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Research paper

Examining tradeoffs between cognitive effort and relief among adults with self-injurious behavior

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ABSTRACT

Background: People engage in nonsuicidal self-injury (NSSI) to reduce negative affect, but it is not clear why they engage in this harmful type of behavior instead of using healthier strategies. The primary goal of this study was to evaluate whether people choose NSSI to reduce negative affect because they perceive it to be less cognitively costly than other available strategies.
Method: In experiment one, 43 adults completed a novel, relief-based effort discounting task designed to index preferences about exerting cognitive effort to achieve relief. In experiment two, 149 adults, 52 % with a history of NSSI, completed our effort discounting task.
Results: Our main results suggest that people will accept less relief from an aversive experience if doing so requires expending less effort, i.e. they demonstrate effort discounting in the context of decisions about relief. We also found and that effort discounting is stronger among those with a history of NSSI, but this association became nonsignificant when simultaneously accounting for other conditions associated with aberrant effort tradeoffs.
Limitations: The use of a control group without NSSI or other potentially harmful relief-seeking behaviors limits our ability to draw specific conclusions about NSSI. The ecological validity of our task was limited by a modestly effective affect manipulation, and because participants made hypothetical choices.
Conclusions: This study demonstrates that preferences about exerting cognitive effort may be a barrier to using healthier affect regulation strategies. Further, the preference not to exert cognitive effort, though present in NSSI, is likely not unique to NSSI. Instead, effort discounting may be a transdiagnostic mechanism promoting an array of harmful relief-seeking behaviors.

Nonsuicidal self-injury (NSSI) refers to intentional harm to one's own body without intent to die (Nock and Favazza, 2009), and most frequently involves behaviors such as cutting or burning the body (Briere and Gil, 1998; Klonsky and Muehlenkamp, 2007). Lifetime prevalence rates suggest that over 13 % of young adults engage in NSSI (Swannell et al., 2014), and NSSI is even more common in those seeking psychiatric treatment (Claes et al., 2007; Kaess et al., 2013). People report engaging in NSSI primarily to gain relief from aversive psychological states (i.e. negative affect; Armey et al., 2011; Klonsky and Glenn, 2009; Nock et al., 2009; Nock and Prinstein, 2004; Taylor et al., 2017). However, NSSI involves substantial costs, including physical pain and scarring, as well as subsequent feelings of guilt or regret (Burke et al., 2019). Given that humans, like other organisms, are motivated for self-preservation, it is unclear why people would choose to accept these costs when there are alternative strategies to relieve distress without such costs.

Previous research has shown that NSSI does lead to relief (Brain et al., 1998; Fox et al., 2017; Franklin et al., 2013a; Franklin et al.,

Abbreviations: NSSI, Nonsuicidal self-injury; DARE, Decisions about relief and effort.

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2013b; Kranzler et al., 2018). However, many alternative affect regulation strategies also lead to relief, but do not entail harming oneself. Examples of non-harmful alternative affect regulation strategies include thinking about an issue from a helpful perspective (i.e., cognitive reappraisal; Silvers et al., 2017), or alternative behavioral strategies (e.g., exercise, taking a shower; Ochsner et al., 2012). One possible reason that people may be motivated to engage in NSSI rather than certain healthier strategies is that people who engage in NSSI may perceive hurting oneself as less cognitively demanding than other available strategies. Although people who engage in self-injurious behaviors are capable of using cognitively demanding affect regulation strategies (Franz et al., 2021), some evidence suggests that they choose to do so less than people without self-injurious behaviors (Andover and Morris, 2014; Richmond et al., 2017; Voon et al., 2014).

Cognitive effort likely influences choices about how to regulate affect because people tend to select the least effortful way to achieve goals (Hartmann et al., 2013; Hull, 1943; Nishiyama, 2016; Seaman et al., 2018; Westbrook et al., 2013). When faced with multiple options for achieving a goal that have different arrangements of effort costs and available benefits, people must decide whether the value of a desired outcome is worth the additional effort required to achieve it. As the effort cost required to attain a more valuable outcome increases, people become more willing to select a less valuable outcome because it requires less cognitive effort, a tradeoff known as effort discounting (i.e., the subjective value of a possible outcome is "discounted" by the perceived effort needed to attain it; Hartmann et al., 2013; Nishiyama, 2016; Seaman et al., 2018; Westbrook et al., 2013). As with other forms of cost discounting (e.g., time, probability), effort discounting tends to vary as an individual difference. For example, people with symptoms of depression (Berwian et al., 2020; Bonnelle et al., 2015; Culbreth et al., 2018; Treadway et al., 2009) or substance use disorder (Stuppy-Sullivan et al., 2020) exhibit higher effort discounting, such that the probability of their making high-effort choices decreases more steeply as the expected value of those choices decreases, relative to control participants.

