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# A meta-analysis on the affect regulation function of real-time self-injurious thoughts and behaviors

**Kevin S. Kuehn, M.S.**[1,*], **Jonas Dora, Ph.D.**[1], **Melanie S. Harned, Ph.D.**[2,3], **Katherine T. Foster, Ph.D.**[1], **Frank Song, B.A.**[1], **Michele R. Smith, M.S.**[1], **Kevin M. King, Ph.D.**[1]

[1]Department of Psychology, University of Washington, Seattle, WA, USA

[2]Department of Psychiatry and Behavioral Sciences, University of Washington, Seattle, WA, USA

[3]Veterans Affairs Puget Sound Health Care System, Seattle, WA, USA

## Abstract

Prominent theories suggest self-injurious thoughts and behaviors (SITBs) are negatively reinforced by decreased negative affect. The present meta-analysis quantifies effects from intensive longitudinal studies measuring negative affect and SITBs. We obtained data from 38 of the 79 studies (48%; 22 unique datasets) involving N = 1,644 participants (80% female; 75% white). Individual participant data meta-analyses revealed changes in affect pre/post SITBs. In antecedent models, results supported increased negative affect before non-suicidal self-injurious (NSSI) behavior ($k$ = 14; 95% CI = 0.09 – 0.31) and suicidal thoughts ($k$ = 14; 95% CI = 0.03 – 0.19). For consequence models, negative affect was reduced following NSSI thoughts ($k$ = 6; 95% CI = −0.79 – −0.44), NSSI behaviors ($k$ = 14; 95% CI = −0.73 – −0.19) and suicidal thoughts ($k$ = 13; 95% CI = −0.79 – −0.23). Findings, which were not moderated by sampling strategies or sample composition, support the affect regulation function of SITBs.

With an age standardized rate of 9.0 per 100,000 people, suicide was the eighteenth leading cause of death in 2019 worldwide[1]. While many more individuals contemplate and/or attempt suicide, approximately 800,000 people die by suicide each year[1]. In the United States, 4.8% of adults 18 and older seriously considered suicide in 2018[2], while about 0.5%



*Correspondence should be addressed to Kevin S. Kuehn, Department of Psychology, University of Washington, Seattle, WA 98105. kevinskuehn@gmail.com.

Author Contributions

K.S.K: Project planning and conceptualization, data curation, literature search, data analysis, software, writing (drafting and editing), final approval

J.D.: Data analysis, software, writing (drafting and editing), final approval

M.S.H: Writing (drafting and editing), final approval

K.A.F.: Writing (drafting and editing), final approval

F.S.: Literature search, writing (drafting and editing), final approval

M.R.S.: Validation, writing (editing), final approval

K.M.K.: Project planning and conceptualization, data analysis, methodology, supervision, writing (drafting and editing), final approval

Code Availability

Analysis scripts to calculate effects from the raw data, and the resulting R code to compute pooled effects are also publicly available (https://github.com/kskuehn/NA-SITB_meta).

Competing Interests:

The authors declare no competing interests

of U.S. adults reported they attempted suicide[2]. Non-suicidal self-injury (NSSI), defined as deliberate damage to ones' body tissue without the intention to die[3], is a risk factor for future suicidal behavior[4]. NSSI is suspected to increase ones' tolerance for painful stimuli and removing barriers to attempting suicide. Worldwide, an estimated 17% of adolescents engage in NSSI[5].

At the same time, researchers' ability to predict self-injurious thoughts and behaviors (SITBs) is poor. A recent meta-analysis of risk factors found that predictive models have not produced larger effect sizes over the past 50 years despite substantially more studies[6]. Critical innovation is needed to ensure that research on suicide-related phenomena is equipped to reliably predict who is at risk for death by suicide and when this risk is most imminent.

Leading theories propose that NSSI is maintained, at least in part, by an immediate reduction in negative affect[7,8]. Although initially developed to explain the continuation of NSSI behaviors, emerging work suggests this affect regulation hypothesis may extend to other forms of SITBs, including suicidal cognitions[9]. Specifically, the affect regulation hypothesis proposes that a) negative affect is increased prior to the occurrence of SITBs (the antecedent hypothesis), b) reduced following (the consequence hypothesis), which c) increases the probability that someone experiences a SITB in the future in response to negative affect. Although the last component, that the relief from negative affect increases the probability of future SITBs, has not been empirically tested, treatments for a variety of psychological disorders target broadening and building emotion regulation skills[10–13]. Indeed, the development of effective emotion regulation strategies is hypothesized to be a mechanism of action accounting for reductions of SITBs in treatment[14].

The affect regulation hypothesis is fundamentally a within person process, positing that when people experience negative affect, SITBs then function to provide relief from distressing negative affect. However, the preponderance of evidence to date for this hypothesis has relied on retrospective reports in which people were asked to reflect about their affective states coinciding with their SITBs and the possible reasons they experienced them. For example, Nock and Prinstein[7] asked 108 self-harming psychiatrically hospitalized youth how often they engaged in NSSI for 22 different reasons upon intake. Confirmatory factor analysis yielded a four-factor structure with automatic negative reinforcement (i.e., the affect regulation hypothesis) being the most frequently endorsed reason for NSSI (e.g., self-harming to reduce emotional distress). Other aspects identified were automatic positive reinforcement (e.g., engaging in NSSI to feel pain/a different emotion) as well as interpersonal negative and positive reinforcement. A recent meta-analysis confirmed this initial work as the affect regulation function was the most endorsed reason for NSSI across studies, with an estimated 63–78% of people reporting this function[15].

However, research on retrospectively reported motives for behavior does not always replicate when motivational processes are measured in the moment. For example, although affect regulation motives are frequently identified as a proximal predictor of alcohol use, ecological momentary assessment research has failed to find consistent evidence that affect regulation plays an important role in drinking episodes when measured in real-time[16]. In

general, retrospective methods have the potential for inaccuracy due to recall bias[17], which may be particularly pronounced for individuals already experiencing high levels of negative affect[18]. It is possible, for example, that individuals who experience elevated levels of negative affect are more likely to engage in SITBs. Additionally, retrospective methods do not allow for the establishment of clear temporal precedence between negative affect and SITBs, nor do they offer the ability to adequately test process theories, such as the affect regulation hypothesis, or model contextual factors that may alter these processes.

Missing the within person nature of the affect regulation hypothesis could run the risk of committing Simpson's paradox[19], an ecological fallacy in which between person conclusions (e.g., that those high in negative affect are more likely to experience SITBs) are expected to generalize to a within person process (e.g., if someone experiences elevated negative affect, they then are more likely to experience a SITB). Repeated observations over time allows for the ability to tease apart between person and within person variance[20], and to more directly test process-based hypotheses by establishing temporal precedence. Thus, there are two types of research designs that are adequate in addressing the affect regulation hypothesis: experiments and intensive longitudinal methods.

