

A Brief Mobile App Reduces Nonsuicidal and Suicidal Self-Injury: Evidence From Three Randomized Controlled Trials

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Objective: Self-injurious thoughts and behaviors (SITBs) are a major public health problem that traditional interventions have been unable to address on a large scale. The goal of this series of studies was to take initial steps toward developing an effective SITB treatment that can be easily delivered on a very large scale. **Method:** We created a brief (1–2 min), game-like app called Therapeutic Evaluative Conditioning (TEC), designed to increase aversion to SITBs and decrease aversion to the self. In 3 separate studies, we recruited participants with recent and severe histories of SITBs from web forums focused on self-injury and psychopathology ($Ns = 114, 131, \text{ and } 163$) and randomly assigned them to receive access to the mobile treatment TEC app or a control app for 1 month. We tested the effect of TEC on the frequency of self-cutting, nonsuicidal self-injury more generally, suicide ideation, suicide plans, and suicidal behaviors. **Results:** Analyses showed that, compared with the control app, TEC produced moderate reductions for all SITBs except suicide ideation. Across studies, the largest and most consistent reductions were for self-cutting episodes (32%–40%), suicide plans (21%–59%), and suicidal behaviors (33%–77%). Two of the 3 studies showed that TEC impacted its intended treatment targets and that greater change in these targets was associated with greater SITB reductions. TEC effects were not maintained at the 1-month posttreatment follow-up. **Conclusions:** Future versions of brief, mobile interventions like that tested here may have the potential to reduce SITBs and related behaviors on a large scale.

What is the public health significance of this article?

Across 3 studies, we found that a brief mobile app generated moderate reductions in nonsuicidal and suicidal self-injury. These findings suggest that mobile interventions may have the potential to impact SITBs on a large scale.

Keywords: mobile app, NSSI, self-injury, suicide, treatment

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Self-injurious thoughts and behaviors (SITBs) are a major public health problem. Suicide accounts for an estimated one million worldwide deaths each year, making suicide responsible for more deaths than war, accidents, or AIDS (World Health Organization, 2012). These deaths are in addition to an estimated 25 million annual nonfatal suicide attempts, many of which result in serious medical injuries (Crosby et al., 2011).

The rates of these behaviors are exceeded by the annual prevalence of suicide plans (0.6%) and ideation (3%) (Kessler et al., 2005). Nonsuicidal self-injury (NSSI; e.g., cutting or burning without suicidal intent) is even more common, with estimates of prevalence rates ranging for 5% to 17% in general populations and more than 50% in certain clinical populations (see Swannell et al., 2014).

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Given the scope and seriousness of this problem, a tremendous amount of research has been devoted to the development of effective SITB interventions over the last several decades. Unfortunately, few interventions have proven effective and even the most promising interventions have produced mixed results (Brown & Jager-Hyman, 2014; Glenn, Franklin, & Nock, 2015). Regardless of their efficacy, most existing interventions are inherently limited in their ability to reduce SITB rates on a large scale. This is because their in-person model of delivery, which typically involves a therapist and client (or group of clients) meeting face-to-face on a weekly basis for an hour, constrains the potential impact of these treatments in several ways (Kazdin & Rabbitt, 2013). First, there is approximately one therapist for every 100 mentally ill individuals; accordingly, even if all therapists practiced evidence-based treatments, there would still be little change in national and international rates of SITBs. Second, this model of delivery is often costly in terms of time, money, and client effort. These cost barriers prohibit many individuals from accessing treatments (Mojtabai et al., 2011; Sareen et al., 2007). Third, this model of delivery is unable to overcome one of the most common barriers to accessing treatment: the desire to handle one's own problems (i.e., the autonomy barrier; Mojtabai et al., 2011; Sareen et al., 2007).

These barriers help to explain why most individuals with SITBs do not receive treatment (Bruffaerts et al., 2011), which in turn helps to explain why there has been little change in SITB rates over the last several decades (Kessler et al., 2005; Nock, Borges, et al., 2008a). These patterns show a clear need for the development of effective SITB interventions that can overcome availability, cost, and autonomy barriers. The present series of studies represent initial steps toward this goal. Specifically, these studies evaluated the first iterations of a novel web app designed to reduce SITBs by targeting two recently identified SITB risk factors.

The first treatment target is the diminished aversion to SITB-related stimuli (e.g., blood, wounds, knives, skulls, etc.). Whereas most people find these stimuli extremely aversive, many people who engage in SITBs find these stimuli neutral or even pleasant (Franklin, Lee, Puzia, & Prinstein, 2014; Joiner, 2005). This diminished aversion may be partially explained by pain offset relief conditioning during episodes of self-injury (Franklin, 2014; Franklin et al., 2013; Franklin, Lee, et al., 2014; Franklin, Puzia, Lee, & Prinstein, 2014). Although pain itself is unpleasant, the removal of pain generates a powerful state of relief; any stimuli present during this relief (e.g., blood, wounds) acquire a more positive valence. Recent evidence indicates that this diminished aversion to SITB stimuli longitudinally predicts future SITBs above and beyond several other competing predictors, including prior SITBs and psychopathology (Franklin, Puzia, et al., 2014). According to recent theories, the aversion to SITB stimuli creates a barrier that dissuades most people from engaging in SITBs, and a reduction in this barrier facilitates SITBs (Franklin, Lee, et al., 2014; Franklin, Puzia, et al., 2014; Joiner, 2005). Based on this work, we hypothesized that increasing the aversion to SITB stimuli would reduce future SITBs.

The second treatment target is aversion toward the self (i.e., one's own representation of their identity or subjective experience). Most people have a positive association with the self (e.g., Koole et al., 2001), but many people who engage in SITBs show aversion toward the self, as indicated by high levels of self-

criticism and similar constructs in this population (e.g., Hooley & Germain, 2014). Recent experimental work indicates that self-aversion may be a particularly important motivator of SITBs (e.g., Hooley & Germain, 2014). Specifically, this work suggests that self-aversion generates the belief that one deserves pain, punishment, or death. In the absence of such beliefs, it may be much more difficult for SITBs to occur. Correspondingly, we hypothesized that decreasing self-aversion would reduce future SITBs.

Our preliminary work is consistent with these two treatment target hypotheses. In a pilot study, Franklin (2014) attempted to increase aversion to SITB stimuli by pairing these stimuli with mildly painful electric shocks. Compared with a control group that received shocks unpaired with SITB stimuli, a group that received aversive conditioning (i.e., shocks paired with SITB stimuli) reported significantly fewer self-cutting behaviors over the ensuing six months. Treatment response was significantly predicted by increases in physiological aversion to SITB stimuli. Similarly, Hooley and Germain (2014) found that a 5-min cognitive intervention aimed at improving self-worth normalized pain endurance in a sample of individuals with a history of self-injury. Although these preliminary findings are promising, one major limitation is that these interventions are impossible to deliver on a large scale in their present formats. Given their relatively simple proposed mechanisms of action (i.e., increasing aversion to SITB stimuli, decreasing self-aversion), however, we believed that these interventions could be transformed into a simple format amenable to large-scale dissemination.

For the present series of studies, we built on this preliminary work to place these two potential interventions into a single, novel evaluative conditioning paradigm. Evaluative conditioning is a form of Pavlovian conditioning that occurs when the liking (i.e., evaluation) of one stimulus changes as a result of its pairing with another stimulus (e.g., Hofmann et al., 2010). For example, the liking of a picture of a blue triangle may change if it is repeatedly paired with a picture of a spider. Evaluative conditioning has traditionally been employed to study changes in attitudes toward neutral stimuli in social psychology (see Hofmann et al., 2010), but more recently has been applied to study clinical phenomena (e.g., Houben et al., 2010). Although there is a wide range of evaluative conditioning procedures (see Hofmann et al., 2010), most involve the simultaneous or sequential pairing of pictures or words. These paradigms are typically short (<100 trials), passive (watching stimuli on screen), and administered a single time in a laboratory. As described in more detail below, we created a modified evaluative conditioning procedure that has an engaging, game-like design and is meant to be played many times outside of the laboratory on a mobile device. We call this procedure Therapeutic Evaluative Conditioning (TEC). In the present series of studies, we designed TEC to increase aversion to SITB-related stimuli (pairing these stimuli with unpleasant stimuli) and to increase liking of self-related words (pairing these words with pleasant stimuli). Across all studies, we hypothesized that TEC would cause decreases in SITBs.

Study 1

In Study 1, we tested TEC within a sample of individuals with a recent history of frequent NSSI. We focused on this population in our initial study because our pilot work focused on this popu-

lation and NSSI is prevalent, frequent, and strongly associated with a range of SITBs (see Franklin & Nock, in press). Participants were randomly assigned to receive access to an active version of TEC ("active group") or a control version of TEC ("control group"), and were allowed to access the appropriate version of the TEC app as much as they desired over a one-month period.