Research examining effort discounting to date has exclusively focused on the tradeoff between the value of *rewards*, such as monetary receipt (i.e., positive reinforcement), and the effort cost of pursuing rewards. No studies have examined whether people make similar tradeoffs between the value of *relief* from an aversive state (i.e., negative reinforcement) and the effort cost of pursuing relief. This gap in our knowledge is especially important given that relief is a goal of many human behaviors, including those that are normative (e.g., swimming to cool off, eating to feel less hungry) and those that are potentially harmful (e.g., procrastination to reduce work anxiety, smoking to reduce stress). Moreover, the centrality of relief as a motivator of NSSI (Armey et al., 2011; Klonsky and Glenn, 2009; Nock et al., 2009; Nock and Prinstein, 2004; Taylor et al., 2017) raises the intriguing possibility that aberrant cost-benefit decisions about relief drive NSSI behaviors. Given that no prior research has tested whether effort discounting also occurs in the context of negative reinforcement, we first aimed to develop a behavioral task to understand whether and how humans discount the value of relief from an aversive state as a function of the effort required to attain that relief. Our second aim was to understand whether effort discounting differs for those who have engaged in NSSI.

1.1. Hypotheses

In Experiment 1, we utilized a novel behavioral task to test the hypothesis that (1a) people demonstrate a decision-making bias to accept less relief so that they will have to exert less effort (i.e. effort discounting in the context of choices about relief). We also hypothesized that (1b) a parabolic discount function would best account for these effort/relief tradeoffs, in accordance with prior studies of effort discounting for rewards (Hartmann et al., 2013).

In experiment 2, we sought to test the hypothesis that, (2a) compared to control participants, individuals who engage in NSSI discount the value of relief more steeply as cognitive effort demands increase. It is worth noting that the willingness to exert cognitive effort is attenuated during negative affective states (Bogdanov et al., 2021), and some have suggested that cognitive effort is experienced as more aversive in such states (Storbeck et al., 2015). Given that those who engage in NSSI exhibit greater negative affect following negative events (Nock et al., 2008), we also hypothesized that (2b) the willingness of such individuals to exert cognitive effort to achieve relief would be further blunted while experiencing negative affect. We were also interested in understanding how effort discounting relates to real-life decisions about affect regulation for people who engage in NSSI. We hypothesized that (2c) cognitive effort discounting would be highest for those who perceived affect regulation strategies other than NSSI to be particularly effortful.

2. Experiment 1 method

2.1. Participants

Participants were a community sample of 43 adults recruited from the greater Boston area using advertisements for a study about emotions and relief. Exclusion criteria included hearing impairment, color blindness, and inability to read/write in English. Sample characteristics are shown in Table 1.

2.2. Baseline tasks: relief and cognitive effort

The Decisions About Relief and Effort (DARE) task used in this study presented participants with the opportunity to expend varying amounts of cognitive effort in order to obtain varying amounts of relief from an aversive stimulus. Relief was operationalized as escape from an aversive noise (similar to nails on a chalkboard) played through headphones, which has been used in prior relief-based decision making studies (Millner et al., 2019; Millner et al., 2017). As part of pre-task training, participants heard the aversive noise for three seconds and then rated how bad the noise made them feel on a 100-point scale. Next, the noise was initiated again and the experimenter demonstrated that participants could shut it off any time by pressing the space bar.

Cognitive effort was operationalized and manipulated using a modified version of the classic-N-Back task (Kane et al., 2007). In this version, participants viewed a sequence of between seven and 11 uppercase letters (randomly selected from the set: B, F, K, H, M, Q, R, or X), each presented for 500 ms with a 2000 ms interstimulus interval. Participants were asked to indicate, via spacebar press, whether the letter currently appearing on the screen matched a letter that appeared "N" places back, where the value of N varied from one to four and was defined before each trial. Participants were provided trial-by-trial performance feedback ("Correct!" or "Wrong. You pressed the spacebar when you shouldn't have/You didn't press the spacebar when you should have"). Participants completed four practice trials to become familiar

Table 1
Experiment 1 sample characteristics.

Characteristic	N (%)	M (SD)
Female	23 (54.8)	
Asian	12 (28.0)	
Black	10 (23.8)	
Latino	1 (2.4)	
Mixed	3 (7.1)	
White	16 (38.1)	
College or graduate degree	29 (69.0)	
Age		25.8 (7.1)
Depression		4.35 (4.9)
Anxiety		3.21 (3.3)
NSSI lifetime history	9 (21.4)	

Notes: Depression and Anxiety scores were measured using the DASS Depression and Anxiety subscales, respectively.

with instructions and timing, followed by 12 "official" trials in which they were told their responses were recorded. N-back trials for the "practice" and "official" trials were evenly distributed across levels of difficulty. We chose a N-back manipulation of cognitive load because working memory is easy to vary parametrically (i.e. by increasing the value of N), is a well validated decision cost in research about rewards (Westbrook et al., 2013), is aversive during negative affect (Storbeck et al., 2015), and is associated with affect regulation abilities (Schweizer et al., 2013).

