

Examination of Real-Time Fluctuations in Suicidal Ideation and Its Risk Factors: Results From Two Ecological Momentary Assessment Studies

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Two studies examined 2 important but previously unanswered questions about the experience of suicidal ideation: (a) How does suicidal ideation vary over short periods of time?, and (b) To what degree do risk factors for suicidal ideation vary over short periods and are such changes associated with changes in suicidal ideation? Participants in Study 1 were 54 adults who had attempted suicide in the previous year and completed 28 days of ecological momentary assessment (EMA; average of 2.51 assessments per day; 2,891 unique assessments). Participants in Study 2 were 36 adult psychiatric inpatients admitted for suicide risk who completed EMA throughout their time in the hospital (average stay of 10.32 days; average 2.48 assessments per day; 649 unique assessments). These studies revealed 2 key findings: (a) For nearly all participants, suicidal ideation varied dramatically over the course of most days: more than 1-quarter (Study 1 = 29%; Study 2 = 28%) of all ratings of suicidal ideation were a standard deviation above or below the previous response from a few hours earlier and nearly all (Study 1 = 94.1%; Study 2 = 100%) participants had at least 1 instance of intensity of suicidal ideation changing by a standard deviation or more from 1 response to the next. (b) Across both studies, well-known risk factors for suicidal ideation such as hopelessness, burdensomeness, and loneliness also varied considerably over just a few hours and correlated with suicidal ideation, but were limited in predicting short-term change in suicidal ideation. These studies represent the most fine-grained examination of suicidal ideation ever conducted. The results advance the understanding of how suicidal ideation changes over short periods and provide a novel method of improving the short-term prediction of suicidal ideation.

General Scientific Summary

Traditionally, suicidal ideation and its risk factors have been studied using long periods of time (e.g., years, months) between measurements, precluding any short-term examination of real-time variation in suicidal ideation. Using smartphone-based assessments collected multiple times per day, this study revealed that suicidal ideation and its risk factors often vary considerably over a period as short as 4 to 8 hours. Additional studies using real-time monitoring are needed to further study dynamic short-term changes in suicidal ideation and its risk factors, and to test the impact of interventions aimed at decreasing their occurrence.

Keywords: ecological momentary assessment, suicidal, suicide, interpersonal theory, hopelessness

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Suicide is a leading cause of death among all age groups (Centers for Disease Control & Prevention, 2016). Despite decades of research, surprisingly little is known about its basic properties. This lack of knowledge is in part due to it being unethical to induce suicidal thoughts or behaviors in the lab as can be done with other psychological states like depressed or anxious mood. It is also due to the inability to observe suicidal thoughts and behaviors “in the wild” as they occur in real time. For decades, leading scholars (Kagan, 2007; Tinbergen, 1974) have suggested that psychological science has not progressed as quickly as other sciences because it has lacked the ability for the intensive study of phenomena of interest in their natural environment, which is what is needed to truly understand the phenomena. Indeed, many fields, such as biology (Grimaldi & Engel, 2007), immunology (Grimaldi & Engel, 2007), and neuroscience (Lichtman & Sanes, 2008) hold descriptive studies in high regard for their ability to verify existing hypotheses and generate new ones. Studies that take a descriptive approach have been especially challenging in the case of sensitive and episodic behaviors like suicide, violence, or substance use. However, recent technological advances, such as the development and proliferation of the smartphone, have provided unprecedented opportunities to do exactly this.

The purpose of this study was to use one of these new technologies, smartphone-based ecological momentary assessment (EMA), to answer two important, but unexplored, fundamental questions about suicidal ideation. First, to what degree does suicidal ideation fluctuate over short periods of time? Second, to what degree do known risk factors for suicidal ideation vary over short periods of time and are they associated with short-term changes in suicidal ideation?

How Does Suicidal Ideation Vary Over Short Periods of Time?

Our first aim was to describe short-term variability in suicidal ideation (i.e., changes in suicidal ideation severity over a 4- to 8-hr period). Most research on suicidal ideation has used retrospective assessments with long intervals between them (e.g., past month, year, or lifetime). Asking someone to retrospectively report on how strong their desire to die has been on average since the last assessment, even if repeated many times over months or years, does not capture fine-grained variation in suicidal ideation, and as such, virtually nothing is known about how suicidal ideation varies over short periods. One study (Bagge, Littlefield, Conner, Schumacher, & Lee, 2014) used a timeline follow-back method to retrospectively assess variability in suicidal ideation in the 24 hours before a suicide attempt. It found an intraclass correlation for suicidal ideation over the 24-hr period of .45, suggesting that more than half of the variability in suicidal ideation was due to within-person, short-term changes, supporting the idea that suicidal ideation varies over short periods of time. However, because these data were collected over a 1-day retrospective period leading up to a suicide attempt, it is still unknown how much suicidal ideation varies from hour to hour when assessed prospectively, across more than one day, and during a “typical” time (i.e., not just in the 24 hr leading up to a suicide attempt).

