Predicting Self-Injurious Thoughts in Daily Life Using Ambulatory Assessment of State Cognition

Thanh P. Le[1], Emma Moscardini[1], Tovah Cowan[1], Brita Elvevåg[2,3], Terje B. Holmlund[3], Peter W. Foltz[4], Raymond P. Tucker[1], Elana K. Schwartz[1], Alex S. Cohen[1]

[1]Department of Psychology, Louisiana State University, USA

[2]Department of Clinical Medicine, University of Tromsø – the Arctic University of Norway, Norway

[3]The Norwegian Centre for eHealth Research, University Hospital of North Norway, Norway

[4]Institue of Cognitive Science, University of Colorado Boulder, USA

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* Send correspondence to

Thanh P. Le, M.A.

Department of Psychology

Louisiana State University

236 Audubon Hall

Baton Rouge, LA 70808

Email: tle87@lsu.edu

Abstract

Self-injurious thoughts (SITs) fluctuate considerably from moment to moment. As such, “static” and temporally stable predictors (e.g., demographic variables, prior history) are suboptimal in predicting imminent SITs. This concern is particularly true for “state” or “fluid” cognitive abilities, which are important for understanding SITs, but are typically measured using tests selected for temporal stability. Advances in ambulatory assessments (i.e., real-time assessment in a naturalistic environment) allow for measuring cognition with improved temporal resolution. The present study measured relationships between “state” cognitive performance, measured using an ambulatory-based Trail Making Test, and SITs. Self-reported state hope and social connectedness was also measured. Data were collected using a specially designed mobile application (administered 4x/week up to 28 days) in substance use inpatients (*N* = 99). Consistent with prior literature, social connectedness, but not hope, was significantly associated with state SITs. Importantly, poorer state cognitive performance also significantly predicted state SITs, independent of hallmark static and state self-reported risk variables. These findings highlight the potential importance of “state” cognition to predict SITs. Ambulatory recording reflects an efficient, sensitive, and ecological valid methodology for evaluating subjective and objectives predictors of imminent SITs.

Keywords: State cognition; self-injurious thoughts; ambulatory technology; prediction; digital phenotyping

Introduction

Self-injurious thoughts (SITs) encompass a broad range of non-suicidal self-injurious (NSSI) and suicidal ideations and are related to future self-harm behaviors such as suicide attempts (Castellví et al., 2017; Ribeiro et al., 2016). Accurately measuring and predicting SITs is potentially important for early identification and intervention of suicide risk. Past research has generally focused on demographic and historical predictors of SITs, such as age, sex, trauma history, and suicide attempt history (Chan et al., 2016; Fox et al., 2015; Haw, Hawton, Niedzwiedz, & Platt, 2013). However, these characteristics are immutable and present in many clinical populations, presenting an issue of non-specificity that contributes to a predictive ability of only slightly above chance (*see* Franklin et al., 2017 for meta-analysis). Moreover, these static characteristics provide limited information about imminent SITs, as they are temporally isolated from SITs in any given moment. To address these concerns, many have advocated for a shift toward identification of "temporally dynamic" predictors of SITs and episodes (Berrouiguet et al., 2018; Tucker et al., 2015). These are predictors that change over time and can more closely approximate SITs in a given moment (Kleiman et al., 2017). For example, self-reported internalizing symptoms, maladaptive cognitive thoughts (i.e., hopelessness), and social distress (e.g., perceived rejection and criticism) have been found to predict greater intensity of NSSI ideation and behaviors next day (Kranzler et al., 2018; Scala et al., 2018; Victor et al., 2018). Of note, Kleiman and colleagues (2017) found that perceived burdensomeness and thwarted belongingness along with hopelessness predicted concurrent suicidal thoughts using ambulatory assessment. Recent advances in ambulatory recording technologies allow for the measurement of a wide range of subjective (i.e., self-report) and objective "state" predictors (e.g., natural language processing, acoustic analysis, cardiac impedance; Cohen et al., 2019; Holmlund, Cheng, Foltz, Cohen, & Elvevåg, 2019; Sperry, Kwapil, Eddington, & Silvia, 2018). The present study extends past work using self-reported predictors of SITs to examine the influence of objectively and ambulatorily measured predictors of SITs in a large sample of inpatients with substance use disorders (SUDs), a population at higher risk for SITs (Yuodelis-Flores and Ries, 2015).