2.3. Experimental task

In the DARE task participants made choices between two options: a low effort/low relief (L/L) option versus a high effort/high relief option (H/H). *Effort* was operationalized as working memory load (i.e. the value of N in the N-back task, ranging from 1- to 4-back; Fig. 1). *Relief* was operationalized as the percent reduction in the aversive noise by either 90 %, 50 %, or 10 %. After participants chose between the H/H and L/L options by pressing the left or right arrow, the selected option changed colors to indicate that a choice had been made. Participants completed 18 trials in total.

Importantly, participants did not complete an N-back or hear the aversive sound while making choices in the DARE Task. Instead, they made hypothetical choices about the tradeoff between relief and effort based on their previous experience during the baseline tasks. However, we instructed participants that at the end of the task, one previously completed trial would be randomly selected and they would have to correctly complete the selected N-back to receive the stated volume reduction.

2.3.1. Experimental procedures

After providing informed consent, participants completed the baseline tasks and then the DARE Task. Participants also completed additional behavioral tasks and self-report measures not described here. Participants received $20 cash or course credit for their participation.

2.3.2. Statistical analyses

We used a binomial Generalized Linear Mixed Model (GLMM) with a logit link function from the *lme4* package in R Version 4 (R Core Team, 2020) to examine the influence of trialwise differences in effort (N-back value) and relief (percent reduction in volume) on the likelihood of making high effort/high relief choices (Hypothesis 1a). We compared the fit of four separate cost discounting models (hyperbolic, exponential, parabolic, and linear) to participants' choice data (Hypothesis 1b) using Random Effects Bayesian Model Selection (Rigoux et al., 2014). Additional details for the four models and comparison methods can be found in **Experiment 1 Supplementary Method**.

3. Experiment 1 results

3.1. GLMM results

We found a significant interaction between effort and relief (OR = 1.42, 95 % CI [1.16, 1.74], $p = .001$), indicating that the influence of effort magnitude on choice depended on the amount of available relief. Specifically, when the difference in required effort was low (left side of Fig. 2), participants' likelihood of choosing the H/H option didn't differ based on the difference in available relief; they most often chose high relief because it did not require much more effort. However, when the difference in required effort was high (right side of Fig. 2) participants' likelihood of choosing the high effort/high relief option depended on the difference in available relief; when there was much more relief to gain, they were significantly more likely to choose the high effort/high relief option than when there was relatively less relief to gain.

3.2. Discounting model fit results

We found that the parabolic discounting model provided the best fit to effort discounting behavior (AIC = 796.35, BIC = 872.92, EXP = 0.78; PXP = 1),[1] relative to the hyperbolic (AIC = 969.18, BIC = 1045.75, EXP = 0.17; PXP = 0), exponential (AIC = 107,024.00, BIC = 1146.81, EXP = 0.02; PXP = 0), and linear (AIC = 1041.65, BIC = 1118.22, EXP = 0.02; PXP = 0) models.

4. Experiment 2 method

4.1. Participants

Participants in Experiment 2 were 153 adults from the greater Boston community. Two participants did not complete the affect induction procedure according to the instructions (described below), and two participants' behavioral data were not fully recorded due to a technical error, so these participants were removed from the sample. Characteristics of the final sample ($n = 149$) are displayed in Table 2.

4.2. Procedure

4.2.1. Recruitment

Participants were recruited using flyers distributed throughout the greater Boston area as well as through the Harvard University online research participant recruitment system. Because NSSI is less common in older adults (Gregg et al., 2018), our advertisements specified that we were seeking adults 18–30 years old who had recently engaged in NSSI, but those who had not engaged in NSSI could qualify. Interested participants were directed to an anonymous online screening survey. All participants were required to be between the ages of 18 and 30, free from hearing impairment and colorblindness, and able to read/write in English. Qualifying participants were sorted into two groups, those who had a lifetime history of NSSI (NSSI group), and those without a history of NSSI (Control group). To qualify for the NSSI group, participants were required to have a lifetime history of NSSI. To qualify for the Control group, participants were required to have no history of NSSI, and also no history of problematic substance use or disordered eating, as these conditions are associated with atypical cost-benefit decision making (Guillaume et al., 2015; Kirby et al., 1999; Stuppy-Sullivan et al., 2020). Additional details of self-report items used for screening can be found in **Experiment 2 Supplementary Method**.

4.2.2. Laboratory procedure

Participants first provided informed consent, then completed the first half of questionnaires, then the experimental tasks, and then the remaining set of questionnaires. Participants received $20 in cash or course credit for their participation.