Two prior studies used real-time monitoring of suicidal ideation over longer periods of time, but they were limited in important ways. Nock et al. (2009) assessed participants twice per day for 2

weeks, providing a relatively coarse assessment of suicidal ideation over only 14 days. Ben-Zeev et al. (2012) used short-term retrospective prompts that assessed average suicidal ideation since the last study prompt, which did not allow assessment of severity of suicidal ideation as it actually occurred. Addressing these gaps, the current paper reports on two studies, conducted over periods of 28 days (Study 1) and the length of inpatient treatment (Study 2), in which we actively and repeatedly prompted those with a recent history of suicidal behavior to complete brief assessments of suicidal ideation and related constructs every four to eight hours, allowing for a fine-grained analysis of how these thoughts vary over the course of the day. It is important to explore such variation because if suicidal ideation does vary considerably over short periods of time, it would suggest that examinations of suicidal ideation over periods of weeks, months, or years do not capture the true nature of suicidal ideation. The idea that suicidal ideation may vary over a short period of time is not a new one and has been noted since the time of Kraepelin (Kraepelin & Johnstone, 1913) but has not yet been formally studied.

Do Risk Factors for Suicidal Ideation Vary Over Time and Predict Changes in Ideation?

Our second aim was to describe the short-term variability in suicide risk factors and to test whether changes in these risk factors are associated with changes in suicidal ideation severity. Given the small number of studies examining suicidal ideation in real time, it is surprising that essentially no research has tested specific theories of suicidal outcomes using a real-time monitoring framework. Such research is necessary because many theories of suicide, including the two that will be the focus of this article, the Hopelessness and Interpersonal Psychological Theories, propose risk factors that are thought to be proximal to the occurrence of suicidal ideation. These propositions, however, have not been verified using real-time monitoring methods. Briefly, Beck’s (Beck, Kovacs, & Weissman, 1975) hopelessness theory proposes that hopelessness (i.e., negative expectations for the future) is fairly stable over time and ultimately leads an individual to believe that suicide is a viable strategy to deal with untenable circumstances. Joiner’s (2005) interpersonal theory proposes that perceptions of burdensomeness and thwarted belongingness also are fairly stable over time and ultimately lead an individual to consider suicide as a means of resolving their situation. Importantly, no prior studies have tested the real-time stability of these risk factors or the extent to which their occurrence or fluctuations may be associated with, or predictive of, real-time changes in suicidal ideation. The importance of understanding short-term risk factors (or “warning signs”; Rudd et al., 2006) has been understood for some time (Glenn & Nock, 2014; Nock, 2016). Yet, there has been little research addressing factors that predict suicidal ideation over just a few hours. As noted in a recent meta-analysis on the prediction of suicidal outcomes (Franklin et al., 2017), less than 1% of suicide risk factor research is focused on time frames of a week or less, the period most important to clinicians tasked with making decisions about the short-term risk of their patients. The final goal of these studies aimed to bridge this important scientific and clinical gap. Accordingly, in line with the precedent set by this theoretical work, we hypothesized that higher levels of the factors from these theories (i.e., hopelessness, burdensomeness, and loneliness [as a

proxy for thwarted belongingness, discussed more below]) would be cross-sectionally and prospectively associated with higher levels of suicidal ideation.

The Importance of Replication

In recent years, there has been growing attention to the relatively low rates of reproducibility in psychological science. In one landmark attempt to replicate 100 psychological experiments from three high-ranking psychology journals, researchers from the Open Science Collaboration (2015) found that only 47% of original effect sizes were in the 95% confidence intervals (CIs) of the replication effect sizes. This raises the idea that nonreplicated findings can be potentially wasteful or dangerous given that clinical implications can be enacted based upon a faulty and limited foundation of research (Simmons, Nelson, & Simonsohn, 2011). This highlights the need to not just increase reproducibility of psychological science but to also actually engage in replication attempts (Ebersole, Axt, & Nosek, 2016; Munafò et al., 2017; Nosek, Spies, & Motyl, 2012). Accordingly, we conducted our analyses in two related, but distinct samples (i.e., past-year attempters and more severe suicidal inpatients). This specific replication paradigm (i.e., close replication; Brandt et al., 2014; Finkel, Eastwick, & Reis, 2015) is important because beyond the need to know if our findings replicate in general, it is important to know if our findings generalize across the spectrum of severity of suicide risk. It may be that findings in a (relatively) less severe group of past-year attempters do not apply to a more severe group of suicidal inpatients. By doing so, our replication attempts serve an important functional purpose to extend our findings to a larger population of suicidal individuals (Schmidt, 2009).

Study 1: Previous Suicide Attempters

Method

Participants. Participants were 54 adults (79.6% female) who had attempted suicide (self-inflicted injury with intent to die) at least once in the past year. The average age was 23.24 years old ($SD = 5.26$ years, range = 18–44 years). Seventy-two percent of the sample self-identified as being of European decent, 7.4% as Hispanic, 7.4% as Asian, and the rest as another race. Participants were recruited worldwide and although the specific countries were kept anonymous, 81% of the sample was from North America and the remaining 19% were from Europe.

Procedure. The study included three parts: (a) recruitment and screening, (b) a baseline assessment, and (c) a 28-day EMA period. Participants were compensated with a \$40 (or local currency equivalent to \$40 USD) Amazon.com gift card. If they completed 75% or more of the EMA prompts, they received an additional \$10. All study procedures were approved by the Harvard University-Area Institutional Review Board (IRB# 15–1975; “A real-time evaluation of suicide risk”).