There is increasing evidence that cognitive dysfunctions in attention, processing speed, working memory, executive control and other "online" abilities are important for understanding temporally concomitant SITs (Cha et al., 2019; Jollant et al., 2011). Beyond biased processing (i.e., disengagement difficulties) on SITs-themed behavioral tasks and self-reports (i.e., Suicide Stroop Task; Cha et al., 2019; Moscardini, Aboussouan, Bryan, & Tucker, 2020), individuals with prior NSSI and suicide attempts exhibit a broad range of significantly poorer basic cognitive abilities (*see* Cha et al., 2019 for review). More specifically, deficits in basic cognitive abilities may make it difficult to disengage from SITs thereby accelerating the transition to self-injurious behaviors (Wenzel and Beck, 2008). These findings help inform cognitive models of suicide that emphasizes cognitive flexibility and importantly emotion regulation (Rudd, 2007; Wenzel & Beck, 2008). Indeed, the Fluid Vulnerability Theory postulates that fluctuations in risk occur as a result of complex interplay between cognitive processes and environmental, affective, and physiological variables (Rudd, 2007). To date, most research on associations between cognitive abilities and SITs have relied on cross-sectional behavioral tasks and self-report measures. Thus, the overall picture of everyday cognitive deficits as risk factors for imminent SITs remain underexplored.

While it is often assumed that cognitive abilities are relatively static, there is accumulating evidence that many abilities, particularly those reflecting "fluid" or "online" abilities, systematically vary within-individuals over relatively brief temporal epochs (e.g., 24-hour day) due to a variety of internal and environmental factors (Hultsch et al., 2008; Moore et al., 2017).

Temporal stability for measures tapping “fluid” cognitive abilities (i.e., the capacity to process and integrate information, act, and solve novel problems in the moment) is generally much lower than for measures related to “crystallized” cognitive abilities (Calamia et al., 2013; Stawski et al., 2010). More recently, state cognition – assessed via ambulatory assessments on smart phone platforms – has been correlated with laboratory cognitive task performance in older adults with HIV (Moore et al., 2020) and exhibited reliable differences between individuals with schizophrenia and controls (Liu et al., 2019). From a practical perspective, ambulatory cognitive measurement has shown acceptable psychometric properties (Chandler et al., 2019; Holmlund et al., 2019b) and provides a real-time, naturalistic, and repeatable method that may be more ecologically valid compared to traditional assessments completed in optimal contexts. Further, good adherence rates for measuring state cognition using ambulatory technologies have been reported in the literature (Moore et al., 2017).

To our knowledge, no studies have examined the role of “state” cognition with SITs using ambulatory technologies. The current study investigated links between state cognition (tapping an array of “fluid” cognitive abilities such as attention), via response time on a modified Trail Making Test, and momentary SITs using ambulatory recording technologies. Also included were traditional static (i.e., demographic) and state self-report measures (i.e., hope and social connectedness) given their links with state SITs based on prior literature (Beck et al., 1985; You et al., 2011). Of note, low hope (a related, but distinct construct from hopelessness; Huen, Ip, Ho, & Yip, 2015) has been linked with suicidal ideation (Davidson et al., 2009; Huen et al., 2015; Tucker et al., 2016). This study was explored in a sample of individuals with SUDs residing in an inpatient setting, a population shown to be particularly vulnerable to SITs (Yuodelis-Flores and Ries, 2015). More specifically, a recent meta-analysis (Poorolajal et al., 2016) highlighted the strong associations between SUDs and increased self-harm risk, and this risk is exacerbated for inpatients with SUDs (Gratz and Tull, 2010; James et al., 2012). It was hypothesized that poorer state cognition would predict state SITs above and beyond static and state subjective risk variables.