4.3. Measures

4.3.1. Questionnaires

Participants self-reported their lifetime history of NSSI using the Self-Injurious Thoughts and Behaviors Interview, self-report version (SITBI; Nock et al., 2007). Participants who indicated they had engaged in NSSI at some point in their lives were asked an additional question, "how much effort would it take you to do something else (instead of NSSI) when you have the urge to hurt yourself?" Participants responded to this question using a five-point scale ranging from "0=no effort at all" to "4=as much effort as I could imagine." Participants self-reported emotion reactivity using the Emotion Reactivity Scale (ERS; Nock et al., 2008), a 21-item scale assessing three constructs related to the

[1] AIC = Akaike's information criterion; BIC = Bayesian information criterion; EXP = expectation of the posterior; PXP = protected exceedance probability

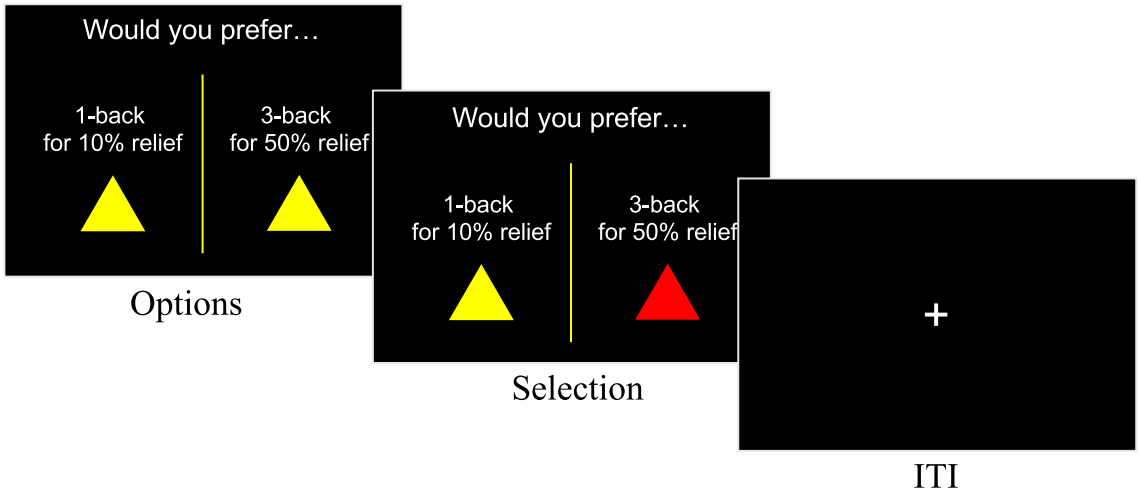

Fig. 1. Relief-based effort discounting task structure.
Note: The participant selection in this example is indicated by the red triangle. ITI = Intertrial interva. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

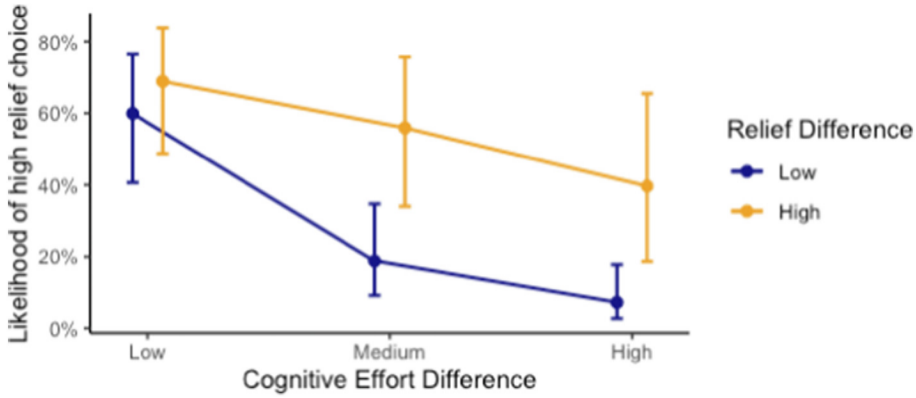

Fig. 2. Influence of effort on likelihood of choosing the high relief option.
the two options on a given trial in the REEF task. This difference was calculated for each trial by subtracting the lower effort amount from the larger effort amount.

experience of emotions: sensitivity of emotional reactions, arousal/intensity of emotional reactions, and persistence of emotional reactions. Scores on the ERS are shown to be higher for those with NSSI (Nock et al., 2008). Each item of the ERS was rated on a five-point scale ranging from "0=not at all like me" to "4=completely like me." The ERS showed excellent internal consistency in this sample ($\alpha = 0.95$).

NSSI is a transdiagnostic behavior that shows high comorbidity with a range of other conditions. To test the selectivity of cognitive effort discounting for NSSI, we assessed five additional clinical constructs that have reported associations to aberrant cost-benefit decision-making. These included eating disorder symptoms (Guillaume et al., 2015), problematic alcohol use (Moody et al., 2017), problematic drug use (Kirby et al., 1999; Stuppy-Sullivan et al., 2020), depression, (Berwian et al., 2020; Culbreth et al., 2018; Docx et al., 2015) and anhedonia (Bonnelle et al., 2015; Treadway et al., 2009). See **Experiment 2 Supplementary Method** for further details on these measures. Missing questionnaire data were sparse (<1 % of all questionnaire data). We used random forest imputation from the *missForest* package (Stekhoven and Bühlmann, 2012) in R to impute missing questionnaire data.