Recruitment. Inclusion criteria were presence of at least one suicide attempt in the past year, fluency in English, age of at least 18 years, and regular access to an Android or iPhone smartphone. Participants were recruited from over a dozen individual forums on the Reddit website (reddit.com). These

forums all involved topics related to self-harm (e.g., psychopathology) and ranged from under 1,000 to over 125,000 members ($M = 26,375$ members). After obtaining moderator approval at each forum, we placed on the forum an advertisement for our study with a link to complete a consent form and screener. Participants who qualified were then contacted via email and asked if they were interested in the study. Those who said they were interested were sent information on how to complete the baseline and EMA assessments.

A total of 854 individuals completed the recruitment screener, 103 of whom qualified and 751 of whom did not. Nearly all 751 individuals ($n = 744$) who did not qualify for the study did not qualify because they had not attempted suicide in the past year. The remaining seven individuals who did attempt suicide in the past year did not qualify because they either did not have daily access to a smartphone and/or did not speak English ($n = 2$) or were under 18 ($n = 5$). Ninety of the 103 individuals who qualified were interested, 54 of whom completed the baseline assessment and began the EMA period. This participation rate (60%) is in line with, albeit slightly lower than, other similar studies of past suicide attempters (e.g., 66.7% in Husky et al., 2014).

Baseline. After receiving a study description and providing informed consent, participants completed a battery of demographic and other self-report measures on a secure study website. Given that the focus of this study was short-term variability of suicidal ideation, no baseline measures were used for this manuscript, other than the demographics which were used to describe the sample and questions regarding suicide history.

EMA. We used the Mobile EMA software (mEMA; ilumiv.com) for EMA data collection. mEMA is a smartphone-based EMA program that runs on both Android and iPhone smartphones. Each day for 28 days, participants were signaled at four random intervals separated by 4 to 8 hr (i.e., signal-contingent monitoring) to report on severity of suicidal ideation and related factors (described in more detail below). Participants also were asked to report on several factors related to their day (i.e., interval-contingent monitoring) and to initiate a survey whenever they had suicidal thoughts (i.e., event-contingent monitoring). As before, given that we were interested in short-term variability in suicidal ideation, we only used the signal-contingent monitoring data for this manuscript.

Baseline measures.

Demographics. Participants completed a brief demographic screener.

Suicide history. Participants completed a self-report version of the Self-Injurious Thoughts and Behaviors Interview (SITBI; Nock, Holmberg, Photos, & Michel, 2007). We used items from this measure that assessed number and recency of suicide attempts and age of first attempt.

EMA measures.

Suicidal ideation. At each of the four daily prompts, participants were asked three questions assessing: (a) the desire to die by suicide (i.e., “How intense is your desire to kill yourself right now?”), (b) the intention to die by suicide (i.e., “How strong is your intention to kill yourself right now?”), and (c) the ability to resist the urge to die by suicide (i.e., “How strong is your ability to resist the urge to kill yourself right now?”). Each item was on

a 0 (*not strong [intense] at all*) to 4 (*very strong [intense]*) scale.¹ We examined individual items and a sum score. The item assessing ability to resist the urge to die by suicide was reverse coded prior to calculation of the sum score. The internal consistency of the sum score was acceptable ($\alpha = .82$, 95% CI = .79, .86).

Risk factor variables. At each of the four daily prompts, participants were presented with a variety of one-word affect labels and asked to rate how much they felt each one on a 0 (not at all) to 4 (very much) scale. These affect labels included “hopeless,” mapping on to the hopelessness theory as well as “burdensome” and “lonely,” mapping on to the interpersonal theory constructs of burdensomeness and thwarted belongingness. Using “lonely” as our one-word measure of thwarted belongingness was an a priori decision made for both pragmatic (i.e., we wanted to use only one word to label the construct; moreover, “lonely” is more easily understood by participants than “thwarted belongingness”) and scientific reasons (i.e., other studies have conceptualized loneliness as a key component of thwarted belongingness; see Van Orden et al., 2010).

Analytic strategy. We conducted all analyses in R (R Core Team, 2016) using the RStudio development environment (RStudio Team, 2015). Individual R packages used for each analysis are noted below where relevant.

How does suicidal ideation vary over short periods of time? In line with recent work exploring the short-term variability of personality factors (Wright & Simms, 2016), we explored variability in suicidal ideation statistically and visually.

We used two statistics to quantify variability: intraclass correlations (ICCs) and root mean square of successive differences (RMSSD; von Neumann, Kent, Bellinson, & Hart, 1941). ICCs show the proportion of variance in a measure attributed to between-person variability. Thus, 1-ICC provides the proportion of variability that can be attributed to within-person variability. RMSSDs show the average variability in a measure over time. RMSSD is preferable to other measures of variability over time (e.g., growth curve modeling) because it simultaneously takes into account temporal dependency, amplitude, and frequency in conceptualizing instability (Ebner-Priemer, Eid, Kleindienst, Stabnow, & Trull, 2009). The RMSSD statistic is interpreted such that larger values equal more variability from one point to the next (i.e., if graphed, larger RMSSD values correspond to a saw tooth pattern). We calculated ICC and RMSSD statistics using the Psych R package (Revelle, 2016).