We hypothesized that, compared with the control group, the active group would display reductions in self-cutting and overall NSSI. Given the specificity of this version of TEC to self-cutting, we expected milder treatment effects for suicide ideation, plans, and behavior. We additionally hypothesized that any treatment effects would remain significant after controlling for stringent covariates including prior month SITBs, emotion reactivity, internalizing symptoms, recent psychiatric treatment (both psychosocial and pharmacological), desire to stop engaging in NSSI, and self-prediction of future NSSI.

Secondary analyses explored a range of other potential effects, including the effect of active TEC dosage on SITBs and whether any treatment effects persisted during the month after TEC access ended. We also hypothesized that active TEC would impact its intended treatment targets (i.e., diminished aversion to NSSI stimuli; heightened aversion to self-related words) and that changes in these treatment targets would be associated with SITB reductions. Finally, we explored the possibility that reductions in SITBs would be accompanied by compensatory increases in non-SITB dysregulated behaviors.

Method

Participants. Participants were 114 individuals (80.70% female) recruited from online web forums that focused on topics relating to self-injury or psychopathology. To be eligible to participate, individuals had to meet the following criteria: (a) 18 years of age or older; (b) English fluency; and (c) two or more episodes of self-cutting in past month. Most participants were young adults ($M = 23.02$ years old, $SD = 5.47$) and most identified as Caucasian (81.57%), with the remaining identifying as Asian (6.14%), Black/African American (1.75%), Hispanic (1.75%), or Other (8.77%; e.g., mixed race). Most par-

ticipants were living in the United States ($n = 96$), with the remaining living in Canada ($n = 2$), Europe ($n = 12$), Asia ($n = 3$), and Australia ($n = 1$). The majority of participants reported a history of psychiatric treatment (lifetime: 76.31%; past month: 55.26%), many reported a history of inpatient psychiatric treatment (lifetime: 29.82%; past month: 3.50%), and 50.87% were currently on psychiatric medication. Participants were randomly assigned via a random sequence generator to either the control group (which received access to the control TEC, $n = 59$) or the active group (which received access to active TEC, $n = 55$). There were no significant demographic or treatment history differences between the two groups (all $ps > .05$). Groups reported similar baseline levels of each of SITBs and covariates (see Table 1), with the exception of significantly fewer prior month suicide plans in the active group ($B = -.29$, $SE = .09$, $p = .001$). CONSORT flow diagrams for each study are presented as Supplemental Figures S1 through S3.

Therapeutic evaluative conditioning (TEC). We designed TEC to be a brief, game-like treatment that could be accessed by any device with an Internet connection. We aimed for TEC to be accessed multiple times a day at the convenience of the user. Several TEC characteristics promoted this aim: It takes 1 to 2 min to complete a single instance of TEC; TEC becomes more challenging as the trials progress; points are awarded for faster and more accurate performance; each instance of TEC is unique, increasing replay value; and although TEC was primarily intended as a mobile app, it includes a responsive design that allows it to automatically format itself for phones, tablets, laptops, and desktops (see Figure 1 and Supplemental Method for a detailed description of TEC). For the present study, we included a version of TEC that targeted self-related words (e.g., me, myself, I, mine) and SITB-related stimuli that primarily depicted self-cutting (in Studies 1 and 2) or suicide/death stimuli (in Study 3).

Measures.

Self-Injurious Thoughts and Behaviors Interview (SITBI; Nock et al., 2007). The SITBI is a structured interview that assesses the presence, frequency, and characteristics of self-injurious thoughts and behaviors. As in previous studies (e.g.,

Table 1
Means and Standard Deviations for Prior Month SITBs, Covariates, and AMPs Across All Studies

Measure	Study 1		Study 2		Study 3	
	Control <i>M</i> (<i>SD</i>)	Active <i>M</i> (<i>SD</i>)	Control <i>M</i> (<i>SD</i>)	Active <i>M</i> (<i>SD</i>)	Control <i>M</i> (<i>SD</i>)	Active <i>M</i> (<i>SD</i>)
Self-cutting episodes	15.88 (28.15)	10.96 (17.85)	8.59 (11.92)	12.31 (29.27)	3.38 (6.90)	3.51 (6.18)
Self-cutting events	—	—	42.46 (80.47)	41.11 (77.61)	22.99 (74.22)	19.81 (62.02)
NSSI episodes	32.47 (61.29)	18.85 (25.61)	24.56 (61.92)	24.16 (59.12)	8.73 (17.60)	8.05 (13.07)
NSSI events	—	—	82.30 (134.17)	60.68 (86.98)	30.54 (59.58)	29.09 (54.56)
Suicide ideation	12.63 (11.30)	11.50 (12.72)	12.50 (10.90)	13.47 (11.21)	8.84 (10.36)	12.29 (12.60)
Suicide plans	6.88 (10.04)	3.85 (6.48)	5.38 (8.76)	6.66 (9.41)	4.45 (7.76)	4.81 (7.16)
Self-prediction of NSSI	4.05 (1.27)	4.13 (.96)	4.42 (.86)	4.23 (.98)	3.52 (1.15)	3.65 (1.14)
Desire to stop NSSI	2.73 (1.27)	2.96 (1.20)	2.99 (1.33)	2.94 (1.25)	2.48 (1.78)	2.55 (1.63)
ERS total	53.53 (18.18)	54.80 (19.23)	59.47 (17.49)	61.89 (14.09)	57.29 (16.34)	53.70 (18.58)
BSI total	40.98 (16.29)	39.09 (13.61)	46.69 (13.38)	43.16 (12.78)	43.45 (12.29)	41.86 (14.83)
IDB total	24.26 (4.04)	23.49 (3.07)	28.04 (2.68)	27.84 (2.66)	28.28 (2.90)	27.82 (2.79)
AMP NSSI	.47 (.30)	.57 (.32)	.52 (.32)	.47 (.30)	.41 (.28)	.48 (.27)
AMP self	.58 (.27)	.47 (.27)	.54 (.34)	.57 (.29)	.55 (.32)	.54 (.34)

Note. *M* = mean; *SD* = standard deviation; — = not available; ERS = Emotion Reactivity Scale; BSI = Brief Symptom Index; IDB = Index of Dysregulated Behaviors; AMP = Affect Misattribution Procedure. Self-cutting and NSSI events were not recorded for Study 1.

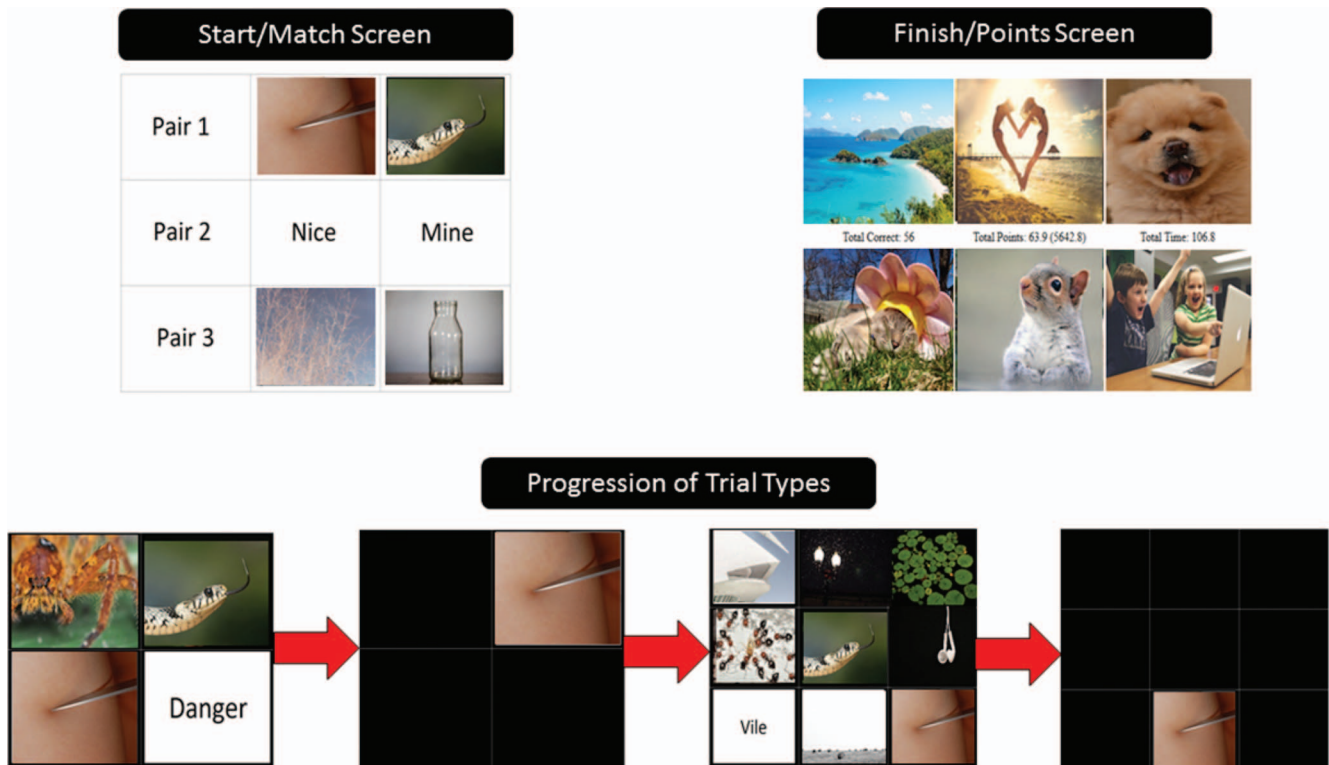


Figure 1. Screenshots of TEC screen types. TEC begins with a screen displaying matches, moves to a 2×2 grid for the first 15 trials; masks alternative options after the first pair member is selected for the second 15 trials; moves to a 3×3 grid for the third 15 trials; masks alternative options within this larger grid for the final 15 trials; and ends with a screen that displays positive (for active TEC) or neutral images (for control TEC), total trials correct, game and total points, and time elapsed for that instance of TEC. See the online article for the color version of this figure.