4.3.2. *Exposure to stimuli from experimental task*

In addition to the Baseline Tasks used to familiarize participants with the choice parameters of our task described in Experiment 1, participants in Experiment 2 also rated their likelihood of correctly completing a single N-back trial at each level of difficulty.

4.3.3. *Experimental task*

Participants each completed two blocks (18 trials apiece) of the DARE task described in Experiment 1. One block followed a negative affect induction (negative affect condition), and the other block followed a neutral affect induction (neutral affect condition). Each block in Experiment 2 contained four additional "catch" trials in which either the required amount of effort or the stated value of relief was equivalent between the two options. In contrast to the standard trials, which assessed participants' subjective preferences, catch trials included an objectively optimal choice (i.e., if the difference in effort between the two choice options is 0, participants should choose the high-relief option; if the difference in relief between choice options is 0, participants should choose the low-effort option). Participants made 0.55 suboptimal catch trial choices on average, which did not differ between the NSSI Group and the Control Group ($t = 0.43$, $p = .666$), and the number of suboptimal catch trial choices was not associated with discount rates for either the negative affect condition ($\rho < 0.01$, $p = .995$) or neutral affect condition ($\rho = -0.8$, $p = .333$). Thus, no participants were excluded on the basis of their responses to catch trials. Catch trials were excluded from further analyses.

Table 2
Experiment 2 participant characteristics.

	NSSI (n = 78)	Control (n = 71)	Test statistic	p-Value	Effect size
Age M (SD)	23.47 (2.37)	24.31 (2.81)	$t(137.46) = 1.95$	$p = .053$	$d = 0.32$
Gender n (%)	–	–	$\chi^2(2) = 3.53$	$p = .171$	$\varphi = 0.15$
Female	51 (34.23 %)	44 (29.53 %)			
Male	20 (13.42 %)	25 (16.78 %)			
Non-binary/ third gender	7 (4.70 %)	2 (1.34 %)			
Race/ethnicity n (%)	–	–	**$\chi^2(5) = 12.05$**	**$p = .034$**	**$\varphi = 0.28$**
Asian	6 (4.03 %)	20 (13.42 %)			
Black	3 (2.01 %)	3 (2.01 %)			
Hispanic	7 (4.70 %)	8 (5.37 %)			
White	56 (37.60 %)	36 (24.16 %)			
Mixed	3 (2.01 %)	2 (1.34 %)			
Other	3 (2.01 %)	2 (1.34 %)			
Highest level of education n (%)	–	–	$\chi^2(4) = 8.45$	$p = .076$	$\varphi = 0.23$
Graduate or prof. degree	15 (10.06 %)	28 (18.79 %)			
College diploma	35 (23.50 %)	25 (16.78 %)			
Some college	25 (16.78 %)	15 (10.07 %)			
H.S. diploma/ GED	1 (0.67 %)	2 (1.34 %)			
Technical/ associates degree	2 (1.34 %)	1 (0.67 %)			
Disordered eating M (SD)	**3.02 (1.65)**	**2.04 (1.19)**	**$t(139.89) = 4.16$**	**$p < .001$**	**$d = 0.67$**
Alcohol use M (SD)	**16.71 (5.75)**	**13.47 (4.09)**	**$t(139.01) = 4.16$**	**$p < .001$**	**$d = 0.64$**
Drug use M (SD)	**18.33 (1.89)**	**19.50 (1.18)**	**$t(130.77) = -4.59$**	**$p < .001$**	**$d = -0.74$**
Depression M (SD)	**8.47 (6.01)**	**4.59 (4.67)**	**$t(143.51) = 4.42$**	**$p < .001$**	**$d = 0.72$**
Anhedonia M (SD)	**1.54 (2.35)**	**0.68 (2.08)**	**$t(146.88) = 2.37$**	**$p = .019$**	**$d = 0.39$**
Emotion reactivity M (SD)	**41.20 (18.60)**	**26.58 (16.25)**	**$t(146.77) = 5.12$**	**$p < .001$**	**$d = 0.83$**

Note: bolded rows indicate $p < .05$.

4.3.4. Affect induction procedure

At the start of each block of the DARE task, participants were asked to complete a five-minute writing prompt similar to that used in prior research to induce negative affect (Fox et al., 2017). In the negative affect condition, participants were asked to write about a time they had failed or let someone else down. In the neutral[2] affect condition, participants were asked to write about a recent typical day, where nothing especially positive or negative happened. In both affect conditions, participants were asked to read over what they had written if they were not able to write for the full 5 min. The order of affect condition presentation was randomized across participants. Before and after the affect manipulation in each block, participants rated their current negative affect using a 100-point visual analog scale.

4.4. Data analysis

4.4.1. Experimental task choice modeling

We followed the approach from Experiment 1 to calculate participants' parabolic (the best-fitting model from Experiment 1) discount rates separately each condition (18 trials per condition).