We used two types of time-series plots to visualize variability: group-mean centered and individual raw data. Group-mean centered time-series plots are useful for visualizing the relative variability over time across an entire sample. Group-mean centering involves subtracting each participant’s overall (i.e., group) mean from each of their individual scores. This standardizes the figure such that units are in units of deviation from each participant’s average (set at 0), allow comparison of variability around a standard mean. Individual raw score time-series plots are useful for fine-grained visual comparison of each participant’s data. We created group-mean centered and individual raw score time series plots for suicidal ideation as an overall composite and for the three components of suicidal ideation (desire, intention, and ability to resist urges to kill self) using the ggplot2 R package (Wickham, 2009).

We conducted supplemental analyses to examine if suicidal ideation varied within a day in any discernable pattern. These analyses involved conducting a three-level model (responses within days within people) and regressing suicidal ideation on daily observation number. A significant effect of observation number on suicidal ideation would indicate a linear pattern throughout the day. A positive relationship would mean ideation increases linearly from morning through night. A negative relationship would mean ideation decreases linearly from morning to night.

Do risk factors for suicidal ideation vary over time and predict changes in ideation? To assess the degree of short-term variability in risk factors for suicidal ideation, we used the same general analytic and visualization strategy as we did for assessing the degree of short-term variability in suicidal ideation. To assess the ability of these risk factors to predict short-term changes in suicidal ideation, we conducted three hierarchical linear models where observations were nested within people. The first model assessed the correlates of suicidal ideation. Hopelessness, loneliness, and burdensomeness (all at Time T) were predictor variables and suicidal ideation at Time T was the outcome variable. The second model assessed short-term prediction of suicidal ideation. All predictors were the same as Model 1, however suicidal ideation at T + 1 was instead used as the outcome variable. Finally, the third model assessed short-term prediction of changes in suicidal ideation. All predictors were the same as Models 1 and 2, and the outcome variable was the same as Model 2; however, suicidal ideation at Time T was added as a covariate. All predictors were group-mean centered with fixed slopes (although interpretations were generally similar when using random slopes). All three models were analyzed using the lme4 R package (Bates, Mächler, Bolker, & Walker, 2015) and tables were made using the sjPlot R package (Lüdtke, 2016).

Results

Participants completed a total of 2,891 unique assessments ($M = 53.54$ responses per participant, $SD = 38.82$) across a total of 1,150 unique days ($M = 21.30$ days per participant, $SD = 11.74$), for an average of 2.51 responses per participant, per day (out of four possible prompts, 62.75% compliance rate). The means, standard deviations, and skewness statistics for all EMA variables are presented in Table 1.

How does suicidal ideation vary over short periods of time? The variability statistics (ICCs and RMSSD) for suicidal ideation as an overall composite as well as the three component items (desire, intention, and ability to resist the urge to kill self) are presented in Table 1. Examining the ICCs shows that approximately 50% of the variability in suicidal ideation and its component items is due to within-person variance (vs. between-person variance). Examining the RMSSD statistics shows that there was considerable variability for suicidal ideation composite scores and items.

The time series plot of the short-term variations in suicidal ideation is presented in the top of Figure 1. The time series plots

¹ Because we used an anchor at the low end that indicated not strong/intense at all, rather than “not present,” our assessment of suicidal ideation could not readily distinguish very low suicidal ideation from an absence of suicidal ideation.

Table 1
Descriptive and Variability Statistics for Suicidal Ideation and Its Risk Factors (Study 1)

Variable	Descriptive statistics					Variability statistics		
	<i>M</i>	<i>SD</i>	Range	% nonzero	Skew	ICC [95% CI]	RMSSD	RMSSD range
Suicidal ideation (overall)	2.67	3.07	0–12	63.0%	1.11	.53 [.44, .63]	2.28	.00–4.54
Desire to kill self	.66	1.06	0–4	53.7%	1.59	.46 [.37, .57]	.77	.00–1.84
Intention to kill self	1.16	1.33	0–4	35.3%	.82	.49 [.41, .60]	1.07	.00–1.85
Ability to resist urge to kill self	3.15	1.16	0–4	43.8% ^a	–1.23	.51 [.42, .61]	.84	.00–1.77
Hopelessness	1.71	1.53	0–4	66.9%	.26	.57 [.48, .67]	1.17	.00–3.00
Loneliness	1.76	1.59	0–4	66.1%	.18	.49 [.41, .61]	1.23	.00–2.06
Burdensomeness	1.69	1.56	0–4	64.4%	.33	.58 [.50, .69]	1.16	.00–2.87

Note. CI = confidence interval; ICC = intraclass correlation; RMSSD = root mean square of successive differences (average of each participant's individual RMSSD).

^aRaw item not reverse coded, except for % nonzero, which corresponds to % responses that are not a 4 out of 4.

of the component items are presented on the left-side column of Figure 1. As suggested by the RMSSD values, the plots appeared to follow a strong saw tooth pattern without any clear linear effect over time. Individual time series plots of raw overall suicidal ideation scores, along with individual means and standard deviations are presented in Figure 2. There was variability in suicidal ideation for nearly all participants: 29.1% of all ratings of suicidal ideation differed from the next consecutive rating by at least one within-person standard deviation (i.e., 29.1% of the time, an individual's rating of suicidal ideation at Time T + 1 was at least one standard deviation from their individual mean above or below their rating at Time T) and 94.1% of participants had at least one instance of a suicidal ideation changing by a standard deviation or more from one response to the next. Although all participants had some degree of variability from their mean, there was a wide range of both individual means and how much each participant varied around their mean. As would be expected, however, participants who had a higher mean level of suicidal ideation had more variability around that mean (i.e., mean and RMSSD for suicidal ideation were positively correlated; $r = .49, p < .001$). The individual plots for the suicidal ideation component scores are presented in supplemental Figure S1 in the online supplemental material. We also conducted supplemental analyses to determine if suicidal ideation followed a discernable pattern throughout the day. Results of these analyses showed that there was no such linear trend ($b = 0.0002, p = .856$).