Franklin, Puzia, et al., 2014), in the present series of studies we employed an online self-report version of the SITBI. The online and in-person versions of the SITBI produce very similar estimates of SITB status and frequency (see Franklin, Puzia, et al., 2014). We used the SITBI to measure the following: self-cutting (defined as number of times someone has cut themselves); overall NSSI (i.e., moderate NSSI behaviors: self-cutting, burning, hitting, inserting objects under the skin, and scraping; see Franklin, Lee, et al., 2014; Franklin, Puzia, et al., 2014); suicide ideation (defined as number of days during which ideation occurred); suicide plans (defined as number of days during which plans occurred); and suicidal behaviors (defined as the number of nonfatal attempts, interrupted attempts, and aborted attempts).

We additionally used the SITBI to measure self-prediction of the likelihood of future NSSI (1 to 5 scale; 1 = definitely not, 5 = definitely) and desire to stop engaging in NSSI (1 to 5 scale; 1 = no desire, 5 = extreme desire). Finally, we used the SITBI to measure demographic and psychiatric treatment history (i.e., both psychosocial and pharmacological). At baseline, the SITBI was used to assess thoughts and behaviors over one's lifetime, past year, past month, and past week. During the treatment month of the study, the SITBI was administered weekly and the timeframe was

past week; during the posttreatment month, the SITBI was administered monthly and the timeframe was past month.

Emotion Reactivity Scale (ERS; Nock, Wedig, Holmberg, & Hooley, 2008). The ERS is a single-factor 21-item self-report scale that measures emotion reactivity, a construct that includes emotional sensitivity, intensity, and persistence. It is strongly correlated with measures of emotion dysregulation, psychopathology, and SITBs (Franklin et al., 2013; Franklin, Lee, et al., 2014; 2014b; Nock, Wedig, et al., 2008), has been shown to mediate the association between psychopathology and self-injury (Nock, Wedig, et al., 2008), and demonstrated excellent reliability in the present series of studies (Cronbach's alphas = .93 to .95). We employed the ERS as a covariate in treatment analyses.

Brief Symptom Inventory (BSI; Derogatis, 2000). The BSI is an 18-item self-report measure of past week psychological distress that includes items pertaining to internalizing symptoms such as anxiety, depression, and panic. The BSI has demonstrated strong construct validity and displayed excellent reliability in the present series of studies (Cronbach's alphas = .88 to .92). As with the ERS, we included the BSI as a covariate in treatment analyses.

Index of Dysregulated Behaviors (IDB). We created the IDB for the present study. It is an 18-item self-report measure of engagement in a wide-range of dysregulated behaviors over the

past month. Behaviors assessed include alcohol abuse, drug abuse, reckless driving, binge eating, purging behaviors, food restriction, abusive relationships, shoplifting/stealing, anger outbursts (e.g., provoking fights, breaking things, setting things on fire), unsafe/reckless sexual behavior, and gambling (beyond small bets). We included this measure to test the possibility that reduction in one dysregulated behavior (i.e., NSSI) would be compensated for by increases in other dysregulated behaviors (e.g., alcohol use, reckless behaviors).

Treatment targets: Implicit aversion to NSSI, death/suicide, and the self. We measured implicit affect with a brief computer-based task called the Affect Misattribution Procedure (AMP; Payne & Lundberg, 2014; see Supplemental Materials for more information). The present series of studies operationalized treatment targets as AMP scores for stimulus categories related to NSSI (Studies 1 and 2), death/suicide (Study 3), and self-related words (all three studies).

Procedure. All procedures were approved by the Institutional Review Board of Harvard University.

Recruitment. Similar to other recent self-injury studies (e.g., Lewis & Michal, 2015), participants were recruited from online web forums ($n = 12$) that focused on discussions of self-injury and related phenomena. Advertisements did not explicitly describe the study as a treatment study. The informed consent form made clear the treatment-related aspects of the study, but did not provide details about TEC that would have allowed participants to discern whether or not they were in the active or control group. This procedure was designed to reduce placebo effects and to more effectively target our intended population—the large number of individuals who engage in SITBs but do not actively seek treatment.

The web-based recruitment strategy provided several advantages. First, it improved speed of recruitment, ease of contact, comfort disclosing psychological and behavioral problems, attention to study instructions, geographic diversity, and number of potential participants (e.g., Casler et al., 2013; Hauser & Schwarz, 2015). On balance, however, online recruitment presents unique challenges that have the potential to threaten the quality of research (e.g., bots, study comprehension assurance). Over the past decade researchers have developed several innovative recruitment procedures and protocols to overcome these challenges (e.g., Bull et al., 2008; Ip et al., 2010). In part because of these procedures, several recent studies have found that online and in-person recruitment procedures produce nearly identical results across a wide range of tasks and populations (Casler et al., 2013; Crump et al., 2013; Hauser & Schwarz, 2015).

Second, instead of confining recruitment to a specific hospital or city, this recruitment strategy allowed us to recruit from our primary population of interest—the worldwide SITB population with an Internet connection. In particular, we were most interested in individuals with highly frequent SITBs who were not currently benefiting from traditional treatments. Third, it ensured that participants were regular Internet users. As TEC is web-based, this improved the odds that participants would regularly access TEC and complete follow-up assessments. Fourth, the large pool of potential participants made it possible to select for individuals with recent and frequent NSSI. Using traditional methods, it is difficult to recruit a large number of such participants. Fifth, compared with

local community recruitment methods, it provided greater confidence in the validity of Participant SITB status.

Building on best practice recommendations for online recruitment (e.g., Bull et al., 2008; Ip et al., 2010), we employed a five step recruitment process (see Supplemental Method for a detailed description).

Design, participation, and compensation. Assessments occurred at baseline, weekly during the treatment month, and at the end of the posttreatment month. All individuals participated anonymously. Participants were asked to provide an email address that did not include identifiable information. Through this e-mail address, participants received automatic e-mails with links to follow-up surveys and were compensated via electronic Amazon gift cards. Participants were compensated \$10 for baseline assessments, \$5 for each weekly assessment during the treatment month, and \$20 for the posttreatment month assessment. Additionally, participants were compensated based on their TEC performance: one cent for each TEC point, up to \$50 (5,000 points; the average participant would need to play TEC ~90 times to accrue this many points). The six participants with the highest point totals (who also completed each study assessment point) were compensated an additional \$100.

Implementation of TEC. Participants were allowed to access TEC as often as they desired over the course of one month (i.e., the “treatment month”). We employed this ‘open dosage’ design for two reasons. First, we wanted TEC use in the present study to approximate real world usage. As such, we did not want to artificially constrict the frequency or timing of usage. Second, because TEC is a new intervention, it was unclear which TEC dosage level would be effective. It is possible that a single dose (i.e., playing TEC once) may be sufficient to reduce SITBs, but it is also possible that SITB reductions would require hundreds of TEC doses. The open design of the present study allowed us to explore these patterns to establish an empirical basis for dosage guidelines in future studies.

Each participant was given a unique ID number for the TEC app. This app was linked to a relational database that automatically stored TEC performance information including the number of points, total correct and wrong matches, total time, and date for a given instance of TEC.

Data analytic plan.

Retention rates and missing data. We calculated retention rates across each week during the treatment month and at the end of the posttreatment month. We note here that there were no significant group differences for retention rates across studies. To determine the representativeness of nonmissing data, we conducted Little’s Missing Completely at Random (MCAR) test (see each Results section for a detailed description of missingness). This test was nonsignificant in all three of the present studies (all $ps = .99$), suggesting that data were missing completely at random. Although this indicated that effect estimates based on nonmissing data were likely accurate and unbiased, we analyzed imputed data to provide additional assurance that these estimates were accurate. Imputation methods and results are described in Supplemental Method and Table S1; nonimputed results are presented in the present paper, but we note here that imputed analyses produced nearly identical results.