A few notable experimental manipulations have provided evidence for the antecedent and consequence hypotheses in laboratory environments, with at least three studies reporting physiological and subjective changes pre- and post-NSSI proxies[21–23]. For example, Reitz et al.[21] experimentally incised participants' forearms and, for participants diagnosed with borderline personality disorder, detected relief from subjective distress following the incision. Similarly, Welch et al.[22] used an imagery design in which participants diagnosed with borderline personality disorder were provided personally tailored scripts describing their own accidental death, episode of NSSI, or suicide attempt. Participants reported decreased negative affect and psychophysiological activity following NSSI and accidental death imagery. Finally, Franklin et al.[23] reported that psychophysiological measures of negative affect, but not self-report measures, were reduced following an NSSI proxy. Although controlled laboratory studies were valuable for testing causal models of the affect regulation hypothesis in SITBs, the generalizability of their results to real-world occurrences both across individuals and time is unclear as they artificially induce single experiences that may not effectively model mechanisms triggering SITBs in daily life.

Intensive longitudinal methods can track in-vivo SITBs alongside their proximal risks and consequences. These methods include ecological momentary assessment, in which participants are surveyed multiple times per day, as well as daily diary designs. The resulting data offer a rich opportunity to develop insights into what accounts for variance in SITBs over time (i.e., within-person) and across people (i.e., between-person). Although intensive longitudinal methods have been used to develop insights across many areas of clinical research, these methods are especially well-suited to capture the specific phenomenology of SITBs[24,25], which appear to be short-lived and highly variable[26].

There has been a rapid increase in the use of intensive longitudinal methods to study the affect regulation hypothesis of SITBs. Despite several narrative reviews, a quantitative synthesis has been impossible due to significant heterogeneity in the way intensive

longitudinal studies have been designed and executed, making it impossible to compute meta-analytic estimates of effect sizes from published reports. Studies have varied in terms of the number of surveys delivered per day, the amount of time in between surveys, the demographics and clinical presentations of the participants studied (e.g., individuals diagnosed with borderline personality disorder or those admitted to psychiatric inpatient units, etc.), the specific SITB variable tested, the proximal risk factors measured, the analytic strategy used to test hypotheses, and the reporting practices of individual studies. Variations in designs, such as the frequency or time interval between observations, may influence the observed effect size[27], as the association between the experience of negative affect and the risk of SITB is likely to be strongest when both are measured close in time. Differences in analytic strategies makes an estimation of the cumulative effect from published articles impossible from published studies alone as coefficients reported in studies can reflect very different model assumptions (such as using a linear versus binary outcome, or a multilevel vs. a structural equation model).

For example, Armey, Crowther, & Miller[28] studied 36 college students with an ecological momentary design of six random samples per day over a 7-day period. Measuring negative affect on a 1–5 scale composed of 9 items (e.g., afraid, guilty, scornful), Armey and colleagues[28] used growth curve modeling to test changes in negative affect in the 5 observations surrounding NSSI behaviors, comparing this trajectory in negative affect to 5 random observations of those who did not engage in NSSI behaviors. In line with the affect regulation hypothesis, the authors reported negative affect increased prior to NSSI and decreased in the observations following, while negative affect exhibited no change when NSSI was not present. Bresin, Carter, & Gordon[29] on the other hand, used a 14-day daily diary design with 67 college-aged participants and measured negative affect on a 5-item, 0–5 scale (e.g., distressed, guilty, angry at self). Using multi-level models, they found that individuals were more likely to experience an NSSI urge on days they experienced higher levels of negative affect (OR = 8.00). In contrast, Kiekens, Hasking, Nock, & Boyes[30] used dynamic structural equation modeling with data (N = 30) derived from a 12-day, eight time per day ecological momentary assessment design with negative affect measured on a 6-item, 0–6 scale (e.g., stressed, irritated, anxious). The authors reported evidence that within-person changes in negative affect prospectively predicted NSSI thoughts and behavior, however only NSSI thoughts, but not behavior, remained significant after controlling for the occurrence of NSSI thoughts at the previous timepoint.

Although each study, at least partially, supports the affect regulation hypothesis, it is clearly impossible to synthesize these findings with a single pooled effect. Thus, the field is left with reports of single, isolated studies involving small numbers of participants and with limited ability to summarize results across studies. Without consistent coefficients or means and standard deviations of negative affect surrounding reports of SITBs, systematic reviews can only “vote count” published effects, counting the proportion of significant effects to non-significant effects as evidence, or lack thereof, for the affect regulation hypothesis. Vote counting as a means of reviewing a body of literature has long been considered an inadequate method[31], because statistical significance is only a function of sample size and the magnitude of the effect[32]. Null effects from underpowered studies (common in SITB research), cannot be taken as evidence for the absence of an effect, but merely the lack of

evidence that an effect exists. Pooling effects across multiple studies improves the estimation of a common effect and increases power to detect even smaller effects than any single study[31]. Moreover, vote counting ignores variation in design across studies, and makes it impossible to discern whether effects are stronger in certain designs or samples. Leveraging the full power of intensive longitudinal methods by pooling effects from individual studies to quantify the magnitude of the antecedent and consequence hypotheses is crucial to better understand the within person process of affect regulation in SITBs.

The success of intensive longitudinal methods in SITB research hinges on the ability to catalog converging evidence across diverging sampling and analytic methods. To date, six systematic reviews of intensive longitudinal studies on SITBs have been published[33–38]. Three of these reviews focused exclusively on NSSI[33–35], and all used vote-counting or qualitative summaries of existing studies. Specifically, Hamza and Willoughby[33] reviewed the 18 studies testing the association between emotion regulation and NSSI in either an experimental or intensive longitudinal design. The authors reported that the experimental studies reviewed suggest negative affect is decreased following NSSI proxies and that, although the seven intensive longitudinal studies consistently offered support for the antecedent hypothesis of affect regulation, only two of these studies examined the consequence hypothesis. Of these two, there were mixed findings with one reporting reduced negative affect and the other reporting increased positive, but not decreased, negative affect. Rodríguez-Blanco et al.[35] reviewed 23 studies examaning NSSI in intensive longitudinal methods, and reported that most of these studies focused on short-term affective changes in response to NSSI. In the studies reviewed, Rodriguez-Blanco and colleagures[33] note that affect regulation was the most commonly self-reported function of NSSI, and highighted the mixed findings of the consequence hypothesis with one study detecting increases of negative affect following NSSI, some no change, and a few reporting decreases.

Finally, Hepp and colleagues[34] used vote counting to summarize the literature on the four-function model in NSSI[7,39], of which the affect regulation hypothesis is one component. Their narrative summary concluded that there is evidence for the antecedent hypothesis, in that most studies reported increases in negative affect prior to NSSI but noted that studies reported both significant and non-significant effects regarding the consequence hypothesis. All three reviews suggest negative affect is increased prior to NSSI but are inconclusive with regards to reduced negative affect post-NSSI and the magnitude of effect sizes for either hypothesis across studies is yet unknown.

The present study aims to solve methodological and substantive gaps in the current understanding of SITBs as they are experienced in daily life. We meta-analyzed individual participant data (IPD) from all available studies which measured negative affect and SITBs in intensive longitudinal data, including data from several unpublished studies, to calculate a standardized effect size estimate for both antecedent and consequence analyses for each of the various SITB outcomes. Using data provided by study authors, we calculated within-subject standardized coefficients. Specifically, we tested whether negative affect was elevated prior to SITBs (vs. non-SITB occasions; the antecedent hypothesis), relative to an individuals' average level of negative affect). We then examined whether negative affect

was reduced following SITBs (vs. at SITB; the consequence hypothesis), relative to an individuals' average level of affect.