Do risk factors for suicidal ideation vary over time and predict changes in ideation? Variability statistics (ICCs and RMSSD) for hopelessness, loneliness, and burdensomeness are presented in Table 1. Examining the ICCs shows that approximately 50% of the variability in all three variables was due to within-person variance (vs. between-person variance). Examining the RMSSD statistics shows that there was nearly the same level of variability in all the measures. Within-person variations over time in hopelessness, loneliness, and burdensomeness are shown in time series plots on the right-side column of Figure 1. Individual plots for hopelessness, loneliness, and burdensomeness are shown in supplemental Figure S2 in the online supplemental material. The patterns follow a strong saw tooth pattern without any clear linear effect over time.

Results of a series of hierarchical linear models examining the association between suicidal ideation and hopelessness, loneliness, and burdensomeness are presented in Table 2.² The leftmost set of

results shows the concurrent association of these variables with suicidal ideation (i.e., all variables assessed at Time T). In line with hypotheses, all variables were significantly and positively associated with suicidal ideation. Partially in line with hypotheses only hopelessness and burdensomeness at T were significantly associated with suicidal ideation at T + 1 (middle column of Table 2). The rightmost column of results shows the prospective association of these variables with suicidal ideation (i.e., predictors assessed at T and suicidal ideation assessed at T + 1), controlling for suicidal ideation at T. Contrary to hypothesis, only suicidal ideation at T was significantly and positively associated with suicidal ideation at T + 1.

Study 2: Suicidal Inpatients

Method

The goal of Study 2 was to attempt to replicate the overall methods and results from Study 1. The sample and monitoring scheme differed in a few ways from Study 1 to Study 2. Study 1 used a sample of adults who had attempted suicide in the past year, whereas Study 2 used a sample of adult suicidal inpatients. In terms of EMA monitoring scheme, Study 2 did not include "burdensomeness," whereas Study 1 did.

Participants. Participants were 36 adults (44.1% female) who were admitted to the psychiatric inpatient unit at Massachusetts General Hospital due to a recent suicide attempt or severe suicidal ideation. The average age was 47.74 years old ($SD = 13.06$ years, range = 23–68 years). Eighty-two percent of the sample self-identified as being of European decent, 5.9% as Hispanic, 5.9% as Asian, and the rest as another race.

Procedure. Data for this study were drawn from the first wave of a study whose goal was to assess the psychological and physiological predictors of imminent suicide risk among suicidal inpatients. The study included three parts: (a) recruitment, (b) a baseline assessment, and (c) an EMA period that lasted the duration of the patient's inpatient stay. The average inpatient stay was 10.32 days ($SD = 6.45$ days, range = 2–46 days, median = 7 days). The

² We also conducted analyses using each individual suicidal ideation component score as a dependent variable and found the same general pattern of results.