Methods

Participants

Male psychiatric inpatients (*N* = 99; see Table 1 for descriptive and demographic data) recruited from a community-based substance use treatment facility completed a series of tasks on a mobile application (the delta Mental Status Exam or *d*MSE; *see* Chandler et al., 2020; Cohen et al., 2019; Cowan et al., 2019; Holmlund et al., 2020; Le et al., 2018) three to four times per week for the duration of their inpatient residency (max = 28 days; average sessions per participant = 6.92). The *d*MSE includes a range of tasks (approximate 13 minutes to complete per session), including self-report, cognition, and speech (to procure acoustic and linguistic features), for examining and tracking sequalae of various psychopathological risks states. All patients met criteria for a substance use disorder per chart review and due to entry requirements to the substance use treatment facility. There was a high degree of co-morbidity in this sample. Approximately 44% also met criteria for an affective disorder, 12% met criteria for anxiety-spectrum disorder, 3% met criteria for post-traumatic stress disorder, and a further 3% met criteria for schizophrenia based on chart diagnoses. Patients were free from major medical or other neurological disorders that would be hinder compliance with the research protocol (per medical records and staff report). Participants were given a mobile device with the *d*MSE application pre-installed and received extensive instruction and technical support on usage. They were asked to find a quiet place to complete testing at a time and place of their choosing. All patients provided their written consent to participate in this study, which was approved by the local institutional review board. Participants were compensated $2.50 per session. All clinical investigations were conducted in accordance with the guidelines of the 2008 Declaration of Helsinki.

[Insert Table 1 here]

State Subjective Variables

All self-report measures consisted of probes that were presented with an analogue visual scale and audio instructions. All self-report items were asked at every session.

State Hope was assessed with a self-report sliding scale using the probe: "Are you hopeful?", with a visual analogue scale from "not hopeful" to "very hopeful" [range: 0–100].

State Social Connectedness was assessed with a self-report slider scale using the probe: "How close do you feel to family and friends?", with a visual analogue scale from "not close" to "very close" [range: 0–100].

State SITs were assessed with a self-report slider scale using the probe: "Do you feel like harming yourself?", with a visual analogue scale from "no self-harm thoughts" to "definite self-harm thoughts" [range: 0–100].

State Cognition

State cognition was measured using a modified Trail Making Test (TMT). Acceptable psychometric properties on cognitive tasks related to verbal memory and fluency using the same *d*MSE app on smart-phone platforms have been previously reported (Holmlund et al., 2020, 2019a). The traditional, paper-and-pencil TMT requires participants to draw lines to connect successively 25 numbered circles (A) or circles containing alternating numbers and letters (B). The traditional TMT (Reitan, 1958) is one of the most widely used clinical and research tool to assess a broad range of cognitive abilities including visual and simple attention, visuospatial abilities, speed of processing, cognitive flexibility, and executive control such as set-shifting and response inhibition (Sánchez-Cubillo et al., 2009). The modified TMT presented in this study comes in three versions. In each version, the participant uses their finger to connect consecutive dots. In Trails version 1, the dots are lettered, and the participant must connect from A to B to C and so on sequentially. In Trails version 2, the dots are numbered, and the participant must connect from 1 to 2 to 3 and so on successively. In Trails version 3, letters and numbers alternate, so the participant connects from 1 to A to 2 to B, and so forth. Average mean time (i.e., average time to complete one connection on the TMT in milliseconds) across three versions of the modified TMT (all administered at every session) was used in analyses due to the fact that a compositive score encompasses facets of "fluid" cognitive abilities. Strong associations were observed amongst versions of the TMT tasks (rs > .58). Increased mean time signaled poorer state cognitive performance. Several studies using a digitally adapted TMT have found moderate to strong associations with the paper and pencil version of the TMT (Fellows et al., 2017) and measures of global cognitive health and executive functioning (Dahmen et al., 2017) and also demonstrated high feasibility, sensitivity, and specificity for discriminating between individuals with mild cognitive impairment and dementia from controls (Kokubo et al., 2018).

