) x 3 (accidental injury vs. aggression vs. neutral)	Guided-imagery script	0.14–0.68 ¹ ; 0.10–0.53 ²	The prison NSSI+ demonstrated a decrease in psychophysiological ¹ and psychological ² response following the imagined NSSI act, which differed from control imagery
Kraus, et al., 2010	21 (11)	Between-Subjects (NSSI/BPD vs. no NSSI/BPD)	Guided-imagery script	<i>a</i>	NSSI/BPD+ showed less activation in the orbitofrontal cortex and increased activity in the dorsolateral prefrontal cortex while imagining the event leading up to NSSI, and decrease in the mid-lingulate while imagining the NSSI act
Welch, Linehan, Sylvers, Chittams, & Rizvi, 2008	42 (37)	Within-Subjects (event: NSSI and/or SA, accidental death/injury, or neutral)	Guided-imagery script	0.33 ¹	Participants did not demonstrate decreases in negative emotion during the NSSI act, but decreases following the imagined NSSI act ¹
Experimenter Administered Pain Stimuli					
<u>Cold Stimuli</u> Chen, Dworkin, Haug, Gehrig, 1989	42 (0)	2 (pain-tolerant vs. pain-sensitive) x3 (stage: baseline vs. pain vs. post)	Cold Pressor Task	<i>a</i>	Pain-tolerant and pain-sensitive participants demonstrated no baseline delta or theta differences; both groups exhibited heightened delta and beta levels during pain, but the pain-sensitive showed higher delta levels.
Hamza et al., 2014	82 (56)	Between-Subjects (NSSI with self-punishment vs. NSSI without self-punishment vs. no NSSI)	Cold Pressor Task	0.64–0.69 ¹	After a stress task, NSSI+ with self-punishment rated the pain as less aversive compared to the other two groups ¹
Franklin et al., 2010	112 (16)	Between-Subjects (NSSI vs. no NSSI high affect dysregulation (AD) vs. no NSSI low AD vs. no NSSI no pain)	Cold Pressor Task	<i>a</i>	After a stress task, NSSI+ reported an increase in distress following the pain, which didn't differ from pain comparison groups; NSSI+, compared to the no NSSI high AD and no NSSI low AD, reported decreased in their startle-

Authors	Participants (NSSI+)	Study Design	Laboratory Task	Effect Size (Cohen's <i>d</i>)	Main Findings
Russ et al., 1992	28 (22)	Between-Subjects (NSSI/BPD no NSSI pain vs. NSSI/BPD NSSI pain vs. no NSSI/BPD)	Cold Pressor Task	<i>a</i>	along reactivity and increase in prepulse inhibition following the pain stimuli NSSI/BPD+ no pain group rated pain as less intense than comparisons, who did not differ; NSSI/BPD+ no pain group reported lower depression, anger, anxiety and confusion following pain than the NSSI/BPD+ pain group
Russ, Roth, Kakuma, Harrison, & Hull, 1994	11 (11)	2 (NSSI/BPD no NSSI pain vs. NSSI/BPD NSSI pain) x 2 (opiate antagonist naloxone vs. saline)	Cold Pressor task	<i>a</i>	NSSI/BPD+ no pain group rated pain as less intense than the NSSI/BPD+ pain group, even after receiving the opiate antagonist naloxone
Russ et al., 1999	76 (41)	Between-Subjects (NSSI/BPD no NSSI pain vs. NSSI/BPD NSSI pain vs. no NSSI depressed vs. no NSSI)	Cold Pressor Task	<i>a</i>	NSSI/BPD+ no pain group reported less pain intensity than other groups, and demonstrated high theta levels during pain compared to the no NSSI depressed and no NSSI groups
<u>Heat Stimuli</u>					
Bresin & Gordon, 2013	115 (59)	2 (NSSI vs. no NSSI) x 2 (pain stimuli vs. non-pain stimuli)	Heat Thermode	0.73 ¹	After a negative mood induction, NSSI+ reported greater reduction in negative affect following pain vs. non-pain stimuli ¹
Leknes, Brooks, Wiesel, & Tracy, 2008	8 (0); 16 (0); 13 (0)	S1: Within-Subjects; S2: Within-Subjects (pain level: threshold vs. mild vs. moderate, vs. intense); S3: Within-Subjects (temperature: heat vs. heat+cooling)	Heat Thermode	S1: <i>a</i> ; S2: <i>a</i> ; S3: 1.46 ¹ ; 1.12 ²	S1: Subjective pain relief began after pain and maximum relief occurred later than peak pain intensity; S2: Subjective pain intensity and relief ratings increased across conditions as did galvanic skin response; S3: Average ¹ and peak ² pain relief with cooling was rated as more pleasant than pain relief without cooling
Schmahl et al., 2004	28 (14)	Between-Subjects (NSSI/BPD vs. no NSSI or BPD)	Laser Radiant Heat Stimuli	2.16 ¹	NSSI/BPD rated the heat stimuli as less painful ¹
Schmahl et al., 2006	24 (12)	2 (NSSI/BPD vs. no NSSI) x 2 (pain type: fixed vs. idiographic)	Heat Thermode	<i>a</i>	During fixed pain NSSI/BPD+ demonstrated lower activity in the right posterior parietal cortex compared, but both revealed a pattern of activity in the lateral and medial pain pathways; NSSI/BPD+ showed lower activity in the parietal cortex, greater activity in the left dorsolateral prefrontal cortex, and deactivation in the right amygdala and perigenual anterior cingulate cortex when presented with idiographic pain
<u>Pressure Stimuli</u>					
McCoy, Fernous, & McNeil, 2010	44 (11)	Between-Subjects (NSSI vs. no NSSI)	Pressure Algometer	0.70 ¹	NSSI+ rated the pain as less intense ²
Schoenleber, Berenbaum, & Motl, 2013	67 (25)	Between-Subject (NSSI vs. no NSSI)	Pressure Algometer	<i>a</i>	NSSI+ reported greater unpleasant and lower pleasant emotions following pain; Both groups experienced reductions in state shame following