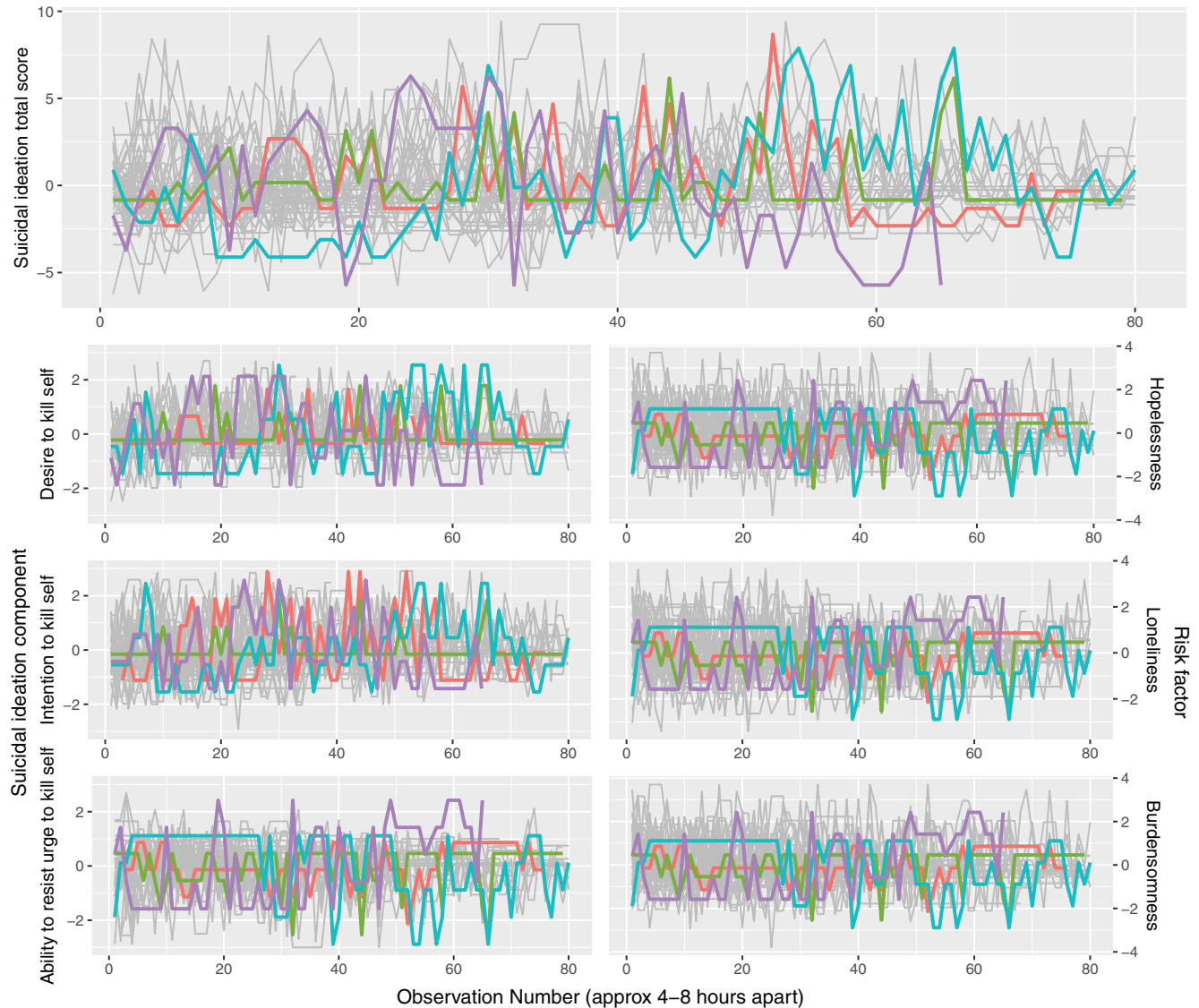


Figure 1. Time series plots of all study variables (Study 1). All variables are group-mean centered. Colored (thicker) lines represent participants randomly selected (to enhance clarity of the figure). See the online article for the color version of this figure.

study also included 2- and 4-week follow-ups, as well as ambulatory physiological monitoring. Because we are using Study 2 to replicate Study 1, we include here only those variables that matched those used in Study 1 (i.e., we do not report here on the physiological monitoring data, follow-up survey data, etc.). Participants were compensated with \$10 per day for completing the assessments. All study procedures were approved by the primary Institutional Review Board Massachusetts General Hospital (IRB# 2015P000598, “Real-time assessment of suicidal thoughts among psychiatric inpatients”). Institutional Review Boards at Harvard University and Massachusetts Institute of Technology relied on the primary approval (i.e., these review boards ceded review to Massachusetts General Hospital’s Institutional Review Board).

Recruitment. Inclusion criteria were admission due to a suicide attempt or severe suicidal ideation and fluency in English (all

patients on the unit were over 18 and we loaned compatible smartphones to those who did not have access to one). Exclusion criteria included anything that would impair the participant from understanding the study instructions (e.g., cognitive impairment). A study research assistant attended rounds each morning to determine if any new admissions from the previous day met these criteria and approached those that did. Initially, 41 eligible patients who approached were willing to participate (approximately 77% of all eligible patients approached). Of the 41 who agreed to be in the study, one potential participant was discharged unexpectedly early and was no longer able to participate, two potential participants appeared to understand the consent process but not the instructions to use the smartphone app and were thus excluded from the study, and two potential participants did not answer any of the smartphone surveys. This left the final sample size at 36.