## Results

### Description of the Included Studies

A total of 79 studies were initially selected for inclusion in the present review (see Figure 1 and Supplementary Table 1). These 79 studies included 5,888 participants. The average age was 28.21 (weighted mean = 31.71; median = 28.02). Participants were primarily female (weighted mean = 73.68%; median = 76.70%) and white (weighted mean = 70.60%; median = 74.00%). Twenty-two of the 79 studies (27.85%) measured NSSI thoughts, twenty-eight (35.44%) measured NSSI behaviors, thirty-four (43.04%) measured suicidal thoughts, and only three studies (3.80%) observed at least one instance of a suicidal behavior.

Of the 22 unique data sets included in the quantitative synthesis, which included 1,644 participants, the average age was 24.42 (median = 23.28). Participants were also primarily female (mean = 80.00%; median = 78.00%) and white (mean = 74.73%; median = 75.00%). The frequency with which a SITB was observed varied significantly across datasets and SITB outcomes (range = 0.05% for NSSI behaviors in Kuehn et al. [unpublished manuscript] to 79.01% for suicidal thoughts in Peters et al.[40]. Six of the 22 studies (27%) used a daily diary design while the rest applied an ecological momentary assessment design. Additionally, eight of the 22 (36.36%) assessed current negative affect with a SITB measured since the last signal (i.e., a retrospective effect) while 15 of the 22 studies queried negative affect and SITBs on the same timescale (i.e., momentarily; one study assessed NSSI thoughts and NSSI behaviors differently). Most of the studies (17/22) exclusively used a signal-contingent design with a few using a combination of signal- and event-contingent prompts.

In the following sections we report the results from the IPD meta-analyses in both antecedent and consequence analyses across the SITB variables measured. These 22 unique data sets corresponded to a little more than half of the studies initially eligible for inclusion. Characteristics of the studies included in the meta-analyses are presented in Supplementary Tables 2–3, and average effect sizes are shown in Table 1.

### NSSI Thoughts

**Antecedent hypothesis.—**Six data sets measured negative affect and NSSI thoughts. Results are reported in Figure S1. One of these eight studies reported an increase in negative affect prior to thoughts of NSSI relative to when participants did not think about NSSI. The average effect size was $\beta = 0.06$ ($k = 6$; 95% CI = −0.07 – 0.19), suggesting that, prior to NSSI thoughts, negative affect was estimated to be increased by 0.06 SD relative to moments not followed by NSSI thoughts. The range of the 95% credible interval indicates that the data was inconclusive with regards to the degree of negative affect experienced prior to NSSI thoughts; small effects in either direction as well as a null result retained posterior plausibility.

**Consequence hypothesis.—**These six data sets were again used to test for decreased negative affect following thoughts of NSSI relative to the timepoint in which NSSI thoughts were reported. Results are reported in Figure S1. All six data sets showed evidence of reduced negative affect with an overall average effect size of $\beta = -0.63$ ($k = 6$; 95% CI = −0.79 – −0.44). This suggests that, following NSSI thoughts, participants' negative affect decreased by .63 SD relative to moments in which a participant continued to think about NSSI. The 95 precent credible interval did not include zero, suggesting effects are consistent with medium to large effects in the expected direction.

## NSSI Behaviors

**Antecedent hypothesis.—**14 data sets were included in the antecedent hypothesis of NSSI behaviors. Results from this test are reported in Figure 2. Seven of the 14 studies (50.00%) detected a significant effect with an average effect size of $\beta = 0.20$ ($k = 14$; 95% CI = 0.09 – 0.31). This indicates that affect was estimated to be increased by 0.20 SD prior to NSSI behaviors relative to moments not followed by self-harm. The 95 percent credible interval did not include zero, suggesting that the results are consistent with a small effect in the anticipated direction.

**Consequence hypothesis.—**10 of the 14 data sets (71.43%) detected evidence of decreased negative affect in the consequence hypothesis of NSSI behaviors. Results from these models are reported in Figure 2. The effect size from the three-level model was $\beta = -0.47$ ($k = 14$; 95% CI = −0.73 – −0.19), suggesting that negative affect was reduced 0.47 SD following NSSI behavior relative to moments in which a participant continued to self-injure. The 95 precent credible interval did not include zero, suggesting effects are consistent with medium to large effects in the expected direction.

## Suicidal Thoughts

**Antecedent hypothesis.—**13 data sets measured negative affect and suicidal thoughts. Results from the antecedent hypothesis are reported in Figure 3. Seven of the 13 data sets (53.85%) detected evidence for increased negative affect prior to suicidal thoughts. The average effect size across these data sets was $\beta = 0.11$ ($k = 14$; 95% CI = 0.03 – 0.19), suggesting that negative affect was estimated to be increased by 0.11 SD prior to suicidal thoughts relative to moments not followed by suicidal thinking. The 95 percent credible interval did not include zero, suggesting that the results are consistent with a small effect in the anticipated direction.

**Consequence hypothesis.—**In the consequence hypothesis, reported in Figure 3, all 13 data sets (100%) found that negative affect was reduced following suicidal thoughts. The average effect size was $\beta = -0.52$ ($k = 13$; 95% CI = −0.79 – −0.23), suggesting that negative affect was reduced 0.52 SD following suicidal thoughts relative to moments in which a participant continued to think about suicide. The 95 precent credible interval did not include zero, suggesting effects are consistent with small to large effects in the expected direction.

### Moderators

Results of moderation analyses are presented in Tables 2–3 and in Supplementary Table 4.

**Antecedent NSSI Behavior:** In NSSI behavior antecedent models, whether a study recruited participants diagnosed with borderline personality disorder moderated the effect size (β = 0.29; SE = 0.09; 95% CI = 0.10 – 0.48). Studies that included participants diagnosed with borderline personality disorder observed larger effects between negative affect and NSSI behavior.

**Consequence NSSI Behavior:** In consequence analyses of NSSI behavior, we found no evidence of moderation.

**Antecedent Suicidal Thoughts:** We did not detect any significant moderators in antecedent suicidal thought models.

**Consequence Suicidal Thoughts:** In consequence analyses of suicidal thoughts, we again found no evidence of moderation.

### Sensitivity Analyses:

Due to the variability in study designs, we standardized raw data to calculate effect sizes. In treating all data sets the same, there were a few decisions we made that differed from the published articles. As these decisions may have inadvertently biased our results, we conducted some sensitivity analyses to compare findings under different scenarios.

First, in two data sets[9,41] in which suicidal thoughts were measured continuously, there was not a clear way to dichotomize the variable to indicate the presence or absence of suicidal thoughts. These two data sets also had a relatively high number of non-zero suicidal thoughts. Therefore, in both data sets, we centered this variable within person and considered suicidal thoughts present when an individual's observation was more than one standard deviation greater than their own average level of suicidal thoughts. Results in which we loosened (from one SD to one half of a SD) and tightened (1.5 and 2 SD) this operationalization are presented in Figures S2–S4. Average effect size in antecedent analyses increased up to .01 (average ß ranged from .11 to .12) under different conditions, while consequence analyses range +/− .02 (average ß ranged from −.50 to −.54) in various scenarios.

Second, one data set[42,43] combined NSSI thoughts and NSSI behaviors. We included this datapoint in both analyses but report effects with this study excluded in Supplementary Table 5. There are minimal differences in NSSI thought and behavior models when excluding this study.