Authors	Participants (NSSI+)	Study Design	Laboratory Task	Effect Size (Cohen's <i>d</i>)	Main Findings
Electric Shock Andreatta, Mulberger, Yarali, Gerber, & Pauli, 2010	101 (0)	Between-Subjects (group: forward delay condition vs. forward trace conditioning vs. backward conditioning)	Electric Shock	<i>a</i>	Stimuli presented in forward delay were indicated as having negative implicit valence; Stimuli presented in backward were indicated as having an implicit positive valence, but explicitly evaluated as emotionally negative; Stimuli present in forward trace did not attain an implicit valence response
Amiz, Dressen, & Merckelback, 1991	55 (0)	2 (anxiety: low vs. high) x 2 (attention: attention vs. distraction)	Electric Shock	0.62 ¹	Participants in the distraction condition reported lower subjective pain ratings ¹ and weaker skin conductance responses as compared to the attention condition; there was no main effect for anxiety or an attention by anxiety interaction
Duker, van den Bercken & Foekens, 1999	60 (0)	Between-Subjects (attention: focusing vs. distracting)	Electric Shock	<i>a</i>	No differences between groups on subjective pain sensations or startle response
Franklin, Lee, Hanna, & Prinstein, 2013	40 (0)	Within-Subjects	Electric Shock	0.38–0.57 ¹ ; 0.39–0.59 ²	Pain offset was associated with significantly elevated postauricular reactivity ¹ , which was greatest after higher-intensity shocks, and diminished startle eye blink reactivity ² , which was stronger after lower-intensity shocks
Franklin, Puzia, Lee, Hanna, Spring & Prinstein, 2013	42 (21)	Between-Subjects (NSSI vs. no NSSI)	Electric Shock	0.62 ¹	At both 3.5-s and 6-s post shock measurements, both groups demonstrated reduced mean startle eye blink and increased postauricular reactivity, and NSSI+ participants displayed greater reduction in eye blink reactivity at 6-s post shock ¹ ; among NSSI+, there was no correlation between NSSI frequency and pain offset
Blade Stimuli Naomus et al., 2016	40 (20)	2 (group: NSSI/BPD vs. no NSSI/BPD) x2 (condition: Blood vs. no-blood) x12 (time)	Blade Stimuli	.52 ¹	No differences on pain rating within group between conditions; NSSI/BPD+ showed higher levels of arousal in blood condition ¹ ; NSSI/BPD+ showed greater decrease in urge for NSSI in blood condition; No differences in heart rate decrease between groups or conditions.
Rietz et al., 2012	32 (14)	2 (group: NSSI/BPD vs. no NSSI/BPD) x2 (condition: incision vs. sham) x2 (time: baseline vs post-stress)	Surgical Incision	.24 ¹ ; .43 ² ; .56 ³	NSSI/BPD+ showed decrease in heart rate after incision ¹ , and lower heart rate after incision vs. sham ² ; NSSI/BPD+ reported lower tension ratings after incision vs. sham for up to 30 minutes after incision ³
Rietz et al., 2015	38 (21)	2 (group: NSSI/BPD vs. no NSSI/BPD) x2 (condition: incision vs. sham) x4 (time)	Surgical Incision	.71 ¹ ; .37 ²	NSSI/BPD+ reported lower tension ratings after incision compared to no NSSI/BPD ¹ ; no differences in heart rate were found; NSSI/BPD+ demonstrated higher heart rate