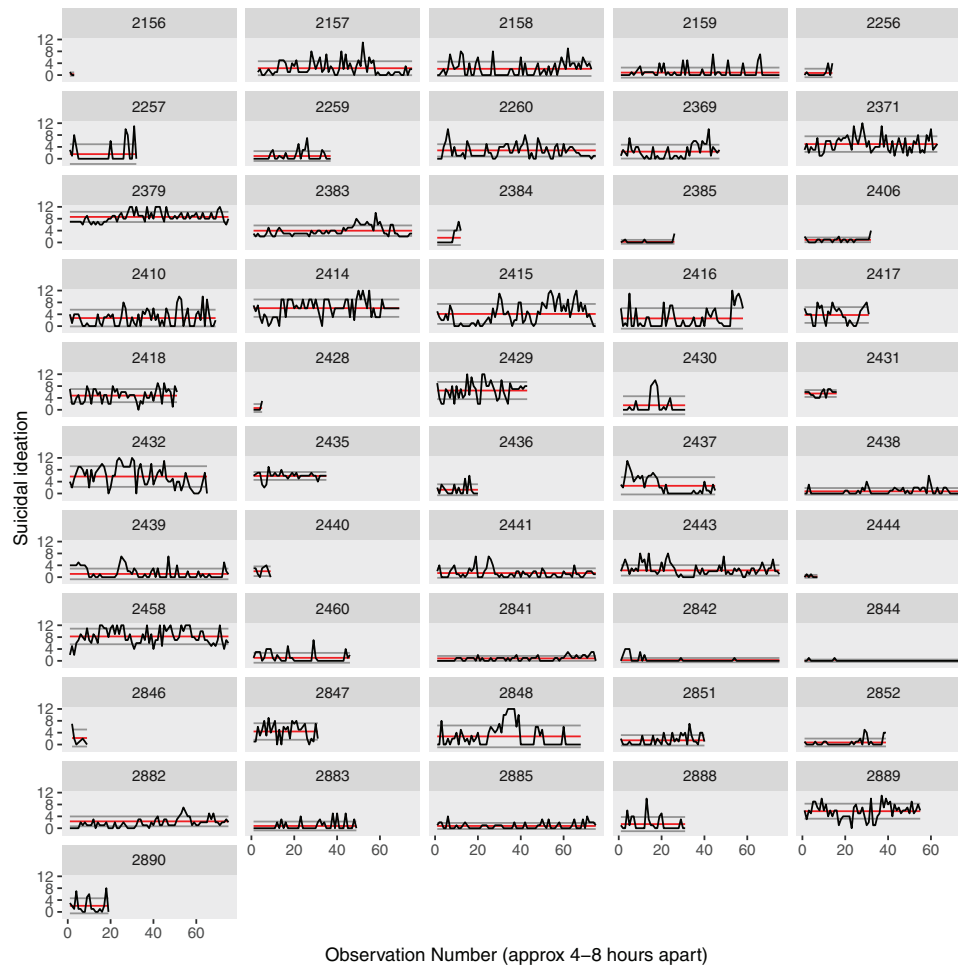


Figure 2. Individual time series plots of raw suicidal ideation scores (Study 1). Three participants who were included in the analyses but did not have three or more consecutive data points are not pictured here. Red (black) line = mean score, gray lines = ± 1 SD. See the online article for the color version of this figure.

Baseline. After receiving a study description and providing informed consent, participants completed a battery of demographic and other self-report measures. As in Study 1, none of the baseline measures were used for this manuscript, other than the demographics and questions regarding suicide history, which were used to describe the sample.

EMA. We used the MovisensXS EMA software (movisens.com). The MovisensXS program is only compatible with Android phones, so we lent participants an Android smartphone if they did not have a smartphone or had another brand of smartphone. For the duration of their inpatient stay, like in Study 1, participants received four signal-contingent prompts per day at random intervals separated by four to eight hours.

Measures.

Baseline. Participants completed the same demographics screener and self-report version of the Self-Injurious Thoughts and Behaviors Interview as Study 1.

EMA. The EMA measures in this study were the same as in Study 1 with two exceptions. First, Study 2 included items assessing the constructs of being “hopeless” and “lonely,” but not “burden-

some.” Second, Study 2 used 10-point scales instead of 5-point scales (e.g., suicidal ideation was rated on a 0 [not strong at all] to 9 [very strong] scale). The anchor labels for each scale were the same across both studies. Study 2 used the same three suicidal ideation items as Study 1 and the internal consistency of the suicidal ideation sum score was acceptable ($\alpha = .79$, 95% CI = .76, .82).

Results

Participants completed a total of 649 unique assessments ($M = 18.03$ responses per participant, $SD = 16.16$) across a total of 263 unique days ($M = 7.31$ days per participant,³ $SD = 6.61$ days), for an average of 2.48 responses per participant, per day (out of four possible prompts, 62.0% compliance rate). The means, standard

³ Participants’ average inpatient stay was longer than their average duration in the study because data collection did not usually begin until the first full day that they were on the unit (i.e., the second calendar day) and often ended the night before they were discharged because discharges typically happened early in the morning.

Table 2

Multilevel Regression Analyses Testing Association Between Hopelessness, Loneliness, and Burdensomeness and Suicidal Ideation (Study 1)

Dependent variable	SI at T				SI at T + 1				SI at T + 1, controlling for SI at T			
	<i>B</i>	95% CI (<i>B</i>)	<i>SE</i>	<i>p</i>	<i>B</i>	95% CI (<i>B</i>)	<i>SE</i>	<i>p</i>	<i>B</i>	95% CI (<i>B</i>)	<i>SE</i>	<i>p</i>
Fixed parts												
(Intercept)	2.57	1.99–3.15	.30	<.001	2.54	1.91–3.16	.32	<.001	2.54	1.92–3.15	.31	<.001
Hopelessness	.70	.62–.78	.04	<.001	.36	.23–.49	.07	<.001	.07	–.05–.20	.07	.265
Loneliness	.26	.19–.33	.04	<.001	.04	–.07–.15	.06	.483	–.04	–.14–.07	.05	.513
Burdensomeness	.33	.25–.40	.04	<.001	.15	.03–.27	.06	.018	.03	–.08–.14	.06	.615
SI at T									.40	.34–.46	.03	<.001
Random parts												
σ^2		3.364				4.360				3.826		
τ_{00} , subject		4.513				4.761				4.677		
N_{subject}		54				52				52		
ICC _{subject}		.573				.522				.550		
Observations		2891				1396				1396		
R^2/Ω_0^2		.650/.650				.582/.582				.634/.633		
Deviance		11916.70				6164.17				5986.00		

Note. CI = confidence interval; SI = suicidal ideation; T = time T; ICC = intraclass correlation.

deviations, and skewness statistics for all EMA variables are presented in Table 3.

How does suicidal ideation vary over short periods of time?