Outcomes. Outcomes were SITBs, including self-cutting frequency, overall NSSI frequency (including self-cutting behaviors),

days of suicide ideation, days of suicide plans, and suicidal behavior frequency. Suicidal behaviors included suicide attempts, interrupted suicide attempts, and aborted suicide attempts. Self-cutting was examined separately from other NSSI behaviors because it is the most common form of NSSI, it is an unambiguously severe form of NSSI, our inclusion criteria specified self-cutting, and the present version of TEC primarily targeted self-cutting. Because of the low frequency of suicidal behaviors, we report these behaviors for each study but analyze them across all studies after all other analyses.

Additional outcomes were changes in implicit affect toward NSSI- and self-related stimuli, and changes in non-SITB dysregulated behaviors. These outcomes were calculated as the difference between baseline and treatment month scores.

Statistical models. SITBs are count variables that tend to produce positively skewed distributions and an excess of zeros. SITBs accordingly violate the assumptions of statistical techniques based on a normal distributions. Fortunately, there are two common statistical models based on the distributions that SITBs tend to approximate: zero-inflated Poisson (ZIP) regression and zero-inflated negative binomial (ZINB) regression. These two models are similar to one another except that ZINB includes an extra parameter that accounts for overdispersion unrelated to excess zeros (i.e., zeros that the model predicts have a 1.0 probability of being a zero). In the present series of studies, for SITB outcomes we only employed ZIP models when ZINB models indicated

nonsignificant overdispersion. We note here that both models always provided very similar results in terms of significance and effect magnitude. Both models produce incident rate ratios (IRRs), which provide the ratio of the frequency of a given behavior in the active group compared to the control group. These models are described in more detail in Supplemental Method.

Overview of treatment-related analyses. Given that TEC use was self-selected, we were primarily interested in overall group effects (i.e., effects where individuals were included in the active/control TEC group analyses regardless of whether or how much they accessed TEC). These tests resemble intention-to-treat tests, but differ from such tests in that they do not include individuals who did not participate at certain time point (true intention-to-treat analyses with imputed data are provided in Table S1). We note here that there were no significant group differences in app usage participation across studies. All dosage analyses (i.e., analyses based on active TEC points) and posttreatment month analyses were exploratory.

Group effects for treatment month. We tested whether group (active vs. control) significantly predicted SITBs during the treatment month. Because of the trade-offs of our open design (e.g., self-selection of frequency and timing of usage, exploratory dosage hypotheses) and the high volatility of SITBs from week-to-week, we primarily focused on the month-based group treatment analyses in the present series of studies. Monthly SITB frequencies were calculated as the sum of SITB frequencies during each week

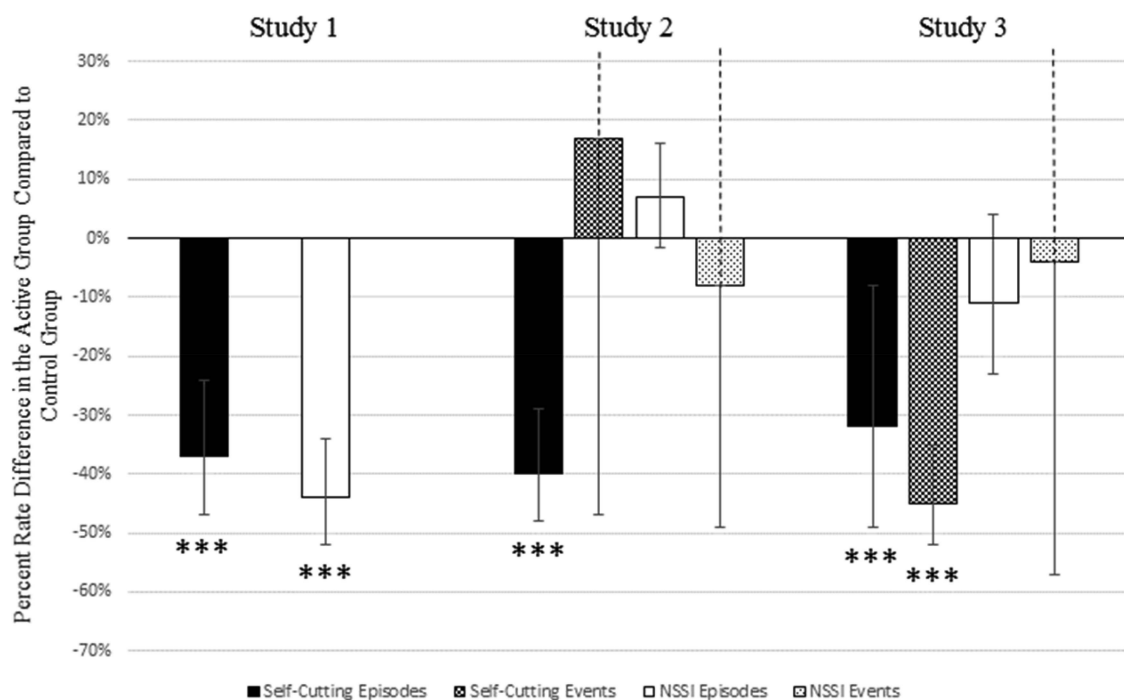


Figure 2. Effect of active TEC on NSSI-related outcomes. All comparisons controlled for several powerful covariates (see Supplemental Tables S2–S4); without these covariates, treatment effects tended to be stronger and there were significant treatment effects on overall NSSI outcomes in Study 3 (see Supplemental Table S1). Error bars = 95% confidence intervals. The upper-bound for the confidence intervals for self-cutting events in Study 2 and NSSI events from Studies 2 and 3 extend beyond the viewable area for the present graph (see Supplemental Tables S2–S4 for more information). Self-cutting events and NSSI events were not measured in Study 1. *** $p < .001$.

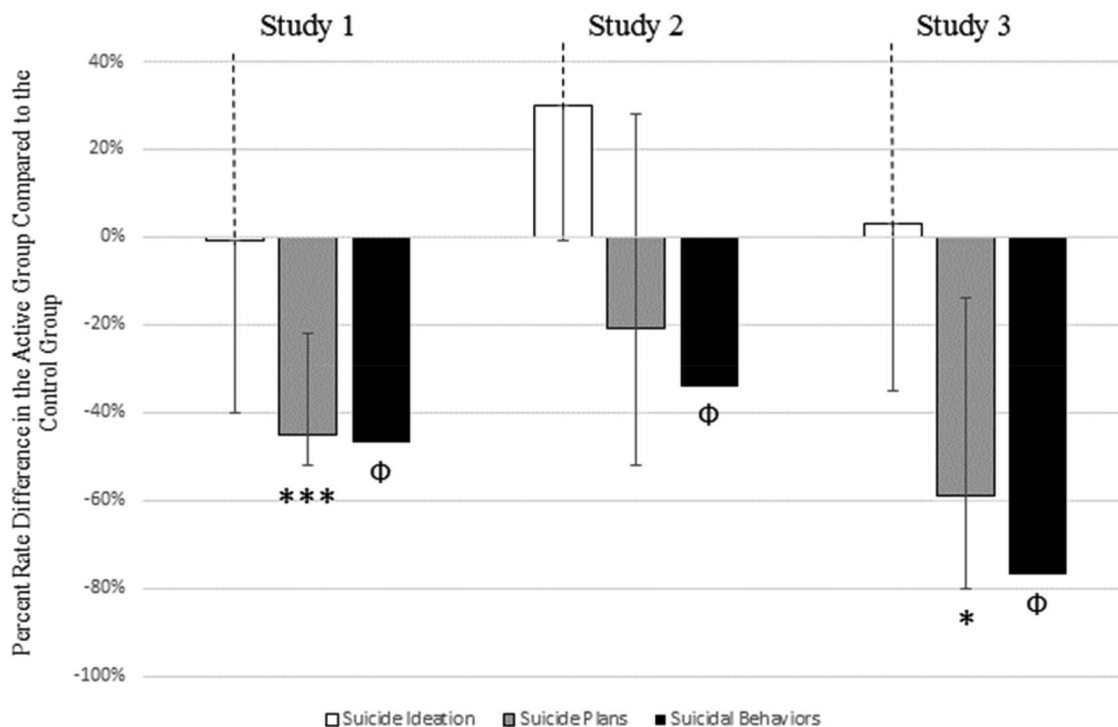


Figure 3. Effect of active TEC on suicide-related outcomes. All comparisons controlled for several covariates (see Supplemental Tables S2–S4). Error bars = 95% confidence intervals. The upper-bound for the confidence intervals for suicide ideation outcomes extend beyond the viewable area for the present graph (see Supplemental Tables S2–S4 for more information). Φ = no statistical tests were performed within individual studies for suicidal behavior outcomes; these were examined in aggregate within the text and the overall treatment effect was statistically significant. * $p < .05$; *** $p < .001$.

of the treatment month. Participants needed to complete each weekly follow-up to allow for calculation of this monthly variable.