Analyses

First, associations between potential static (e.g., age, ethnicity, education) variables and study variables that might inform subsequent analyses were computed. Multi-level modeling (MLM) results were not substantially changed when static variables were entered. Stability of variables were examined next, with a particular focus on state SITs. Correlations were used to examine the inter-relationships between state study variables. Finally, concurrent relationships between state subjective (e.g., hope and social connectedness) and cognition variables with SITs using MLMs were evaluated. Participants were set as a random factor. All variables were group mean centered (by testing session) and entered simultaneously. To increase parsimony, one model was used containing state hope, state social connectedness, and state cognition as the predictor variables while state SITs was the criterion variable. All predictor variables showed low multicollinearity (i.e., variance inflation factor < 1.5). Extreme scores (>3.5 SD) were Winsorized (i.e., replaced with values 3.5 SD) for all state variables. Exploratory analyses consisting of interactions among the subjective variables (i.e., hope and social connectedness) with state cognition predicting state SITs were computed; interactions were not significant. The analyses were computed using the R "Lme4" package (Bates et al., 2015).

Results

Temporal stability and reliability estimates using intraclass correlation coefficient (ICC) for predictor variables can be viewed in Table 1. Overall, SITs were relatively low in frequency and intensity overall though there was notable variability. At the between person level, approximately 15% of participants reported experiencing at mild-severe levels of state SITs; this was defined as an *average* SITs per participant greater than 10.0 (range 0 – 100) across the testing window. At the within person level, 24% (out of N=99) of participants endorsed state SITs greater than 10.0 on at least one of their respective testing sessions. The state SITs score showed modest reliability across sessions (ICC = 0.63). Indeed, similar findings with regards to the range of ICC values (range = 0.58 to 0.75) were exhibited by all other state predictor variables. State SITs were significant associated age, ($r = .24$, $p < .01$), but not with the education or ethnicity (rs< .08). As noted earlier, significant MLM results were not substantially changed when static variables (i.e., age) were entered.

Correlations (between subjects) among study variables are shown in Table 2. Strong associations between state SITs and cognition were observed, and modest but significant associations were found between state SITs and hope. Modest and significant associations were also observed between state cognition, hope, and social connectedness. State social connectedness was not associated with state SITs.

[Insert Table 2 here]

MLM results are shown in Table 3. Overall, state social connectedness and cognition both significantly predicted state SITs as expected. State hope did not predict state SITs (see Figure 1). The fit statistic (X^2) this model was significant as well. As noted earlier, exploratory analyses consisting of interactions among the self-report variables (i.e., hope and social connectedness) with state cognition predicting state SITs were computed; interactions were not significant.

[Insert Table 3 here]

[Insert Figure 1 here]

Discussion

The current study employed novel ambulatory recording technologies to evaluate the role of cognition in predicting "state" SITs in an inpatient SUDs sample. This study builds on an emerging literature extolling the importance of state factors for predicting SITs. More specifically, decreases in state cognitive performance predicted increases in state SITs, even after accounting for other hallmark static and self-report risk predictors (i.e., hope and social connectedness). Previous studies that have examined the temporal associations between cognition and SITs were mismatched in their respective time scales (Cha et al., 2010; Interian et al., 2019) in that the measure of SITs could cover an epoch of weeks to years, whereas the measure of cognition might reflect cognitive resources in that moment. This study improves on the temporal precision of these prior retrospective studies by matching measures in time scale.

It is worth considering potential mechanisms by which state cognition may contribute to SITs - or vice versa. Emotion-related regulatory processes stand as potentially important mechanisms, as diminished state cognitive abilities may attenuate implementation of successful emotion regulation skills when SITs emerge. In support of this notion, Bryan and Rozek (2018) reviewed converging data from physiological, psychosocial, and behavioral studies and reported that emotion regulation and cognitive flexibility (an "online" cognitive ability) reflect two critical mechanisms for suicidal risk. Preserved cognitive function provides a "chassis" for many vital emotion, cognitive, and behavioral regulatory functions (Joormann and Quinn, 2014; Mitchell, 2011), and helps buffer the effects of stress, negative affect, and impulsivity (e.g., Schmeichel, Volokhov, & Demaree, 2008). In sum, "fluid" cognitive abilities reflect an individual difference variable that fluctuates within individuals over time. At any given time, "fluid" cognitive abilities can mitigate inefficient or unhelpful allocation of resources, such as self-injurious attentional biases or preservative thoughts, or limit the resources available for other tasks, such as effective emotion regulation (Grillon, Quispe-Escudero, Mathur, & Ernst, 2015; Le, Najolia, Minor, & Cohen, 2017).