4.4.2. Statistical analyses

We tested the effect of our affect manipulation using a Gaussian GLMM as implemented in the *lme4* package in R. To test our main discount rate hypotheses, we rescaled participants' discount rates so they would be bounded between zero and one using the beta squeezer technique (Smithson and Verkuilen, 2006). We then used a beta GLMM as implemented in the *glmmTMB* package in R to test the effects of NSSI history (group; Hypothesis 2a), affect condition (Hypothesis 2b), and perception of non-NSSI affect regulation strategies as effortful (Hypothesis 2c) on discount rates. We conducted an additional series of six beta GLMMs examining the effects of affect condition, group, and their interaction on discount rates, each including one additional variable of interest. We first included presentation order in one GLMM. We next included eating disorder symptoms, alcohol use, and drug use in separate GLMMs, as these conditions are each characterized by potentially harmful strategies for affect regulation, and are associated with atypical cost-benefit decision-making (Guillaume et al., 2015; Kirby et al., 1999; Moody et al., 2017). Finally, we included depression symptoms and anhedonia in separate GLMMs, given that these were associated with NSSI in this sample, and prior work indicates that depression (Berwian et al., 2020; Culbreth et al., 2018; Docx et al., 2015) and anhedonia (Bonnelle et al., 2015; Treadway et al., 2009) are each associated with higher effort discount rates. To understand whether participants in the NSSI group perceived affect regulation strategies other than NSSI as highly effortful, we tested whether higher ratings of this perception were associated with higher effort discount rates using a beta GLMM. This analysis also served as an index of convergent validity for our task.

5. Experiment 2 results

5.1. Affect manipulation check

Participants across both groups reported their negative affect prior to and following the *neutral* affect induction as a 34.9/100 (SD = 23.6) and a 32.0/100 (SD = 23.8), respectively. Participants across both groups reported their negative affect prior to and following the *negative* affect induction as a 32.2/100 (SD = 23.7) and a 40.5/100 (SD = 25.1), respectively. We tested whether negative affect was reported as higher following the negative versus neutral affect induction for both groups, and whether NSSI participants, who had higher trait emotion reactivity (Table 2), reported higher negative affect following the negative affect induction. As expected, we found a main effect of condition, such that

[2] We use the term "neutral affect" because we intended the neutral affect induction to provide a more neutral, or less negative comparison condition, simulating participants' "baseline" affective state. Whether neutral affect exists is a matter of debate (Gasper, 2018), and participants in this study actually reported their affect as somewhat negative in the neutral affect condition, which is shown in Fig. 2.

participants in both groups reported significantly higher negative affect following the negative affect versus the neutral affect induction (β = 0.38, 95 % CI: [0.21, 0.55], $p < .001$, Fig. 3). We also found a main effect of group, such that participants in the NSSI group reported higher negative affect on average (β = 0.48, CI: [0.17, 0.79], $p < .001$). The interaction between condition and group was non-significant (β = −0.07, CI: [−0.30, 0.16], $p = .540$).

5.2. Discount rate differences by group and condition

We found a main effect of group, such that those in the NSSI group had a higher discount rate than those in the Control group on average (β = 0.49, CI: [0.01, 0.96], $p = .042$). However, the difference in discount rates between affect conditions (β = −0.21, CI: [−0.21, 0.49], $p = .434$), as well as the interaction between group and condition (β = 0.25, CI: [−0.94, 0.03], $p < .068$) were non-significant. Discount rates by group and affect condition are illustrated in Fig. 4.

5.3. Selectivity analyses

We examined differences in discount rate across groups and affect conditions using six additional beta-distributed GLMMs, adding a single covariate of interest to each model. The first of these selectivity analyses showed that the presentation order of affect condition was non-significant (β = −0.01, CI: [−0.20, 0.19], $p = .951$), and no other effects changed meaningfully, including NSSI group, which remained significant. The effect of alcohol use (β = −0.10, CI: [−0.31, 0.11], $p = .336$) and drug use (β = 0.12, CI: [−0.09, 0.33], $p = .264$) were non-significant, and no other effects change meaningfully, including NSSI group, which remained significant. When including the effect of eating disorder symptoms, all effects were non-significant (β estimates 0.05 to 0.46, p-values 0.067 to 0.434), though the effect size of NSSI group was only marginally reduced in this model (β = 0.46, CI: [−0.03, 0.95], $p = .059$) compared to the model that did not include eating disorder symptoms. When including the effect of depression symptoms (β estimates 0.14 to 0.45, p-values 0.070 to 0.426) or anhedonia (β estimates −0.09 to 0.17, p-values 0.170 to 0.354), all effects were non-significant.

5.4. Effort required by strategies other than NSSI

Among participants with a history of NSSI, the modal rating of effort to engage in strategies other than NSSI (after they have experienced the urge to hurt themselves) was a three on a five-point scale with response values ranging from zero to four ($n = 27$, 34.6 %), and the majority of NSSI participants ($n = 62$, 79.5 %) rated a two or higher. We further found that individuals who perceived alternative strategies as more effortful had higher discount rates on average (β = 0.41, CI: [0.11, 0.71], $p = .008$), even while simultaneously testing for the effect of affect condition (β = −0.30, CI: [−0.63, 0.05], $p = .081$), and the interaction between other strategy effort rating and affect condition (β = −0.05, CI: [−0.39, 0.29], $p = .760$).