Third, one study[44] used a measure of depressive symptoms in the past 24-hours instead of depressed affect. Since the items (depressed, hopeless, interested, and worried) overlapped with other conceptualizations of negative affect, we included this datapoint in the pooled analysis. Results with this study excluded are presented in Supplementary Table 6 and whether this study is included does not affect any of our findings.

Fourth, NSSI thought models with urges removed are presented in Supplementary Table 7. Removing NSSI urges and analyzing only studies that asked specifically about NSSI thoughts did not affect results.

Finally, as has been done in prior studies[30,45,] we tested whether controlling for SITB at *t - 1* influenced antecedent estimates, and if controlling for negative affect at *t - 1* influenced consequence estimates. These results are reported in Supplementary Table 8. Controlling for dependent variables at *t - 1* did not affect any of the main analyses.

### Publication Bias

We tested for publication bias by removing unpublished studies and reanalyzing results based exclusively on published articles. These analyses are reported in Supplementary Table 9. Results were nearly identical when excluding unpublished articles.

### Results Summary

Overall, results from the meta-analyses suggest negative affect is consistently increased prior to the occurrence of various SITBs (95% CI ß = 0.09 – 0.31 for NSSI behavior and 95% CI ß = 0.03 – 0.19 for suicidal thoughts). There was also evidence for reduced negative affect following SITBs (95% CI ß = −0.79 – −0.44 for NSSI thoughts, 95% CI ß = −0.73 – −0.19 for NSSI behaviors, and 95% CI ß = −0.79 – −0.23 for suicidal thoughts). There did not appear to be publication bias in the literature, although most of the intensive longitudinal studies of SITBs published to date include small samples. Studies that included participants diagnosed with borderline personality disorder detected stronger effects, but only in NSSI behavior antecedent analyses. We did not find evidence of moderation for any of the other factors tested.

## Discussion

The primary aim of this meta-analysis was to estimate the strength of the evidence for the affect regulation hypothesis of SITBs from studies using intensive longitudinal methods. Although the affect regulation hypothesis is the predominant theory regarding the maintenance of NSSI behaviors, the model had primarily been tested in single studies using relatively small sample sizes across a wide variety of methods, and systematic reviews had been unable to estimate pooled effect sizes, limiting our understanding of the magnitude and precision of these effects. Additionally, although there was preliminary evidence to suggest that affect regulation may similarly maintain suicidal thoughts[9,46], most of the evidence to date narrowly focused on NSSI behaviors. Results from this meta-analysis suggest that there is broad support for the affect regulation hypothesis in maintaining SITBs, such that negative affect is generally higher prior to NSSI behaviors and suicidal thoughts, and exhibits moderate to large reductions following all SITBs.

Broadening prior systematic reviews, we included studies that measured both NSSI and suicidal forms of SITBs, in addition to analyzing observation level data across studies. In both antecedent and consequence analyses, effects were largely consistent across the range of SITBs. Pre-STIB affect was weakly to moderately elevated across SITBs, and there were only small differences in effect sizes across all forms of SITBs. This implies that negative

affect alone is not likely to accurately discriminate between NSSI thoughts or behaviors from suicidal thoughts or behaviors. Future research should investigate between and within person differences which might better discriminate who is most likely to engage in NSSI and suicidal forms of SITBs and indicate when suicide risk is most acute. For example, within-person fluctuations in reflexive emotion regulation strategies[47], or momentary improvements in self-efficacy to avoid self-injurious behavior[26,48], may discriminate between episodes of NSSI from suicidal forms of SITBs[49].

Effect sizes were substantially larger in consequence models across all forms SITBs. These findings suggest relief from distressing negative affect is crucial in reinforcing SITBs and suggest that behavioral interventions should continue to teach replacement behaviors, such as emotion regulation skills, to obtain relief from negative affect in lieu of SITBs. Low-cost and scalable treatments, such as ecological momentary interventions[50] could be designed to increase an individual's ability to down-regulate from increased negative affect immediately prior to a SITB and/or block the relief experienced from SITBs.

It is notable that there were large differences in magnitude between the antecedent and consequence models of negative affect and SITBs. Although the evidence provides clear support that SITBs function to reduce negative affect, the evidence that negative affect could be used to predict when SITBs would occur was only modest. This is critical for understanding the contexts and conditions in which SITBs are likely to occur and should dampen enthusiasm for the field's ability to predict and intervene on SITBs until we can collectively gain greater precision of prediction. Although it is critical to align sampling in longitudinal data collection with the time frame in which a hypothesized process is expected to occur[25], there is no systematic research that has examined when SITBs may occur following peaks in negative affect. Thus, it may be that antecedent effects, on average, were diluted by observing affect far in time from the occurrence of SITBs (although it is important to note that the estimated effect did not vary as a function of number of EMA prompts). Future research should seek to understand the temporal dynamics of how and when peaks in negative affect lead to SITBs.

Intensive longitudinal designs offer a clear improvement over prior methods in better understanding SITBs and there is a growing number of studies using this method. Despite this promise, there was considerable between study heterogeneity. A variety of factors could explain this cross-study variation in results. Various definitions of negative affect, negative emotions, and types of SITBs have been studied using differing statistical tests and methods. For example, study sample sizes ranged from 11 to 1,709 (M = 103.30), the number of prompts per day ranged from 1 to 12 per day (M = 4.98) and the duration of the study period ranged from 3 days to 196 days (M = 19.37; median = 14). Analyses also varied widely between projects with some examining mean levels of general negative affect (broadly defined), others focusing on variance or activation, and some looking at specific forms of negative affect. Even when similar SITB and negative affect variables were measured, the scale of the negative affect variable was different and standardized coefficients were not reported. To account for some of this heterogeneity and compare inferences across studies, we standardized the negative affect variables, however, this meant that the average effect

sizes derived from these meta-analyses included many different operationalizations and measures.

Although the methods used to test hypotheses were diverse, the participants enrolled in these studies certainly were not. Young adult, white women were overrepresented across studies suggesting that these findings may not adequately characterize the affect regulation hypothesis of SITBs in men, children, older adults, or black, indigenous, and people of color (BIPOC). To ensure findings from these studies apply to everyone at risk, research studies need to make every effort to recruit more diverse samples.

Beyond the between study heterogeneity within this body of literature, there were a few more notable limitations to the present study. First, due to the various measurements across studies, we made decisions necessary to standardize analyses across studies. This meant that our methods inevitability had to diverge from a few published studies. Sensitivity analyses are included in the Supplemental Materials which consider how different decisions affected the results. Second, we were only able to obtain data from about half of the published articles. Every effort to obtain as much data as possible was made, however, more data would certainly be preferable. Diverging research designs, analytic techniques, and reporting practices meant we were unable to extract information necessary to calculate effect size from any of the published articles, relying on individual authors to provide raw data. Finally, our moderation analyses were exploratory and examined study-level, as opposed to individual-characteristics. We tested any variable we could operationalize from the published articles; however, it is likely that testing some of the moderators (e.g., compliance and frequency of SITB) on the individual-level would most likely lead to more precise estimates.