The causal link between cognition and SITs remains unclear. While it is our guiding presumption that cognitive constraints exacerbate SITs, it stands to reason that state SITs may attenuate state cognition. While the evidence base for this is limited, in-the-moment negative affect and stress, two states that have been linked with reduced self-reported concentration (Brose et al., 2012), are associated with reduced "fluid" cognitive performance (e.g., via response time on working memory and processing speed tasks) in a variety of laboratory tasks (Lukasik et al., 2019). The timing of the data assessment in our study (which was optimized for measuring a 28-day epoch) did not permit for a causal investigation of state SITs and cognition. Future research would benefit from more frequent sampling within a shorter time period to attain the temporal resolution (i.e., assessment time windows) to clarify the pathways among state cognition and SITs.

The present findings have implications for assessment and intervention. Generally speaking, these results are consistent with the notion that assessment of SITs requires consideration of a variety of state factors (Glenn & Nock, 2014; Kleiman et al., 2017). That said, ambulatory cognitive assessment is much more complex and demanding than ambulatory self-report assessment; and the latter is probably sufficient for many clinical functions. Hence, the role of cognitive assessment for measuring SITs in individual patients may be relatively specialized. Current prediction and prevention of self-injurious risk is suboptimal, and this may be due to constraints of historial assessment procotol that do not effectively consider the complex and dynamic interplay among various cognitive, environmental, affective, and physiological risk factors (Rudd, 2007). Moreover, research has consistently demonstrated that SITs fluctuate considerably over short period of times, potentially explaining why research has suggested that a large porportion of individuals who die by suicide deny suicidal ideation in their most recent medical encounter (Busch et al., 2003). Ambulatory cognitive assessment can help provide contextual information for exacerbated SITs, and therefore improve prediction. Finally, SITs are common across many psychopathologies, and there is considerable heterogeneity across and within mental disorders in terms of level of cognitive functioning (Joyce and Roiser, 2007; Ruocco, 2005). Precipitants of SITs are likely idiographic across individuals, and state cognition – which is likely important for many emotional regulatory and decision-making processes – may be more relevant for certain individuals than others. Longitudinal ambulatory measurement can answer questions about how and why SITs fluctuations as function of mediators such as state cognition at the individual level. As recent idiographic, ambulatory research suggests (Wright and Zimmermann, 2019), there are likely differences in the presence, strength, and direction of the cognition-SITs linkage across individuals within their own dynamic natural environment (Bentley et al., 2019). Tracking state cognitive functioning over time can also be important for identifying contexts (e.g., time-varying influences or social contexts) in which an individual's cognitive efficiency peaks, which could aid individuals structure their daily routines to optimize cognitive rehabilitation efforts and lower self-harm risk.

If indeed cognition function is mechanistically tied to SITs, it reflects a potential intervention target for reducing SITs. The current study's results suggest that cognitive remediation, defined as an intervention targeting cognitive deficit such as attention, memory, or executive function through repetitive practice and principles of learning (e.g., errorless learning, reinforcement, massed learning), may be useful for reducing SITs. Cognitive remediation has successfully been used (medium to large effect sizes for cognitive and functional outcomes; Kim et al., 2018) for individuals with mood and psychotic symptoms and brain injuries and represents a potential intervention opportunity to improve "fluid" cognitive deficits associated with self-harm risk. Improved cognitive functioning can complement skills training in emotion regulation and cognitive flexibility that are emphasized in current empirically supported treatments for individuals suffering SITs (e.g., Brief Cognitive Behavioral Therapy, Crisis Response Planning, and Collaborative Assessment and Management of Suicidality; Bryan & Rozek, 2018). The present results also have implications for therapeutic modalities which focus on *how* (opposed to *what*) an individual is thinking, such as mindfulness-based interventions, which have been shown to be related to clinically significant changes in NSSI (Bentley et al., 2017). Importantly, improvements in executive attention and cognitive reactivity have been linked with mindfulness-based therapy in high risk suicide outpatients (Chesin et al., 2016).