We conducted two levels of analyses for SITB outcomes. First, we examined the effect of group on the outcome while including the relevant baseline month SITB as a covariate (e.g., if suicide ideation was the outcome, past month suicide ideation assessed at baseline was included as a covariate). Second, we examined the effect of group on the outcome while including the relevant baseline month SITB, ERS score, BSI score, baseline month treatment status, and baseline self-prediction and desire to stop NSSI (for self-cutting and NSSI analyses) as covariates. Only the latter analyses are presented, but unless otherwise noted in the results section, lower-order analyses produced nearly identical results in terms of significance. For ease of interpretation, group effects for the treatment month are presented in Figures 2 and 3; detailed analyses of group and covariate effects are included in Tables S2 through S4.

We also examined the effect of group on changes in IDB scores and treatment targets (i.e., implicit affect toward NSSI images and self-related words). We then tested whether these latter two difference scores were associated with SITBs during the treatment month. These latter analyses included the relevant baseline SITB as a covariate.

Active TEC dosage effect analyses. To explore potential dosage effects of active TEC, we calculated the proportion of participants who activated the active TEC app and how many points they

scored. Because points were so positively skewed (with a range of nearly 20,000), we transformed points into three general active TEC dosage categories. First, participants were placed in the no dose group if they either (a) were assigned to the control group and thus never had the opportunity to open the active TEC app or (b) were assigned to the active group but never opened the app. Second participants were placed in the low dose group if they scored between 0.1 and 1,999 points in the active TEC app. Third, participants were placed in the high dose group if they scored 2,000 or more points in the active TEC app. Results were similar when more fine-grained class intervals were used (e.g., 4, 5, or 6 class intervals). Including the relevant baseline month SITB as a covariate, we explored the effect of dosage on SITBs. We note here that there were no significant dosage effects for control TEC points in any study (all $ps > .05$); all presented dosage analyses refer to the dosage of active TEC.

Posttreatment month analyses. To explore whether any treatment effects persisted after TEC access ended, we examined the effect of group on SITBs during the posttreatment month while including the relevant baseline month SITB as a covariate. For comparability, only participants included in treatment month analyses were included in posttreatment month analyses.

Suicidal behavior analyses. Given the low base rates of suicidal behaviors over short intervals, we calculated suicidal behaviors over the course of both months of each study and conducted analyses on combined behaviors from all three studies (descriptive

statistics for specific types of suicidal behaviors across studies and groups is provided in Supplemental Table S6). Outcomes included the number of individuals per group reporting any suicidal behaviors and the number of suicidal behaviors per group. We analyzed group treatment effects as well as dosage group effects. Given the relatively low frequency of suicidal behaviors, participants were placed into one of two dosage groups: no active TEC dose (0 points), and any active TEC dose (.1 or more points).

Results

Descriptive statistics.

Retention rates for follow-up assessments. Retention rates gradually dropped from weeks one to four (81.57%, 67.54%, 64.91%, and 60.52%, respectively), with 86.49% of participants completing at least one follow-up during the treatment month and 52.25% of participants completing all follow-ups. Compared with the control group (42.37%), a higher proportion of the active group completed all treatment month follow-up assessments (60.00%). However, nearly identical proportions of each group completed at least one follow-up assessment during the treatment month (control group: 86.44%; active group: 87.27%). A total of 69.29% of participants completed the posttreatment month follow-up, with similar completion rates across groups (control group: 64.41%; active group: 74.54%).

Treatment participation. Most participants accessed their assigned version of the TEC app at least once (70.15%), with similar proportions across groups (control group: 67.79%; active group: 73.36%). There were no significant group differences in TEC points ($p = .45$), as both the control group ($M = 1,311.99$ points; $SD = 2,764.54$ points; $Mdn = 161.85$ points; $Range = 19,181.90$ points) and active group ($M = 1,514.53$ points; $SD = 2,742.78$ points; $Mdn = 270.2$ points; $Range = 14,889.30$ points) displayed similar point distributions. In terms of active TEC dosage, 72 participants received no dose (i.e., assigned to control TEC or assigned to active TEC but did not open the app), 29 received a low dose (.1 to 1,999 points), and 13 received a high dose (2,000 + points). As shown in Supplemental Figure S4, TEC usage was highest during the first week, dropped during the second week and slowly began to increase thereafter.

Treatment analyses.

Self-cutting. During the treatment month, the active group reported significantly fewer self-cutting episodes (i.e., count regression portion of the model; see Figure 2) and self-cutting frequency decreased significantly as active TEC dosage increased ($B = -.38$, $SE = .07$, $IRR = .68$, $p < .001$). The effect of active TEC did not extend into the posttreatment month ($p = .50$).

Overall NSSI. The active group reported significantly fewer overall NSSI behaviors during the treatment month (see Figure 2), with overall NSSI behaviors significantly decreasing as active TEC dose increased ($B = -.44$, $SE = .06$, $IRR = .64$, $p < .001$). This effect did not reach significance during the posttreatment month ($p = .16$).

Suicide ideation. Groups did not differ significantly on suicide ideation during the treatment month (see Figure 3) or posttreatment month ($p = .17$), and the dosage effect was not significant during the treatment month ($p = .08$).

Suicide plans. As shown in Figure 3, the active group reported significantly fewer suicide plans during the treatment month. As

with self-cutting and NSSI behaviors, there was a significant active TEC dosage effect on suicide plans ($B = -.40$, $SE = .17$, $IRR = .67$, $p = .02$). The active group continued to report significantly fewer suicide plans during the posttreatment month ($B = -.59$, $SE = .23$, $IRR = .55$, $p = .01$).

Suicidal behaviors. A total of nine participants reported at least one suicidal behavior; five in the active group (producing 10 behaviors) and four in the control group (producing 19 behaviors). Among participants who accessed the active TEC app at least once, three reported at least one suicidal behavior (producing five behaviors). Among participants who never accessed the TEC app, six reported suicidal behaviors (producing 24 behaviors).

Non-SITB dysregulated behaviors. There was no effect of group on non-SITB dysregulated behaviors during the treatment month ($p = .42$).

Treatment targets. Analyses showed that, compared with the control group ($M = .09$, $SD = .22$), the active group ($M = -.04$, $SD = .21$) displayed a significantly greater increase in aversion toward NSSI stimuli during the treatment month, $t(49) = 1.71$, $p = .04$, $d = .60$ (note: positive change scores diminished aversion toward stimuli, negative scores indicate increased aversion toward stimuli). Diminished aversion to NSSI stimuli during the treatment month (i.e., the inverse of the present treatment target effect on NSSI) was significantly associated with greater NSSI ($B = 1.12$, $SE = .16$, $IRR = 3.06$, $p < .001$), suicide ideation ($B = .48$, $SE = .19$, $IRR = 1.62$, $p = .02$), and suicide plans ($B = .68$, $SE = .32$, $IRR = 1.97$, $p = .04$). There was no significant effect for self-cutting. These treatment target findings showed that TEC increased aversion to NSSI stimuli and that increased aversion was associated with decreased in NSSI, suicide ideation, and suicide plans.

The active group ($M = -.05$, $SD = .27$) showed a significantly smaller drop in positive affect toward self-related words compared to the control group ($M = -.17$, $SD = .24$), $t(49) = -1.77$, $p = .04$, $d = .47$. Diminished aversion toward the self (i.e., the present treatment target effect for self) was associated with less self-cutting ($B = -2.49$, $SE = 1.10$, $IRR = .08$, $p = .02$), NSSI ($B = -.77$, $SE = .17$, $IRR = .46$, $p < .001$), suicide ideation ($B = -1.02$, $SE = .20$, $IRR = .36$, $p < .001$), and suicide plans ($B = -.92$, $SE = .36$, $IRR = .40$, $p = .01$). These results also indicated that TEC diminished aversion to self-related words and that this was associated with reductions in self-cutting, NSSI, suicide ideation, and suicide plans.

Discussion

Results indicated that active TEC had a positive impact on most SITBs. We hypothesized that active TEC would produce reductions in self-cutting and overall NSSI, but expected much milder effects on other SITBs and limited evidence of dosage and posttreatment month effects. Findings exceeded these expectations as, compared with the control version of TEC, the active version of TEC significantly reduced self-cutting (37% reduction), overall NSSI (43% reduction), and suicide plans (45% reduction), even after for including several powerful covariates. There were also fewer suicidal behaviors in the active group, especially among those who played active TEC at least once (see below for suicidal behavior analyses/discussion across all three studies).