Authors	Participants (NSSI+)	Study Design	Laboratory Task	Effect Size (Cohen's <i>d</i>)	Main Findings
Shabes et al., 2016	26 (0)	Within-Subjects (stimulus type)	Blade Stimuli	.02 ¹	following the stress induction after sham compared to incision ² ; connectivity of amygdala with superior frontal gyrus was increased in NSSI/BPD+ after incision vs. sham
<u>Multiple Pain Stimuli</u>					
Bohus, et al., 2000	31 (12)	2 (group: NSSI/BPD with no pain during NSSI vs. no NSSI/BPD) x 2 (condition: calmness vs. distress)	Cold Pressor Task; Tourniquet Pain Test	<i>a</i>	NSSI/BPD+ in self-reported calmness rated pain as subjectively less intense than no NSSI/BPD and this difference was greater when participants were in self-reported distress
Bresin, Gordon, Bender, Gordon, & Joiner, 2010	167 (0); 184 (0)	Within-Subjects	Pressure Algometer; Heat Thermode	S1: 0.23 ¹ , 0.46 ² ; 0.72 ³ , 0.44 ⁴ ; S2: 0.03 ⁵ , 0.12 ⁶ , 0.74 ⁷ , 0.45 ⁸	S1: Participants reported subjective decreases in positive affect (PA) and negative affect (NA) following pressure pain, which was more pronounced in females ¹⁻³ than males ^{2,4} ; S2: Participants reported subjective decreases in PA and NA follow heat pain, and those high in emotion reactivity ^{5,7} reported larger decreased in NA than those low in emotion reactivity ^{6,8}
Self-Selected Pain Stimuli					
<u>Shock Stimuli</u>					
Berman, Bradley, Fanning, & McCloskey, 2009	40 (0)	2 (alcohol: alcohol vs. placebo) x 2 (awareness: low self-awareness vs. high self-awareness)	Self-Aggressive Paradigm	1.21 ¹ , 0.31 ²	Alcohol low self-awareness participants used more extreme shocks than placebo low self-awareness participants ¹ , but no differences between high self-awareness groups; Alcohol condition participants used more extreme shocks than the placebo condition ²
Berman, Jones, & McCloskey, 2005	46 (0)	Between-Subjects (dose: 10mg diazepam vs. 5mg diazepam vs. placebo)	Self-Aggressive Paradigm	0.83 ¹ , 0.86 ²	Participants receiving 10mg of diazepam administered higher average ¹ shock and more extreme shock ² than placebo groups
Berman & Walleye, 2003	94 (0)	3 (mood: depressed, elated, neutral) x 2 (condition: self-aggressive model vs. non-self-aggressive model)	Self-Aggressive Paradigm	0.85 ¹	Intensity of self-selected shock increased over time for all participants; participants exposed to the self-aggressive model set higher average shocks ¹ , and this effect increased over time
Bracken, Berman, McCloskey, Bullock, 2008	85 (0)	2 (condition: self-harm vs. no self-harm) x 2 (dissociation assessment: 90s before shock vs. 90s after shock)	Self-Aggressive Paradigm	1.54 ¹	There were no differences on dissociation scores pre- or post-shock between the self-harm and no self-harm condition; women reported greater levels of dissociation compared to men in the self-harm, post shock condition ¹
Inbar, Pizarro, Gilovich, & Ariely, 2013	46 (0)	Between-Subjects (condition: guilty vs. sad vs. neutral)	Electric Shock	0.78 ¹ , 0.74 ²	Participants in the guilt mood induction inflicted more intense electrical shocks than those in the sad ¹ or neutral conditions ¹ ; stronger shock was associated with great guilt relief