Several limitations and subsequent recommendations are worth noting. Ambulatory cognitive testing, while promising, is still in its infancy. While prior studies have demonstrated acceptable psychometric properties of using touch screens on smartphones to assess aspects of cognition in patients (Liu et al., 2019; Moore et al., 2017), concerns about validity due to potential distractors or lack of effort/motivation have been raised and could have influenced the results of this study (Calamia, 2019). These concerns persist even in the most optimal of laboratory settings (Holmlund et al., 2019b; Strauss et al., 2015), though they are less controlled with ambulatory assessment. Potential solutions may include increased data collection over time for more stable estimates, use of multiple ambulatory cognitive tasks to evaluate measurement variance, and use of built-in sensors such as eye-tracking to assess effort. Interestingly, prior research has demonstrated that patients are interested in and willing to engage with digital health tools (i.e., ambulatory technologies/mobile apps) that they perceive as beneficial (Ben-Zeev et al., 2018;

Torous and Hsin, 2018). Relatedly, patients were compensated for this study; future research would benefit from investigating the "real-world" acceptability of ambulatory assessment with and without the influence of monetary compensation. Second, single items were used to query state self-report variables. While use of a singular item for a construct is common in ambulatory studies and aids in interpretability and eases burden (Myin-Germeys et al., 2018), multiple items, including those that query hopelessness and perceived burdensomeness, would improve the depth and breadth of measuring this study's SITs related constructs. SITs encompass both active and passive NSSI and suicidal thoughts. Research has shown some differential physiological and environmental pathways concerning NSSI and suicidal related concerns (Jollant et al., 2011; Westlund Schreiner et al., 2015), and differential gender effects related to self-injurious thoughts and behaviors (Aboussouan et al., 2019; Bresin and Schoenleber, 2015). Future studies would benefit from replicating the analyses with a broader sample, including both women and individuals with NSSI and suicidality history from various psychopathologies (i.e., other clinical disorders at putative high risk for SITs) to see how those static variables effect the relation between cognition and SITs. Finally, our sample endorsed relatively modest levels of SITs; several reasons could explain this finding. For example, previous ecological momentary assessments of self-harm risk are typically comprised of inpatients who were psychiatrically hospitalized for acute suicide risk/severe depressed state or have lifetime suicidal ideation or behaviors (Kleiman et al., 2017; Liu et al., 2020). Also, our singular SITs item may have been specific to active self-ham thoughts rather than passive suicidal thoughts or death ideation.

Significant associations between state cognitive abilities and SITs signal the viability of using objective variables in ambulatory risk assessment that can aid in the moment, high-risk clinical decision-making rather than solely relying patient self-report, clinician ratings, or static risk factors. Leveraging “online” cognitive abilities and “state” SITs aligns with the emerging literature on digital phenotyping self-harm risk (Kleiman et al., 2018) and other complex, clinical phenomenon (Cohen et al., 2021, 2020a). The emergence of consumer-grade, biobehavioral, and ambulatory technologies promise to provide unprecedented opportunity for ecological valid and time-efficient detection or prediction of risk states across psychopathology and thus informing early intervention (Cohen, Schwartz, et al., 2020; Torous, Onnela, & Keshavan, 2017).

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Conflicts of Interest

The authors report no conflict of interest.

Contributors

TL performed the literature search, conducted data analyses, and wrote the bulk of the manuscript. EM, TC, and AC aided with data interpretation. All other authors helped interpret the findings and provided conceptual material to the planning and presentation of this project. All authors contributed to the writing of the manuscript.

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Table 1. Descriptive and Demographic Date for Inpatient Male Participants (*N* = 99)

Variable	*M (SD)*	ICC
Demographics		
Age	36.6 (11.2)	
% Caucasian	43%	
% African American	52%	
Education (years)	12.3 (.4)	
Ambulatory Assessment		
Hope	74.5 (35.4)	.58
Social Connectedness	68.5 (38.1)	.75
SITs	4.9 (16.7)	.63
Cognition	846.1 ms (710.2)	.68

Note. SITs = Self-injurious thoughts; State cognition was measured by average mean time (i.e., average time to complete one connection on the TMT in milliseconds) across three versions of the modified TMT.