Exploratory analyses revealed that treatment effects for some SITBs became more powerful as active TEC dosage increased. Notably, even individuals who received a high dosage of active TEC (i.e., 2,000 points or more) played TEC for less than an hour total during the treatment month. This suggests that relatively infrequent use of TEC (e.g., once per day, 15 min per week) may be effective. However, few treatment effects remained significant during the posttreatment month, indicating that persistent TEC effects may require consistent TEC use. As hypothesized, TEC appeared to impact its intended treatment targets—particularly aversion toward NSSI stimuli, and greater changes in these treatment targets were associated with greater reductions in SITBs. Contrary to findings for other SITBs, there was no effect of active TEC on suicide ideation, suggesting that TEC may primarily impact more active/behaviorally focused SITBs. Taken together, these findings suggest that TEC may generate moderate reductions in SITBs in a short amount of time.

The present findings are promising, but we emphasize that they should be interpreted with caution. In addition to several general limitations of the present series of studies (see General Discussion below), it should be kept in mind that many individual studies often either overestimate effects or cannot be replicated (e.g., Ioannidis, 2005). It is especially difficult to replicate findings of studies with small samples and highly variable outcomes (e.g., SITBs). Although the present findings were consistent with our preliminary work (Franklin, 2014; Hooley & Germain, 2014) and hypotheses, we attempted to replicate these findings to obtain a more accurate estimate of the true effects of TEC.

Study 2

We designed Study 2 to be a close replication of Study 1, with a few minor modifications. First, we altered the unpleasant stimuli in the active version of TEC to make them more disgusting and fear-inducing. We hypothesized that this change would increase the potency of TEC by more powerfully conditioning negative associations with SITB-related stimuli. Second, consistent with evidence that most replication studies are underpowered (McShane & Bockenholt, 2014), we recruited slightly more participants. Third, to retain more participants for treatment month effects, we included past month SITB questions in the week four follow-up assessment. Fourth, we enacted procedures designed to encourage increased retention rates (e.g., compensating participants immediately after assessment completions via Amazon.com). Fifth, we distinguished between self-cutting/NSSI episodes and events. These alterations are described in more detail below. Study 2 hypotheses were identical to those of Study 1.

Method

Aside from the aforementioned changes and the minor details noted below, the measures, procedures, and data analytic plan were identical to Study 1.

Participants. Participants were 131 individuals (74.05% female) recruited from online web forums primarily devoted to the discussion of topics related to self-injury or psychopathology. We recruited from a total of nine forums (out of nine forums that we requested to post advertisements on). Inclusion criteria were the same as for Study 1, except that individuals were ineligible to

participate if they had participated in Study 1. Participants were made aware of this criterion in study postings on forums and we additionally excluded anyone with email addresses or Internet Protocol addresses that were duplicates from Study 1 ($n = 0$). The majority of participants were young adults ($M = 22.91$ years old; $SD = 4.99$) and the majority identified as Caucasian (83.21%), with the remaining identifying as Asian (5.34%), Hispanic (3.82%), Native American (1.53%), or Other (6.12%). Most participants were living in the United States ($n = 107$), with other participants living in Canada ($n = 1$), Europe ($n = 19$), Asia ($n = 1$), Africa ($n = 1$), and Australia ($n = 2$). As in Study 1, most participants reported a history of psychiatric treatment (lifetime: 81.68%; past month: 46.56%), many reported a history of inpatient treatment (lifetime: 29.77%; past month: 3.05%), and nearly half were currently on psychiatric medication (45.80%). Participants were randomly assigned to either the control group ($n = 69$) or the active group ($n = 62$). There were no significant demographic or treatment history differences between the groups (all $ps > .05$). There were no significant group differences on SITBs or covariates, with the exception of significantly higher suicide ideation in the active group ($B = .18$, $SE = .05$, $p < .001$; see Table 1).

Stimuli. Study 1 included a broad range of unpleasant stimuli within the active version of TEC (and the AMP). In an effort to increase the potency of TEC, in the present study we only included unpleasant stimuli that were disgusting (e.g., infected toenails) or fear-inducing (e.g., close up of cluster of spiders). These images were a combination of IAPS pictures and Creative Commons Zero pictures from the Internet.

Data analytic plan. The data analytic plan was similar to that of Study 1, with two exceptions. First, we distinguished between self-cutting/NSSI *episodes* (i.e., discrete periods when someone self-injurers; this could include a single cut to the skin or hundreds of cuts to the skin) and self-cutting/NSSI *events* (i.e., individual instances of actual or attempted tissue damage during an episode). After Study 1, we realized that some participants may interpret questions about self-cutting/NSSI frequency to refer to episodes whereas others may have interpreted these questions as referring to events. In SITBs for Studies 2 and 3, we separately defined and assessed episodes and events, thereby adding two additional SITB outcomes. As shown in Table 1, there were marked differences in the frequency of self-cutting/NSSI episodes and events, with events being 4 to 5 times more frequent. Second, we assessed past month SITBs at the week four follow-up to increase the number of participants that could be included in treatment month analyses.

Results

Descriptive statistics.

Retention rates. Retention rates were improved from Study 1, with smaller drops in retention from weeks one to four (84.73%, 82.44%, 74.81%, and 73.38%, respectively), 90.84% of participants completing at least one follow-up during the treatment month, and 64.89% of participants completing all follow-ups. Unlike Study 1, all participants who completed the week four follow-up were able to be included in treatment month analyses ($n = 96$), with very similar completion rates across groups (control group = 75.36%; active group = 70.97%). A total of 71.75% of participants completed the posttreatment month follow-up assessment (control group = 75.36%; active group = 67.74%).

Treatment participation. Compared with Study 1, a greater proportion of participants accessed the TEC app (90.84%), with high access rates in both groups (control group = 92.75%; active group = 88.71%). There were no significant group differences in points ($p = .33$), but the control group ($M = 1,737.99$, $SD = 2,924.59$; $Mdn = 500$; $Range = 21,271.30$) averaged more points than the active group ($M = 1,482.92$, $SD = 2,088.06$; $Mdn = 546.55$; $Range = 8,881.00$). In terms of active TEC dosage, 76 participants received no dose, 39 received a low dose, and 16 received a high dose. Active TEC points were highest during the first week (though much lower than in Study 1), with points diminishing during the second week and leveling off thereafter (Figure S4).

Treatment analyses.

Self-cutting episodes. The active group reported significantly fewer self-cutting episodes during the treatment month (see Figure 2), and episodes dropped significantly as active TEC dose increased ($B = -.15$, $SE = .05$, $IRR = .86$, $p < .001$). However, this treatment effect did not persist during the posttreatment month ($p = .67$).

Self-cutting events. There was no effect of group (see Figure 2) or active TEC dosage ($p = .58$) on self-cutting events during the treatment month. Likewise, there was no group effect on self-cutting events during the posttreatment month ($p = .53$).

Overall NSSI episodes. During the treatment month, there was no effect of group (see Figure 2) or active TEC dosage ($p = .44$), and no group effect during the posttreatment month effects ($p = .59$).

Overall NSSI events. As with self-cutting events, there was no effect of group on overall NSSI events during the treatment month (see Figure 2) or posttreatment month ($p = .72$), and there were no dosage effects ($p = .87$).

Suicide ideation. There was no significant effect of group (see Figure 3) or dosage ($p = .95$) on suicide ideation during the treatment month. However, the active group reported significantly more days of suicide ideation during the posttreatment month ($B = .50$, $SE = .20$, $IRR = 1.65$, $p = .01$). It is important to note that the active group did not report an increase in suicide ideation relative to baseline. Both groups showed declines in ideation across the course of the study (see Table S5); the present results indicate that the active group's decline in ideation during the posttreatment month was less steep than that of the control group.

Suicide plans. There was no significant effect of group (see Figure 3) or dosage ($p = .75$) on suicide plans during the treatment month. Similar to suicide ideation analyses, however, the active group reported significantly more days of suicide plans during the posttreatment month ($B = .85$, $SE = .35$, $IRR = 2.34$, $p = .02$). As with suicide ideation, both groups displayed declines in suicide plans across the course of the study (see Table S5). The present analyses indicate that the active group's decline in suicide plans during the posttreatment month was less steep than that of the control group.

Suicidal behaviors. Four participants in the active group reported at least one suicidal behavior (producing 14 behaviors) whereas eight participants in the control group reported at least one behavior (producing 21 behaviors). Among participants who accessed the active TEC app at least once, three reported at least one suicidal behavior (producing eight behaviors); among participants

who never accessed the active TEC app, nine reported at least one behavior (producing 27 behaviors).

Non-SITB dysregulated behaviors. As in Study 1, there was no effect of group on non-SITB dysregulated behaviors during the treatment month ($p = .68$).

Treatment targets. Contrary to the findings of Study 1, there were no group effects on change in implicit affect toward NSSI stimuli ($p = .33$) or self-related words ($p = .47$), and change in implicit affect was not significantly associated with any SITB outcome ($ps > .05$).