Although intensive longitudinal methods offer a promising solution for stagnation in suicide research, studies date do not yet offer clear, well-converged inferences about SITBs. Instead, close review presented here has highlighted critical opportunities for improving this work to catalyze advances in the field. By incorporating principles of open science[51] (i.e., pre-registering hypotheses and making data/analysis scripts publicly available), meta-analyses could be conducted more efficiently, possibly leading to more reliable findings to assist in the prevention of SITBs. Additionally, the field should value replication studies from intensive longitudinal designs that verify findings to increase confidence in the stability of our discoveries and, if replication is not supported, may assist in identifying potential moderators and mediators.

Furthermore, exploration of reliable effects will require larger periods of data collection to ensure that tests of effects are based on ample observations of SITBs. Fourteen days, the average duration of intensive longitudinal studies, is an especially narrow window to observe processes that, although prevalent at the between person level, are of short duration and rare at the within-person level. Increasing the window of observation for SITBs will increase the number of observations, thereby increasing power to explain effects. The use of a longitudinal burst design, or a multiple period of intensive longitudinal methods windows separated by months and years could also increase power while balancing participant response fatigue[52].

Finally, all statistical tests reviewed in the present report commonly estimate *average* effects across individuals, relying on the assumption that effects are homogeneous between people and over time. However, the degree of between study heterogeneity observed in this review and recent findings suggesting SITBs are likely a multiply determined complex process that vary widely across individuals[26,53], suggests that any assumption of homogeneity in the link between negative affect and SITBs on the person level may be incorrect[54,55]. It is possible that this variability may be so great both between and within individuals that links between SITBs and candidate risk factors could be non-ergodic (i.e., effects are not consistent across people or within the same person over time). Rather than using a nomothetic, group-level approach to render uniform inferences across diverse individuals, an idiographic approach[54–57] may be especially beneficial for identifying consistency in relations between negative affect (or other antecedents/consequences) and SITBs across individuals and time.

Despite all these challenges, the present meta-analysis was able to extend the three prior systematic reviews by quantifying the association between negative affect and SITBs across studies. The prior reviews noted mixed evidence for some aspects of the affect regulation hypothesis. By pooling studies together, we were able to provide a much more refined understanding of the affective dynamics in the hours and minutes before and after SITBs. Results demonstrated a small effect for increased within-person affect prior to NSSI behaviors and suicidal thoughts (but not NSSI thoughts), and medium to large effects for decreased negative affect following all forms of SITBs.

## Method

### Article Search and Study Selection

We conducted a thorough search for intensive longitudinal studies measuring both negative affect and SITBs following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[58]. The search was performed using PsycINFO, PubMed, Google Scholar, and PsyArxiv with the following search terms “suicid* AND ecological momentary assessment”, “suicid* AND experience sampling”, “suicid* AND daily diary”, “suicid* AND ambulatory assessment”. For published articles, we included studies circulated before January 15, 2022. We also included pre-prints, studies that included a measure of negative affect in an intensive longitudinal study of at least one SITB but never published on the negative affect-SITB association, and one dataset in which data collection was complete but the main manuscript was not yet published. Inclusion criteria for the current review were: (a) an empirical study (e.g., not literature reviews, theoretical articles, case studies etc.) (b) measured a SITB variable (i.e., NSSI urges, thoughts, or behaviors and/or suicidal urges, thoughts, or behaviors) in intensive longitudinal methods, (c) measured negative affect continuously in intensive longitudinal methods.

This initial search identified 168 unique possible studies for inclusion (163 published articles, two pre-prints, two unpublished dissertations, and one unpublished dataset). Consistent with PRISMA guidelines, the titles, abstracts, and keywords of these 168 studies and datasets were initially reviewed independently by two people (the first and fourth authors) to assess whether they appeared to meet inclusion criteria. Thirty studies

were removed in this initial search as they were determined to be non-empirical articles. The two raters reviewed 138 full-text articles and descriptions of datasets to determine whether they met inclusion criteria. Inter-rater agreement for the initial inclusion/exclusion determination was substantial ($\kappa$ = .86.). The two raters met following their independent searches to resolve disagreements on 9 of the articles. Of the original 168 studies, 89 were excluded based on initial inclusion/exclusion criteria leaving 79 articles or datasets eligible for inclusion.

## Compilation of Data

Due to the variation in analytic procedures and reporting practices, none of the 79 studies reported the necessary information to calculate standardized effect sizes from the published articles alone. We attempted to contact the corresponding author of each study individually to provide us with the raw data. We obtained the raw data for 22 of the 57 unique data sets ($N$ = 1,644), which corresponded to 38 of the 79 articles (48.10%).We made three total attempts to contact corresponding authors prior to excluding studies. To obtain unpublished data, we also emailed the list-serv for the American Association of Suicidology and asked all contacted authors if they had any unpublished data relevant to the present study.

Participants in the studies for which we had data were significantly younger $t$ (df = 51.78) = 2.56, p = .01; Cohen's $d$ = 0.72, 95% CI $t$ = 1.19 – 9.77. There were no other differences in terms of publication year, sample size, duration of the observation period, number of prompts per day, percentage of female participants, or the percentage of white participants in the sample.

## Meta Analyses

We conducted six separate IPD meta-analyses[59]. Antecedent models examined changes in pre-SITB negative affect, while consequence models detected differences in negative affect post-SITB. Both antecedent and consequence models were run separately for NSSI thoughts, NSSI behaviors, and suicidal thoughts. As there were a small number of studies that measured NSSI urges ($k$ = 1) and suicidal urges ($k$ = 1), thoughts and urges were combined and labeled NSSI thoughts and suicidal thoughts. Only one study reported any instances of suicidal behavior (i.e., suicide attempts), limiting our ability to include this outcome.

We standardized negative affect in each study to account for measurement differences. We then aggregated individual studies into a combined data set prior to separating within- and between-person variance of the standardized affect variable. To tease apart within and between-person variance, we first averaged each participants' EMA responses across the study period to create person-level averages. We then centered each observation of negative affect within-person by subtracting the participant-level mean from each EMA observation, and then grand-mean centered those participants' averages[60]. Thus, by centering level-1 variables within-person, any one observation reflects an individuals' deviation from their own average across all time points.

For each of the six analyses, we used a three level Bayesian multi-level model (observations nested within individuals nested within studies). Besides accounting for the nested structure,

we also nested these participant-level intercepts within studies to account for differences in SITBs across studies. We further included random slopes to account for variability in the negative affect - SITB association between participants and studies. For all models, we lagged the data so that we could make comparisons in negative affect prior to and following incidents of SITB.

We used the following R syntax to calculate antecedent effects:

$$\text{NA . standard . CWP . lag} \sim 0 + \text{Intercept} + \text{NSSI\_thgts} + (0 + \text{Intercept} | \text{Study}) + (0 + \text{Intercept} | \text{Study:PID}) + (0 + \text{NSSI\_thgts} | \text{Study}) + (0 + \text{NSSI\_thgts} | \text{Study:PID})$$

Although somewhat counterintuitive, we chose to use within-person negative affect at *t*-1 as the dependent variable instead of SITBs. As we were concerned with the *relative* difference in affect between a SITB versus a non-SITB report, the coefficient from the above model provided a clean and interpretable effect size of interest, because it estimated the differences in within-person negative affect at observations prior to observing SITB versus not. Conversely, a model with a dichotomous SITB as the dependent variable would produce a coefficient that, when exponentiated, represents a change in the odds ratio of a SITB for increasing levels of negative affect. We felt a model with negative affect as the dependent variable allowed for effect sizes to be comparable between antecedent and consequence models and produced effect sizes that were easy to interpret.