Table 2. Correlations among study variables

	2.	3.	4.
1. State Hope	.29*	-.48*	-.29*
2. State Social Connectedness	-	-.21*	-.07
3. State Cognition		-	.59*
4. State SITs			-

* $p < .01$

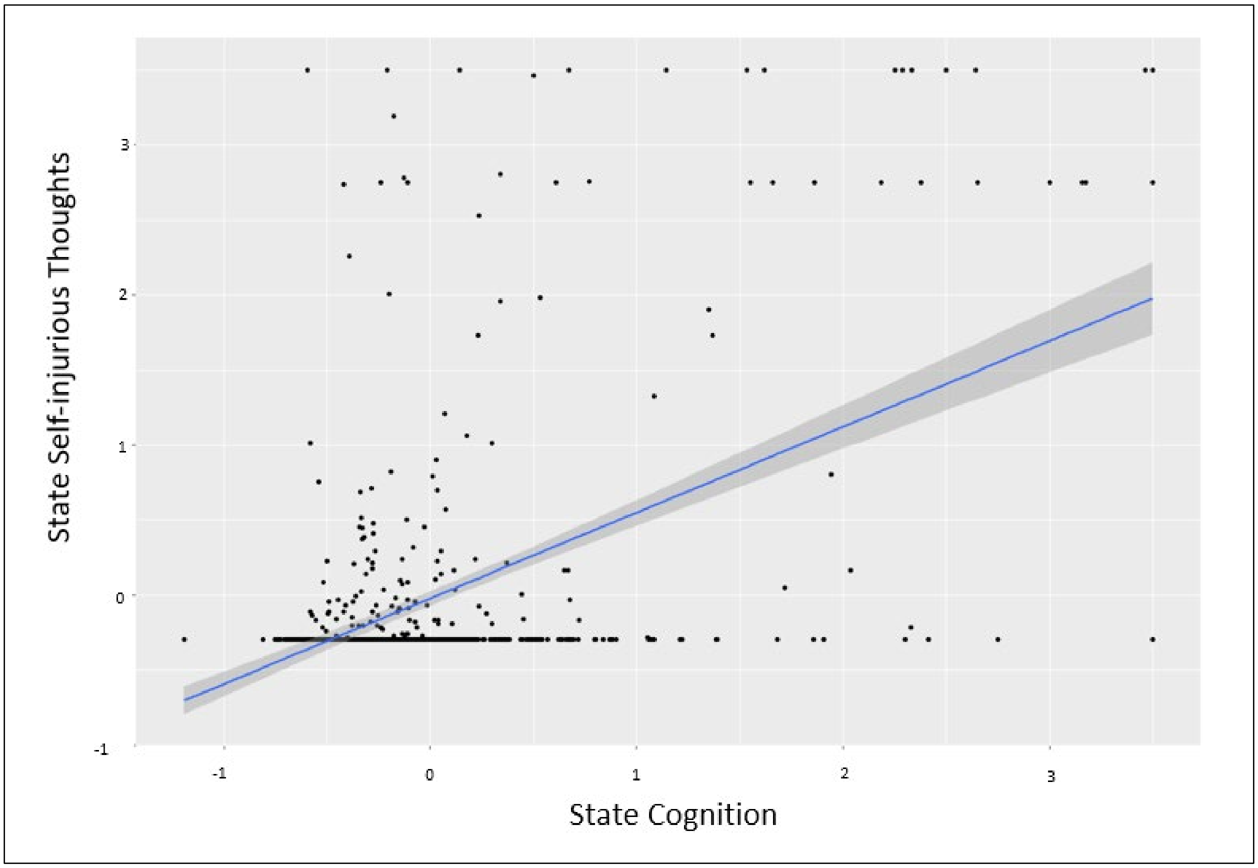
Note. SITs = Self-injurious thoughts. Increased mean time on state cognitive measure signaled poorer state cognitive performance.

Table 3. MLM for the prediction of State SITs

	Fit Statistic - X2	B	SE	t value
	*8.13***			
State Hope		-0.04	0.03	-1.62
State Social Connectedness		-0.11	0.03	-3.36*
State Cognition		0.13	0.04	3.09*

* $p < .05$
** $p < .01$
Note. Increased mean time on state cognitive measure signaled poorer state cognitive performance.

Figure 1. Main effect of state cognition on state SITs. Blue line represents regression line, while gray boundary represents standard error.



Note. Increased mean time on state cognitive measure signaled poorer state cognitive performance.