Discussion

Study 2 partially replicated some of the findings from Study 1, but produced much weaker results overall. Similar to Study 1, the active group displayed significant reductions in self-cutting episodes (40% reduction) that increased as active TEC dosage increased. Also similar to Study 1, the active TEC group displayed fewer suicidal behaviors, with individuals who played the active TEC app at least once reporting 70% fewer suicidal behaviors compared to those who did not play the app. Contrary to hypotheses, there were no significant effects on self-cutting/NSSI events. This suggests that TEC may primarily impact the number discrete instances that someone decides to engage in self-injury (i.e., episodes) rather than the number of times someone attempts to damage their tissue across all episodes (i.e., events). Also contrary to hypotheses, the active group displayed significantly higher suicide ideation and plans compared to the control group during the posttreatment month. As noted above, however, both groups displayed reductions in suicide ideation and plans during the study (see Table S5); reductions in the active group were less steep than those of the control group. Finally, unlike Study 1, the present study did not detect a significant effect of TEC on its intended treatment targets.

There are many possible explanations for the reduced effects observed in Study 2. One possibility is that the changes to active TEC (i.e., more disgusting and fear-inducing images) altered the effects of active TEC. Another possibility is that the present control group was more engaged and motivated than the active group. However, the most likely explanation for these divergent effects is chance. Study effects are drawn from a distribution of potential effects. Across hundreds of studies, most effects will cluster near a mean, but by chance many effects will be substantially above or below this mean. This between-studies heterogeneity is likely to be especially common among small studies and highly variable outcomes (e.g., SITBs). With just two studies, it is unclear whether Study 1 provided overly optimistic effect estimates, Study 2 produced overly pessimistic effect estimates, or both. In part to address this question, we conducted a third study.

Study 3

Study 3 was an extension of Studies 1 and 2, with one major change: it was primarily suicide-focused. SITB-related targets in the active version of TEC were primarily suicide-related (rather than NSSI-related) and participants were recruited on the basis of suicidal behavior rather than NSSI. Hypotheses were the same as those from Studies 1 and 2, except that we expected stronger effects on suicide-related outcomes and milder effects on NSSI-related outcomes.

Method

Participants. Participants were 163 individuals (58.89% female) recruited from online web forums that focused on topics related to suicide and psychopathology. We recruited from a total of nine forums (27 were contacted, 14 did not reply, four said no). Inclusion criteria were similar to Studies 1 and 2, except that participants were required to report at least one suicidal behavior within the past year and were not eligible to participate if they had participated in either of the prior studies ($n = 0$). Most participants were young adults ($M = 24.50$ years, $SD = 6.61$) and most self-identified as Caucasian (82.21%), with the remaining identifying as Hispanic (6.13%), Asian (4.91%), Black/African American (1.84%), Native American (1.23%), or Other (3.68%). The majority of participants were living in the United States ($n = 138$), with others living in Canada ($n = 7$), Europe ($n = 14$), Asia ($n = 3$), and South America ($n = 1$).

Similar to Studies 1 and 2, most participants had a history of psychiatric treatment (lifetime: 71.78%; past month: 40.49%), many reported a history of inpatient treatment (lifetime: 32.51%; past month: 1.80%) and nearly half were currently taking psychiatric medication (42.94%). Participants were randomly assigned to either the control group ($n = 85$) or active group ($n = 78$). There were no significant group differences on any demographic or treatment history variables, with the exception of age, $F(1, 161) = 4.70$, $p = .03$. The control group ($M = 25.61$, $SD = 7.26$) was slightly older than the active group ($M = 23.42$, $SD = 5.40$), and we note here that this factor did not alter the magnitude or significance of analyses when entered as a covariate. There were no group differences for any baseline SITB or covariate (see Table 1).

Stimuli. Non-SITB stimuli were the same as those from Study 2. Rather than SITB stimuli depicting only NSSI, the present study included SITB stimuli related to pill overdose ($n = 4$), hanging ($n = 2$), jumping from heights ($n = 2$), pointing a gun at one's own head ($n = 2$), self-cutting ($n = 2$), skulls/bones ($n = 2$), and the words "death" and "suicide." All stimuli were either created by our group (words and self-cutting pictures), taken from the IAPS, or Creative Commons Zero images from the Internet.

Design. The design of the present study was similar to that of Studies 1 and 2, except that participants were allowed continued access to (and compensation for) TEC during the second month of the study. This allowed us to explore whether (or to what degree) TEC use patterns declined over a longer period of time and what effect this might have on SITBs. To maximize comparability with prior studies, the data analytic plan remained the same, with analyses primarily concentrated on the first month of the study.

Results

Descriptive statistics.

Retention rates for follow-up assessments. Retention rates for Study 3 were comparable with those of Study 2, with rates gradually diminishing from weeks one to four (81%, 79.1%, 71.8%, and 67.5%, respectively). A total of 84.47% of participants had data for at least one follow-up during the first month, and 60.87% had data on all month one follow-ups for all assessments. A total of 55.21% of the sample completed the month two follow-up. As with Study 2, the present month one SITB-based analyses are based on month-based estimates of SITBs assessed during the

week four follow-up (control group: 68.24%; active group: 65.38%).

Treatment participation. TEC usage was between that of Studies 1 and 2, with 78.53% of participants accessing the TEC app at least once during the first month (control group: 78.82%; active group: 78.20%). There were no significant group differences in TEC points during the first month ($p = .35$), though the active group ($M = 1,434.85$, $SD = 3,081.06$; $Mdn = 273.65$; $Range = 21,841$) scored more points than the control group ($M = 1,054.73$; $SD = 1,867.07$; $Mdn = 165.20$; $Range = 7,882.90$). As in the two prior studies, TEC points were highest during the first week. Thereafter, TEC points remained relatively high during the second week and diminished across weeks three and four (Figure S4).

TEC usage fell sharply during the second month, with only 36.02% of participants accessing the app. Both the active group, $t(72) = 4.27$, $p < .001$, and the control group, $t(82) = 3.94$, $p < .001$, showed significant reductions in points from month one to month two. Both groups showed similar low levels of play (active: $M = 488.48$, $SD = 2,277.84$, $Mdn = 0$, $Range = 19,047$; control: $M = 355.84$, $SD = 1,340.04$, $Mdn = 0$, $Range = 11,431$), with the majority of participants receiving zero points.

Treatment analyses.

Self-cutting episodes. The active group reported significantly fewer self-cutting episodes during the first month (see Figure 2), but there was no dosage effect ($p = .22$). The treatment effect did not persist into the second month ($p = .37$).

Self-cutting events. Analyses indicated significantly fewer self-cutting events in the active group during the first month (see Figure 2) and this effect persisted into the second month ($B = -.66$, $SE = .15$, $IRR = .52$, $p < .001$); however, there was no evidence of a dosage effect ($p = .20$).

Overall NSSI episodes. Analyses that only controlled for prior month NSSI episodes (vs. the full range of covariates) revealed that the active group reported significantly fewer overall NSSI episodes during the first month (see Table S1). However, this effect was no longer significant when the full range of covariates were included (see Figure 2; Table S2). There was no effect of group on overall NSSI episodes during second month ($p = .38$), and there was no evidence of a dosage effect ($p = .65$).

Overall NSSI events. As with NSSI events, analyses that only controlled for prior month NSSI events showed that the active group displayed significantly fewer NSSI events during the first month (see Table S1). But analyses including the full range of covariates found that there was no effect of group on overall NSSI events in the first (see Figure 2) or second month ($p = .58$), and there was no dosage effect ($p = .98$).

Suicide ideation. There was no effect of group (see Figure 3) or dosage ($p = .43$) on suicide ideation during the first month, and no effect of group during the second month ($p = .12$).

Suicide plans. Analyses indicated a significant reduction in suicide plans for the active group during the first month (see Figure 3), but tests were nonsignificant for a dosage effect during the first month ($p = .09$) and a group effect during the second month ($p = .07$).

Suicidal behaviors. Three participants in the active group reported at least one suicidal behavior (producing five behaviors); five participants in the control group reported at least one behavior (producing 22 behaviors). Among participants who accessed the

active TEC app, two reported at least one behavior (producing four behaviors); among participants who never accessed the TEC app, six reported at least one behavior (producing 23 behaviors).

Non-SITB dysregulated behaviors. As in both previous studies, there was no effect of group on IDB scores ($p = .74$).

Treatment targets. Similar to Study 1, the active group ($M = -.07$, $SD = .19$) showed a significantly larger increase in implicit aversion to SITB stimuli compared with the control group ($M = .03$, $SD = .21$), $t(79) = 2.22$, $p = .02$, $d = .50$ (note: positive change scores indicate diminished aversion toward stimuli, negative scores indicate increased aversion toward stimuli). Diminished aversion to SITB stimuli (i.e., the inverse of the present treatment target effect) significantly predicted more self-cutting episodes ($B = 2.86$, $SE = .79$, $IRR = 17.46$, $p < .001$) and NSSI episodes ($B = 1.83$, $SE = .19$, $IRR = 6.23$, $p < .001$). These findings indicate that TEC increased aversion to NSSI stimuli and that this increased aversion was associated with reduced self-cutting and NSSI episodes. However, compared with the control group, the active group did not display a significant increase in positive implicit affect toward self-related words ($p = .20$).