Consequence models were based on Kleiman et al.[9] and reflect the relative difference in negative affect at time point *t* when a SITB was reported as compared to mean levels of within-person affect when a SITB was not reported at *t +1*. As such, here we compare a participant's reported level of negative affect together with the report of SITB to the report of negative affect at the time point following the report of SITB. The following R script was used for analyses:

$$\text{NA . standard . CWP} \sim 0 + \text{Intercept} + \text{NSSI\_thgts} + (0 + \text{Intercept} + \text{NSSI\_thgts} | \text{Study/PID/pair})$$

**Priors—**To specify prior information, in line with recommendations from Gelman, Simpson, and Betancourt[61], we chose a weakly informative prior. The purpose of these priors is to regularize parameters while taking minimal influence on the results, provided sufficient amounts of data are available. The following priors were used:

$$Intercept \sim N(0, 1)$$

$$\text{B(SITB)} \sim N(0, 1)$$

$$\text{SD} \sim Student\ t(3, 0, 2.5)$$

$$\sigma \sim Student\ t(3, 0, 2.5)$$

We used the "brms" package[62] in the R statistical environment[63] to conduct all analyses.

**Moderation Analyses—**We tested for moderation using the interaction between our hypothesized moderators and SITB variables in a three-level model. Moderation was tested in both antecedent and consequence models. We did not test for moderation with NSSI thought models due to the small number of studies. We examined sources of heterogeneity between studies and used the following variables as moderators (all moderators were tested as study-level characteristics):

**Number of Prompts Per Day.:** We extracted the number of intensive longitudinal prompts sent to participants per day (M = 5.04; SD = 3.31; range = 1 – 12).

**Number of Hours Between Prompts.:** The average amount of time (in hours) between study prompts. This was either stated in the publication or was calculated by dividing the number of prompts by the duration of the observation period used in the study (M = 10.43, SD = 10.41; range = 0.5 – 24).

**Frequency of SITB.:** The frequency with which each SITB variable was observed over the course of the study. This was calculated by diving the number of observations in which a SITB was endorsed by the total number of observations (NSSI thoughts: M = 12.44%, SD = 7.37%; range = 3.15% – 26.60%; NSSI behaviors: M = 3.53%, SD = 2.85%; range = 0.05% – 8.92%; suicidal thoughts: M = 22.82%; SD = 27.28%; range = 3.73% – 79.01%).

**Compliance Rate.:** The proportion of surveys completed by participants. This was either reported in the study or calculated from the raw data (M = 69.15%; SD = 17.46%, range = 36% – 100%).

**Percentage of Sample who Identify as Female.:** We extracted the percentage of the sample that identified as female from each study (M = 74.73%; SD = 36.66%; range = 38.30% – 91.00%).

**Percentage of Sample who Identify White.:** We derived the percentage of the sample reporting a white identity from each study (M = 80.00%; SD = 11.07%; range = 57.00% – 100%)

**Mean Age of the Sample.:** We also extracted the mean age of the sample from each study (M = 24.42; SD = 7.02; range = 15.50 – 37.90).

**Borderline Personality Disorder (BPD).:** We created a binary variable that indicated whether studies included participants diagnosed with borderline personality disorder. Seven studies (31.82%) mentioned borderline personality disorder as an inclusion criterion and/or reported enough diagnostic information to determine if this was assessed.

**Sampling Strategy (EMA versus Daily Diary).:** We categorized studies as using an EMA ($n$ = 16; 72.72%) or daily diary ($n$ = 6; 27.27%) design.

**Momentary versus Retrospective Prompts.:** We then examined the wording of the time frame assessed in prompts and categorized them as momentary ($n$ = 15; 68.18%) or retrospective ($n$ = 7; 31.82%).

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## Data Availability

Although this study was not preregistered, the raw data are publicly available (https://github.com/kskuehn/NA-SITB_meta).

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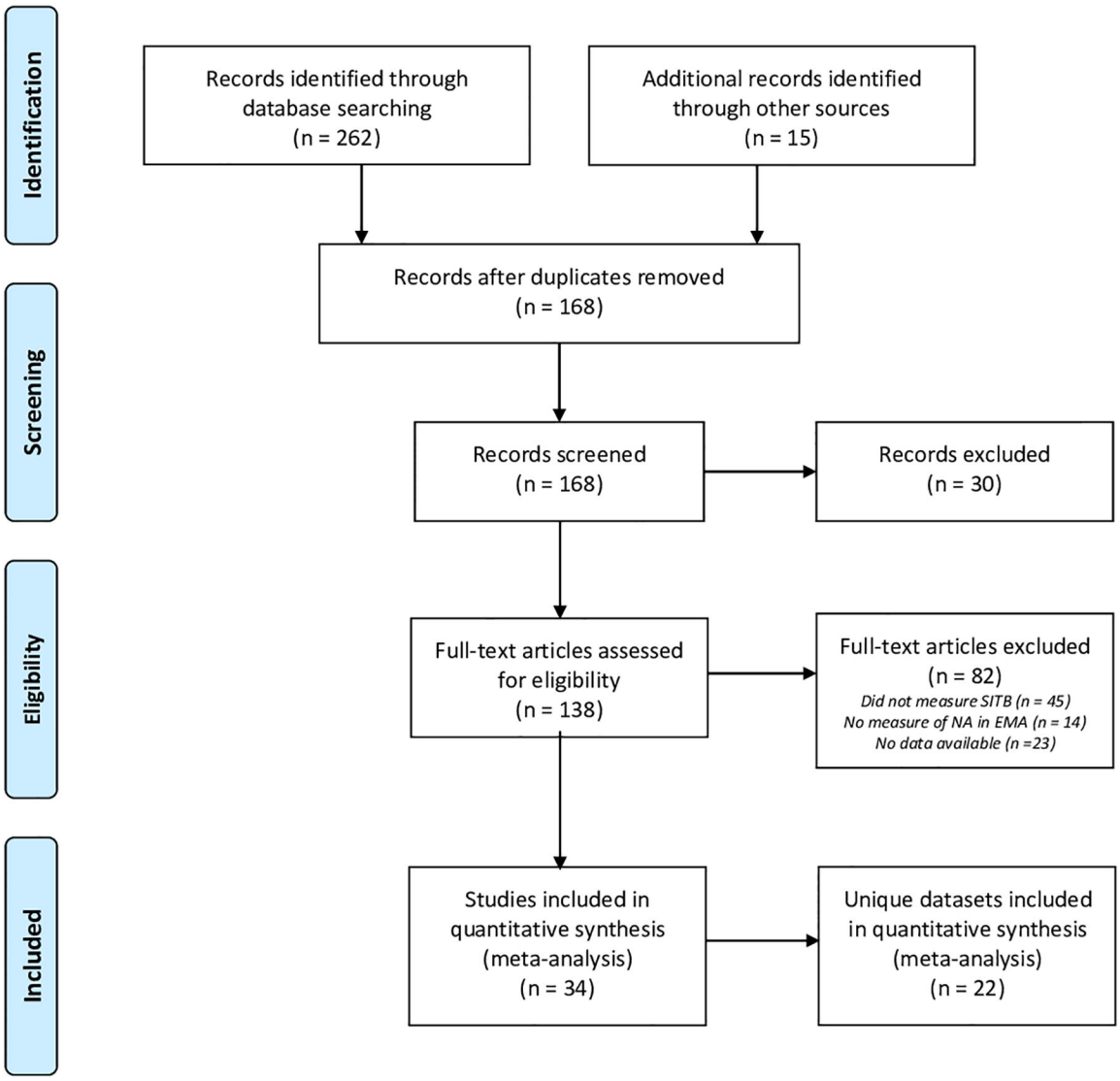