Authors	Participants (NSSI+)	Study Design	Laboratory Task	Effect Size (Cohen's <i>d</i>)	Main Findings
McCloskey & Berman, 2003	40 (0)	2 (alcohol: alcohol vs. placebo) x 2 (condition: self-aggressive model vs. no self-aggressive model)	Self-Aggressive Paradigm	1.37 ¹ ; 0.19 ²	Alcohol participants administer higher mean shock ¹ and more severe shock compared to placebo participants; self-aggressive model participants set higher mean shocks ² as the task progressed, but there was no interaction effect
McCloskey, Ben-Zeev, Lee, Berman, & Coccaro, 2009	32 (0)	2 (group: aggression vs. non-aggression) x 2 (condition: tryptophan depletion vs. placebo)	Self-Aggressive Paradigm	^a	Participants in the tryptophan depletion condition selected higher average shocks than those in the placebo condition; aggressive participants were more likely to selected higher average shocks than non-aggressive participants, but no interaction with condition was observed
McCloskey, Look, Chen, Pajoumand, & Berman, 2012	79 (24)	Between-Subjects (NSSI vs. no NSSI vs. healthy control)	Self-Aggressive Paradigm	0.84 ¹	NSSI+ participants set higher mean shock than healthy controls ¹ ; self-rated and behavioral impulsivity were associated with mean level of selected shock
Sloan, Berman, Zeigler-Hill, Greer, & Mae, 2006	107 (0)	Between-Subjects (condition: high self-aggression norm vs. low self-aggression norm vs. mixed self-aggressive norm vs. no norm)	Self-Aggressive Paradigm	1.03 ¹ ; 0.82 ² ; 1.60 ³	High self-aggression norm participants set higher shocks compared to the mixed ¹ , no ² , and low ³ norms groups, and low self-aggression norm participants set lower shocks compared to the other three groups; mean shock for men was higher than mean shock for women, but no interactions were present
Sloan, Berman, Zeigler-Hill, & Bullock, 2009	164 (0)	Between-Subjects (condition: unanimous self-aggression norm vs. nonunanimous self-aggression norm with first dissenter vs. nonunanimous self-aggressive group norm with last dissenter vs. no agreement)	Self-Aggressive Paradigm	0.34 – 0.89 ¹	Participants in unanimous self-aggression condition selected more extreme shocks than the other conditions ¹ and participants in the non-unanimous self-aggression with first dissenter condition selected more extreme shocks than the no agreement condition; women were less likely to conform to the groups norm when in non-unanimous condition
Weinberg & Klonsky, 2012	72 (39)	2 (NSSI vs. no NSSI) x 2 (condition: high shock vs. mild shock)	Self-Selected Electric Shock	0.65 ¹ ; 0.76 ²	NSSI+ reported greater pain analgesia during pain ¹ ; high shock condition lead to greater negative arousal reduction in no NSSI but not NSSI+, however, high shock predicted greater reduction in negative arousal in NSSI+ ² ; higher subjective pain ratings predicted smaller reduction in negative arousal
<u>Cold Stimuli</u>					
Osuch et al., 2014	28 (13)	2 (administration: experimenter vs. self) x 2 (condition: instruction vs. stimulation) x 2 (type: cool vs. cold) x 2 (group: NSSI vs. no NSSI)	Ice in Plastic Bag	.95 ¹	No changes within group on urges to self-injure following cold stimuli; NSSI+ reported similar pain ratings for experimenter vs. self-administered cold stimuli; NSSI+ reported greater relative than controls for self-administered cold stimuli ¹ but not experimenter administered cold stimuli; relief ratings showed differences in BOLD response in the self-

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Authors	Participants (N/SSI+)	Study Design	Laboratory Task	Effect Size (Cohen's <i>d</i>)	Main Findings
					administered cold condition in the precuneus/cuneus bilaterally, right thalamus/caudate/globus pallidus, and left parahippocampal gyrus

Note: Cohen's *ds* are presented for significant group comparisons of interest and are denoted with corresponding numerical superscripts;

^a = Unable to calculate effect size (e.g., not able to contact authors, authors could not locate data, etc.);

S1 = study 1, S2 = study 2, etc.;

* = Information not available