Discussion

Study 3 extended the general TEC findings of Studies 1 and 2. The overall pattern and magnitude of effects were in between those of Studies 1 and 2, suggesting that these prior studies may have respectively provided optimistic and pessimistic estimates of TEC effects on SITBs. The active group displayed significant reductions for most SITB outcomes except suicide ideation (see Tables S1 and S4, Figure 2), and NSSI effects were no longer significant when accounting for the full range of covariates (see Table S1, Figure 2). There was some evidence of a dosage effect, but very little evidence that treatment effects extended beyond the first month. The present study extends prior TEC findings to a modified version of TEC (i.e., suicide-related stimuli) and a sample selected on the basis of prior suicidal behavior.

Suicidal Behavior Analyses Across All Three Studies

Although rates of suicidal behaviors were in the expected direction for each study, there were too few behaviors to conduct reliable analyses within each study (see Table S6 for information on specific suicidal behaviors). Accordingly, we collapsed suicidal behaviors across each study to provide a more reliable assessment of TEC on these behaviors. Given the low rate of behaviors, however, these analyses should be considered exploratory and preliminary.

Group treatment analyses. Combining data from all three studies, more individuals in the control groups reported at least one suicidal behavior ($n = 17$ of 135 participants) than in the active groups ($n = 12$ out of 130 participants), but this difference was not significant, $\chi^2(1) = .73$, $p = .19$. A significantly higher frequency of suicidal behaviors was reported in the control groups ($n = 62$ behaviors from 135 participants) compared with the active groups ($n = 29$ behaviors from 130 participants), $B = -.71$, $SE = .26$, $IRR = .49$, $p = .01$ (i.e., 51% reduction in the rate of suicidal behaviors); however, this effect was no longer significant after controlling for baseline month suicidal behaviors, $B = -.49$, $SE = .27$, $IRR = .61$, $p = .07$).

Dosage analyses. We conducted these same analyses after dividing participants into those who did and did not access active TEC at least once (i.e., any dose vs. no dose). Significantly fewer participants who received any dose of active TEC reported at least one suicidal behavior ($n = 8$ out of 117 participants) compared with those who received no dose ($n = 21$ out of 147 participants), $\chi^2(1) = 3.70$, $p = .02$. Similarly, compared with the no dose group ($n = 74$ behaviors from 147 participants), the any dose group reported significantly fewer suicidal behaviors ($n = 17$ behaviors from 117 participants), $B = -1.24$, $SE = .30$, $IRR = .29$, $p < .001$ (i.e., 71% reduction in suicidal behaviors after accounting for excess zeros). This effect held when controlling for baseline month suicidal behaviors ($B = -1.12$, $SE = .31$, $IRR = .33$, $p < .001$).

Although these effects are consistent with hypotheses and the effect of TEC on other SITBs, much larger studies are needed to provide a more reliable estimate of the effect of TEC on suicidal behaviors.

General Discussion

There is a need for SITB interventions that overcome the barriers to large-scale treatment. The present series of studies represent the initial steps toward the development of such an intervention. The results of Study 2 were relatively weak, but aggregated results across studies indicated that our brief, game-like app reduced self-cutting episodes, overall NSSI episodes, suicide plans, and suicidal behaviors. Notably, most of these reductions remained in the context of several powerful covariates—including prior month SITBs—that significantly predicted SITBs during the treatment month. Also of note, participants were not made aware of how TEC might work and qualitative debriefing interviews indicated that participants did not ascertain TEC's intended mechanisms of action. These findings suggest that TEC is a brief (i.e., 1–2 min), low effort, game-like intervention that stimulates moderate reductions in most SITBs in a short amount of time.

Although these findings are promising, several other findings make clear the need for improvements that can increase TEC potency, identify additional treatment targets, and increase user engagement. First, despite reductions in most SITBs, no study showed a significant treatment effect on suicide ideation. Second, even though group effects were reliable, there was mixed evidence that greater use of TEC was associated with greater SITB reductions. Third, treatment effects rarely persisted after TEC cessation (i.e., after month one of each study). Fourth, there was mixed evidence that TEC engaged its intended treatment targets, with TEC primarily impacting the diminished aversion to SITB stimuli target rather than the self-aversion target.

These latter results only partially support the hypothesized mechanisms of action for TEC, but they also highlight the promise of targeting a novel risk factor—the diminished aversion to SITB stimuli (or, capability for SITBs). The Benefits and Barriers Model of NSSI (Franklin, Lee, et al., 2014; Franklin, Puzia, et al., 2014) and the Interpersonal-Psychological Theory of Suicide (Joiner, 2005) both note this as a critical SITB ingredient. The present results suggest that the capability to enact nonsuicidal and suicidal self-injury is not an immutable trait; rather, it appears to be a malleable risk factor that reduces SITBs when appropriately targeted.

Along with limitations related to the present findings, several methodological limitations should be kept in mind when interpreting the results of the present study. First, all participants were recruited via online forums that focused on topics related to self-injury, suicide, and psychopathology. The present samples accordingly may have been biased in terms of desire and ability to engage in a web-based treatment. On balance, these samples were drawn from our major population of interest—the worldwide population of individuals with Internet access and a history of SITBs. Nevertheless, it would be helpful to replicate the present findings in large samples recruited from the community, local clinics, and inpatient units. Given the high concordance between in-person and Internet-based studies (e.g., Casler et al., 2013; Crump et al., 2013; Hauser & Schwarz, 2015) and the consistency of the present findings and with our in-person preliminary studies (Franklin, 2014; Hooley & Germain, 2014), we would expect similar findings across the two types of studies.

Second, an additional sampling-related limitation was that participants were primarily young adults. This is a very important population as all SITBs (with the exception of suicide death) are particularly common among this age group. However, it will be important to replicate the present findings in adolescents and older adults. This may require modifying stimuli to be appropriate for adolescents and modifying the nature of the intervention (i.e., app-based) to be more appropriate for elderly adults. Third, the present studies were large compared with most SITB treatment studies, but it would be helpful to replicate the present findings in a much larger sample (e.g., >10,000 participants). This would allow for more reliable estimates of TEC effects on very low base rate behaviors (e.g., specific types of suicide attempts) and provide sufficient power to examine moderators of TEC effectiveness.

Fourth, we paid participants to use TEC. It is unclear whether (or to what degree) participants would use TEC in the absence of such compensation. Given that the control group and active groups were both paid for TEC use and accessed their respective versions of TEC at similar rates, this payment issue is unlikely to account for the present treatment effects. Nevertheless, for feasibility purposes, studies are needed to test TEC use in the absence of monetary compensation and to determine which factors best predict TEC use. Fifth, across studies, 70% to 90% of participants opened the TEC app (whether active or control); these figures are encouraging but far from our ideal treatment engagement rate of 100%. To improve on this limitation, future versions of TEC must be modified in several ways to increase its potency, reinforcing qualities, and ability to impact SITBs on a large scale. For example, we are working on new versions that include a much higher number (and greater variety) of stimuli, greater variations in difficulty, integration of ecological momentary assessments that allow for personalization and optimization algorithms to tailor TEC to each individual across time, and a feature that automatically translates TEC into a wide range of languages.

Sixth, TEC use and dosage were self-selected. This self-directed use approximates how TEC might be used in the real world, but it also leaves open many questions about how assigned TEC dosage may affect SITBs and what the optimal dosage of TEC might be. Future studies would benefit from exploring these important questions. Seventh, the present study primarily examined TEC effects over the course of a single month and results indicated that the effects of TEC likely do not persist long after TEC cessation.

Furthermore, month two results from Study 3 suggest that TEC use may have to be fairly regular (e.g., at least once per week) to produce significant benefits. Future studies should evaluate whether improvements such as personalization algorithms and additional gamification elements generate more TEC use and more lasting TEC effects. Eighth, the active group displayed a less steep decline in suicide ideation and plans during the posttreatment month of Study 2. Given that similar patterns were not observed in Studies 1 or 3, these may be chance findings. However, it will be important for future studies to more thoroughly investigate the possibility of adverse TEC effects.

Ninth and finally, the present version of TEC was only designed to impact SITBs. Indeed, results indicated the TEC did not affect a range of other dysregulated behaviors. This suggests that the effects of TEC were specific and did not generate any compensatory dysregulated behaviors. Ideally, however, TEC would have a much broader impact. Given its design and underlying principles, TEC could be modified to target a wide range of psychological issues, especially those that can be clearly represented by specific images or words.

These significant limitations notwithstanding, the present series of studies indicates that TEC is a promising intervention for SITBs that has the potential overcome many of the traditional barriers to mass dissemination of treatment. With further testing and continued improvement, TEC may eventually extend beyond its present limitations and have the potential to generate large-scale reductions in SITBs and other psychopathological phenomena. Given its format, TEC could contribute to such reductions as either an add-on to existing treatments or as a low-cost, highly disseminable standalone intervention.

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