**Figure 1.**
CONSORT FLOW Diagram. Flow chart from literature search to inclusion in quantitative synthesis.

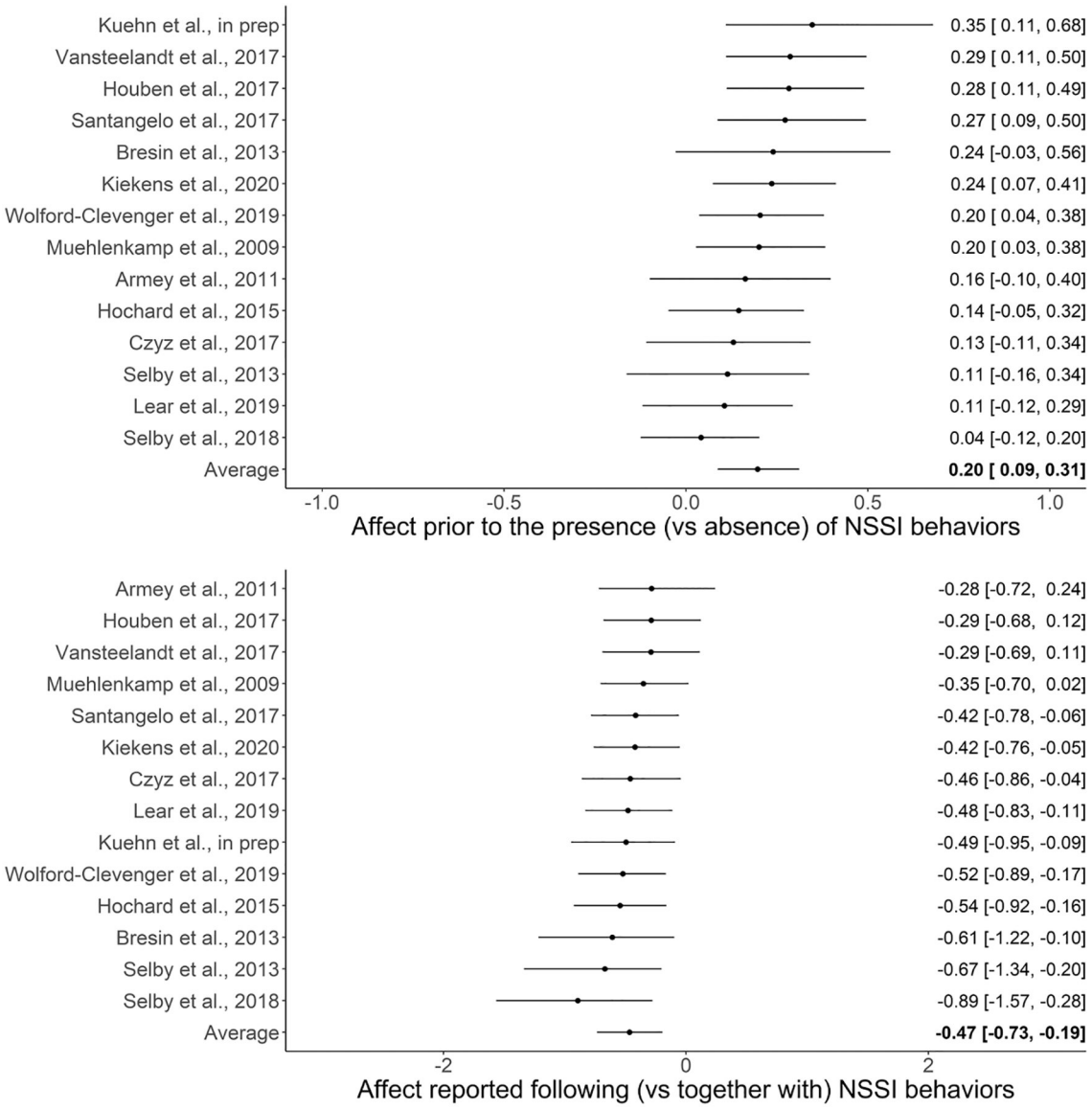


**Figure 2.**

Forest plots of NSSI Behaviors in both Antecedent and Consequence Models. Effect sizes from antecedent *(top)* and consequence *(bottom)* models of the negative affect, NSSI behavior association (n = 897 participants nested in 14 studies). Data presented as random effects estimates from a three-level model +/− 95% credible interval.

**Notes:* Average effect size (fixed effect from three level model and 95% credible interval) is in bold at the bottom of the respective plots.