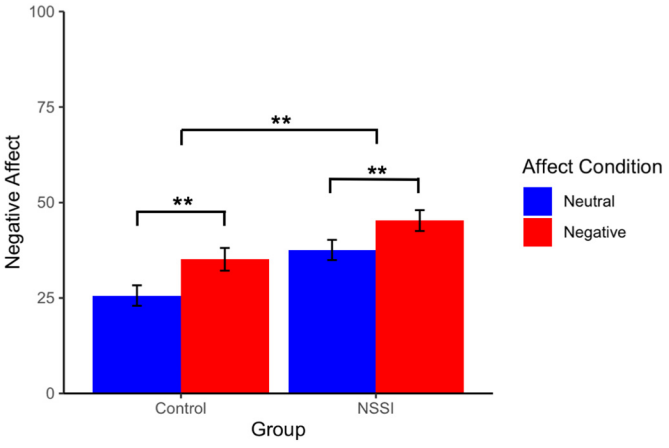

Fig. 3. Self-rated negative affect following the affect manipulation in the negative and neutral affect conditions.
Notes: Participants in both groups reported higher negative affect following the negative affect manipulation (Negative affect condition) than the neutral affect manipulation (Neutral condition). The NSSI group reported higher negative affect in both conditions. $^{**}p < .001$.

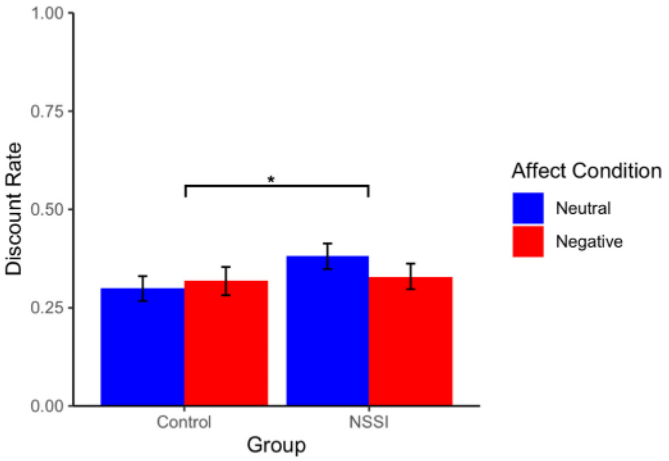

Fig. 4. Discount rate differences by affect condition and NSSI history.
Note: Participants in the NSSI group had higher effort discount rates on average than participants in the Control group (main effect of group), but effort discount rates did not differ by affect condition. $^{*}p < .05$.

6. Discussion

The goal of this study was to understand whether NSSI is associated with atypical tradeoffs between cognitive effort and relief. We found evidence in support of four out of our five hypotheses. In Experiment 1, we found that people are willing to accept less relief if doing so enables them to exert less cognitive effort, a tendency known as effort discounting. We also found that effort discounting in the context of choices about relief is best accounted for by a parabolic discount model. In Experiment 2, we found that effort discounting is higher in people who have engaged in NSSI, but this effect became nonsignificant when simultaneously accounting for some comorbid conditions. Unexpectedly, we found that effort discounting was similar during the experience of negative versus neutral affect, irrespective of NSSI history. Finally, we found that perceiving affect regulation strategies other than NSSI as more effortful was positively associated with effort discounting among people with a history of NSSI. We provide further commentary on each of these results below.

6.1. Experiment 1

This study is the first to document effort discounting in the context of relief from an aversive state, suggesting that perceived effort requirements function as a cost that influences people's decisions about how to attain relief. Further, the tradeoff between effort and relief was parabolic, indicating that increases in required effort/decreases in relief have very little influence at the lower end of the effort or relief spectrum, but are highly influential at the higher end of either spectrum. This pattern of results has also been observed in the context of exerting effort for rewards (Hartmann et al., 2013).

Both relief and reward reinforce instrumental behavior (Guitart-Masip et al., 2012), but in conceptually different ways (Campese et al., 2015; Elliot, 1999; Elliot and Thrash, 2002). Until now, the field lacked a

straightforward behavioral approach to interrogate cost/benefit decision-making to gain relief. The paradigm used in the present study offers a practical approach that can be used in future studies of normative and pathological relief-based decision making.

6.2. Experiment 2

Participants in the NSSI group from Experiment 2 showed evidence of higher discount rates than those in the control group, indicating that those who engage in NSSI may require more expected relief to offset the cost of effort required to attain relief. Thus, it could be that NSSI is selected because it provides more relief than alternative affect regulation strategies and/or because NSSI is perceived to require less cognitive effort. One implication of this finding is that those with a history of NSSI may be less willing to employ more cognitively effortful affect regulation strategies (that may be more effective/helpful in the long term), leaving them vulnerable to the prolongment and recurrence of intense negative affective states often observed in this population (Nock and Mendes, 2008). Such affective states have the potential to maintain and even escalate self-injurious behavior, possibly leading to increasingly severe self-injurious acts (Case et al., 2020).