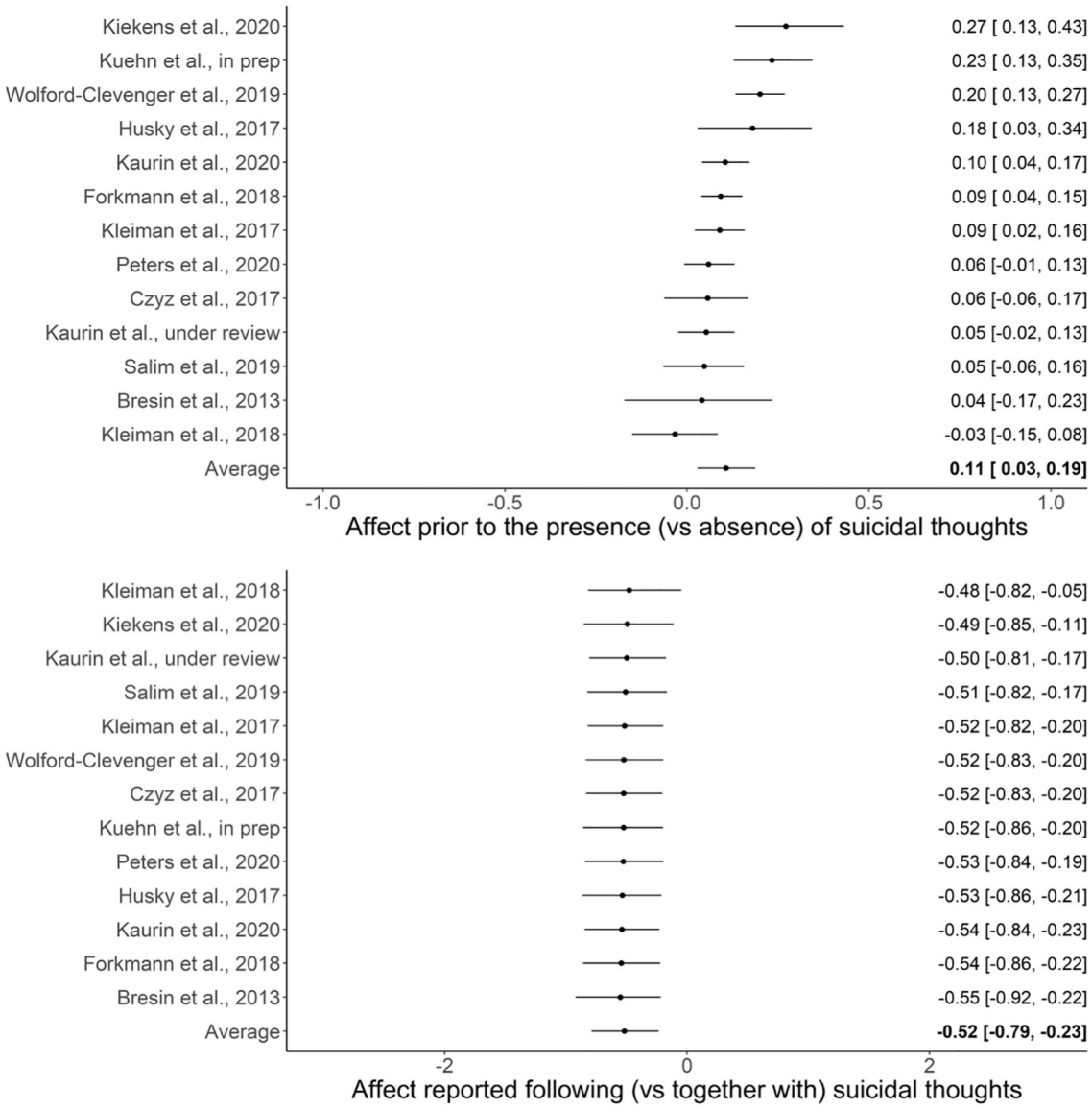


**Figure 3.**

Forest plots of Suicidal Thoughts in both Antecedent and Consequence Models. Effect sizes in antecedent *(top)* and consequence *(bottom)* models of the association of negative affect with suicidal thoughts (n = 1108 participants nested in 13 studies). Data presented as random effects estimates from a three-level model +/− 95% credible interval.

**Notes:* Average effect size (fixed effect from three level model and 95% credible interval) is in bold at the bottom of the respective plots.

**Table 1:**

Average effect sizes by SITB variable for antecedent and consequence models.

| | Antecedent Models | | | |
|---|---|---|---|---|
| | **k** | **β** | **SE** | **95% CI** |
| NSSI thoughts | 6 | 0.06 | 0.06 | −0.07 – 0.19 |
| NSSI behaviors | 14 | 0.20 | 0.06 | 0.09 – 0.31 |
| Suicidal thoughts | 13 | 0.11 | 0.04 | 0.03 – 0.19 |
| | **Consequence Models** | | | |
| | **k** | **β** | **SE** | **95% CI** |
| NSSI thoughts | 6 | −0.63 | 0.09 | −0.79 – −0.44 |
| NSSI behaviors | 14 | −0.47 | 0.14 | −0.73 – −0.19 |
| Suicidal thoughts | 13 | −0.52 | 0.14 | −0.79 – −0.23 |

*Notes:* None

**Table 2:**

Moderation results in antecedent and consequence NSSI behavior analyses.

| **NSSI Behaviors Antecedent** | | | |
|---|---|---|---|
| **Moderator** | | | |
| | **β (SE)** | **95% CI LB** | **95% CI UB** |
| # of prompts | 0.03 (0.01) | 0.01 | 0.06 |
| # of hours | −0.01 (0.01) | −0.02 | 0.01 |
| Frequency of SITB | −0.08 (0.49) | −1.02 | 0.89 |
| Compliance | −0.34 (0.25) | −0.81 | 0.19 |
| % women | 0.34 (0.35) | −0.39 | 1.00 |
| % white | 0.28 (0.29) | −0.34 | 0.82 |
| Mean age | 0.02 (0.01) | −0.01 | 0.04 |
| BPD (1 = Yes; 0 = No) | 0.29 (0.09) | 0.10 | 0.48 |
| Sampling (1 = EMA; 0 = Daily Diary) | 0.10 (0.13) | −0.17 | 0.35 |
| Timing (1 = Concurrent; 0 = Lagged) | 0.10 (0.12) | −0.13 | 0.33 |
| **NSSI Behaviors Consequence** | | | |
| | **β (SE)** | **95% CI LB** | **95% CI UB** |
| # of prompts | 0.03 (0.04) | −0.04 | 0.11 |
| # of hours | −0.00 (0.01) | −0.03 | 0.02 |
| Frequency of SITB | −0.02 (0.49) | −0.98 | 0.94 |
| Compliance | −0.48 (0.40) | −1.26 | 0.34 |
| % women | 0.44 (0.43) | −0.40 | 1.27 |
| % white | 0.50 (0.48) | −0.46 | 1.39 |
| Mean age | −0.00 (0.03) | −0.06 | 0.06 |
| BPD (1 = Yes; 0 = No) | 0.15 (0.24) | −0.33 | 0.61 |
| Sampling (1 = EMA; 0 = Daily Diary) | −0.03 (0.25) | −0.52 | 0.43 |
| Timing (1 = Concurrent; 0 = Lagged) | −0.07 (0.23) | −0.53 | 0.38 |

**Table 3:**

Moderation results in antecedent and consequence suicidal thought analyses.

| **Suicidal Thoughts Antecedent** | | | |
|---|---|---|---|
| **Moderator** | | | |
| | **β (SE)** | **95% CI LB** | **95% CI UB** |
| # of prompts | 0.02 (0.01) | −0.01 | 0.05 |
| # of hours | −0.00 (0.01) | −0.02 | 0.01 |
| Frequency of SITB | −0.03 (0.14) | −0.31 | 0.25 |
| Compliance | 0.04 (0.24) | −0.42 | 0.53 |
| % women | −0.02 (0.35) | −0.71 | 0.67 |
| % white | 0.37 (0.36) | −0.38 | 1.06 |
| Mean age | 0.00 (0.01) | −0.01 | 0.01 |
| BPD (1 = Yes; 0 = No) | 0.01 (0.09) | −0.16 | 0.19 |
| Sampling (1 = EMA; 0 = Daily Diary) | 0.11 (0.09) | −0.05 | 0.29 |
| Timing (1 = Concurrent; 0 = Lagged) | 0.12 (0.16) | −0.19 | 0.46 |
| **Suicidal Thoughts Consequence** | | | |
| | **β (SE)** | **95% CI LB** | **95% CI UB** |
| # of prompts | −0.00 (0.05) | −0.11 | 0.11 |
| # of hours | −0.01 (0.02) | −0.05 | 0.03 |
| Frequency of SITB | 0.20 (0.31) | −0.41 | 0.79 |
| Compliance | −0.06 (0.35) | −0.73 | 0.62 |
| % women | 0.41 (0.40) | −0.38 | 1.19 |
| % white | −0.21 (0.41) | −1.01 | 0.59 |
| Mean age | 0.01 (0.02) | −0.03 | 0.05 |
| BPD (1 = Yes; 0 = No) | −0.08 (0.23) | −0.54 | 0.38 |
| Sampling (1 = EMA; 0 = Daily Diary) | −0.21 (0.22) | −0.63 | 0.23 |
| Timing (1 = Concurrent; 0 = Lagged) | −0.08 (0.32) | −0.70 | 0.54 |