The association between NSSI history and discount rates in the present study remained significant when simultaneously accounting for problematic substance use, but not for symptoms of eating disorders, depression, or anhedonia, which are each associated with abnormal cost-benefit decision making (Arulpragasam et al., 2018; Berwian et al., 2020; Cooper et al., 2018; Guillaume et al., 2015; Kirby et al., 1999; Moody et al., 2017; Salamone et al., 2016; Treadway et al., 2009). Effort discounting may therefore not be specific to NSSI, but rather may be a transdiagnostic mechanism that increases risk for NSSI and other problematic strategies for attaining relief. Future studies can test this possibility by using a psychiatrically-matched control group, which would enhance internal validity.

Contrary to our expectations, negative affect did not appear to moderate effort discount rates, which may reflect that the negative affect induction was not potent enough. As shown in Fig. 2, participants rated their negative affect close to the mid-point on the negative affect scale, likely limiting our ability to detect differences in effort discounting that result from more intense negative affect. Future studies can use alternative affect induction procedures, such as the Trier Social Stress paradigm, which was used in a recent study that showed effort willingness is lower during negative affect (Bogdanov et al., 2021).

Participants in the NSSI group who found it particularly effortful to pursue an alternate affect regulation strategy (other than NSSI) show a stronger effort discounting bias. Although prior studies indicate that people use NSSI as a means for attaining relief (Taylor et al., 2018), this is the first to indicate that effort is a relevant component of decisions about NSSI, a finding that also demonstrates convergent validity of our relief-based effort discounting task. Future studies can more directly assess the effort required for NSSI and alternative strategies.

Our results also have implications for treating and preventing NSSI. In this study we used a revealed preference paradigm to identify whether the cost of cognitive effort is an important consideration in decisions about relief for those who engage in NSSI. Existing interventions help individuals learn to increase awareness of the costs and benefits of affect regulation strategy choices (Hayes et al., 2011; Linehan, 1993). Future research can examine whether increasing awareness of the costs of NSSI (e.g., physical pain or scarring), as well as increasing the willingness to exert cognitive effort for relief, can help prevent NSSI.

6.3. Additional limitations and future directions

We considered effort as fundamentally aversive, in line with classic economic and psychological models of effort that suggest effort is perceived as aversive/costly, decreasing the subjective value of outcomes (Kahneman et al., 1997). However, some research suggests that effort may not always be experienced as aversive (e.g. "learned industriousness;" Eisenberger, 1992). Future research on effort discounting in the context of relief can identify whether certain people find effort rewarding by using existing self-report measures (e.g. Cacioppo et al., 1984).

There are at least three potential threats to the ecological validity of our study. First, when completing our DARE task, participants were not making decisions about whether to hurt themselves, so it is unclear how our task parameters approximate the features of real-life decisions to engage in NSSI. Second, the effort-relief tradeoffs that participants made during the task were hypothetical, in that the consequences of their decisions were not realized in real time, as they would be in their daily lives. Third, participants made decisions about effort and relief under a somewhat contrived affective context (i.e., our negative affect induction), and this affective context was not reflected in their choice options during the task. Together these issues limit our ability to ascertain whether the tradeoff between effort and relief indexed by our task influences the decision to hurt oneself, though the intent of this study was to provide preliminary evidence for this possibility. More research is necessary to know how the mind represents effort-relief tradeoffs while experiencing negative affect and when actively considering NSSI. Recently-popularized methods for ecological assessment of affect and self-injurious behaviors (Armey et al., 2011; Coppersmith et al., 2019; Kleiman et al., 2018; Kranzler et al., 2018; Nock et al., 2009) may be a helpful approach for examining the interplay between affect, decision-making, and NSSI in daily life.

7. Conclusion

This study shows that the cost of cognitive effort influences choices about how to attain relief from an aversive context, a decision-making bias that is present in, but not specific to NSSI.

CRediT authorship contribution statement

PJF conceived of and designed the study, oversaw data collection, performed all analyses, and drafted the initial manuscript. RGF assisted with study design, results interpretation, and manuscript editing. AJM, ACJ, JEA, and JWB assisted with manuscript editing. EMW assisted with data collection and manuscript editing. MKN supervised all aspects of the study and provided manuscript editing.

Role of funding source

Funds used for participant payment in this study were provided by the Harvard University Psychology Department to Peter J. Franz.

Ethics statement

This study was approved by the Harvard University Area Committee on Research with Human Subjects (IRB16-1796).

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Declaration of competing interest

Dr. Nock receives publication royalties from Macmillan, Pearson, and UpToDate. He has been a paid consultant in the past year for Microsoft Corporation, the Veterans Health Administration, Cerebral Inc., and for a legal case regarding a death by suicide. He is an unpaid scientific advisor for Empatica, Koko, and TalkLife. The additional authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2022.10.029.

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