The variability statistics (*ICCs* and *RMSSD*) for suicidal ideation composite scores as well as the three component items (desire, intention, and ability to resist urge to kill self) are presented in Table 3. Examining the *ICCs* shows that approximately 33% of the variability in suicidal ideation is due to within-person variance (vs. between-person variance). Although less variance is due to within-person variance in this study compared to Study 1, the 95% confidence intervals for each *ICC* in Study 2 overlap with the corresponding 95% confidence intervals in Study 1, suggesting that the interpretations are similar across both studies.

The time series plot of the short-term variations in suicidal ideation is presented in the top of Figure 3. The time series plots of the component items are presented on the left-side column of Figure 3. Like Study 1, and as suggested by the *RMSSD* values (see Table 3), the plots follow a strong sawtooth pattern without any clear linear effect over time. Individual plots of raw overall suicidal ideation scores, along with individual means and standard deviations are presented in Figure 4. Like Study 1, there was variability in suicidal ideation for nearly all participants: 28% of all ratings of suicidal ideation differed from the next consecutive rating by at least one within-person standard deviation and 100% of participants had at least one instance of a suicidal ideation changing by a standard deviation or more from one response to the next. Although all participants had some degree of variability from their mean, there was a wide range of both individual means and how much each participant varied around their mean. The individual plots for the suicidal ideation component scores are presented in supplemental Figure S3 in the online supplemental material.

Do risk factors for suicidal ideation vary over time and predict changes in ideation? Variability statistics (*ICCs* and *RMSSD*) for hopelessness and loneliness are presented in Table 3. Examining the *ICCs* shows that approximately 34% of the variability in hopelessness and 39% of the variability in loneliness was due to within-person variance (vs. between-person variance). Within-person

variations over time in hopelessness and loneliness are shown in time series plots on the right-side column of Figure 3. Individual plots for hopelessness and loneliness are shown in supplemental Figure S4 in the online supplemental material. The patterns follow a strong saw tooth pattern without any clear linear effect over time.

Results of a series of hierarchical linear models examining the association between suicidal ideation and hopelessness and loneliness are presented in Table 4. The leftmost set of results shows the concurrent association of these variables with suicidal ideation (i.e., all variables assessed at Time T). In line with hypotheses, all variables were significantly and positively associated with suicidal ideation. Partially in line with hypotheses, only hopelessness at T was significantly associated with suicidal ideation at T + 1 (middle column of Table 4). The rightmost column of results shows the prospective association of these variables with suicidal ideation (i.e., predictors assessed at T and suicidal ideation assessed at T + 1), controlling for suicidal ideation at Time T. Contrary to our hypothesis, only suicidal ideation at T was significantly and positively associated with suicidal ideation at T + 1.

Discussion

These studies provide the finest-grain examination of the basic characteristics of suicidal ideation conducted to date. The results revealed two key findings. First, for nearly all participants across both studies, suicidal ideation varied dramatically over the course of most days. Nearly one third of all ratings of suicidal ideation were a standard deviation above or below the previous response from just 4 to 8 hr earlier. Second, well-known risk factors for suicidal ideation such as hopelessness, burdensomeness, and loneliness also varied considerably over just a few hours and correlated with suicidal ideation, but were limited in predicting short-term change in suicidal ideation. Each of these findings warrants additional comment.

The first aim of these studies was to describe short-term variability in suicidal ideation. The data revealed that suicidal ideation and its components (desire to die, intention to kill self, and ability to resist the urge to kill self) vary considerably over short periods

Table 3
Descriptive and Variability Statistics for Suicidal Ideation and Its Risk Factors (Study 2)

Variable	Descriptive statistics					Variability statistics		
	<i>M</i>	<i>SD</i>	Range	% nonzero	Skew	ICC [95% CI]	RMSSD	RMSSD range
Suicidal ideation (overall)	5.44	5.53	0–27	82.4%	1.32	.67 [.56, .78]	3.08	.00–7.37
Desire to kill self	2.01	2.32	0–9	65.1%	1.32	.65 [.55, .77]	1.32	.00–3.46
Intention to kill self	1.36	2.12	0–9	49.7%	1.98	.69 [.59, .80]	1.07	.00–2.99
Ability to resist urge to kill self	6.98	2.14	0–9	72.7% ^a	–1.29	.43 [.32, .58]	1.66	.00–5.32
Hopelessness	4.59	2.78	1–10	84.4%	.40	.66 [.55, .77]	1.92	.61–2.07
Loneliness	5.82	2.81	1–10	93.8%	<.01	.61 [.49, .73]	2.11	.00–4.50

Note. CI = confidence interval; ICC = intraclass correlation; RMSSD = root mean square of successive differences (average of each participant's individual RMSSD).

^a Raw item not reverse coded, except for % non-zero, which corresponds to % responses that are not a 4 out of 4.

of time (i.e., hours). These findings are similar to an earlier study by Bagge et al. (2014) that reported an ICC of .45 when using a timeline follow-back methodology to assess suicidal ideation in the 24 hr before a suicide attempt. To put this variability into context, suicidal ideation, with an ICC of .53 in Study 1 and .67 in Study 2 (i.e., 47% and 33% of variance is due to within-person variability in Study 1 and 2, respectively), varied from observation to observation as much as negative affect varied among depressed individuals in another study with a similar monitoring frequency (ICC = .56; Peeters, Berkhof, Delespaul, Rottenberg, & Nicolson, 2006).

The second aim of these studies was to assess short-term variability in three suicide risk factors (hopelessness, loneliness, and burdensomeness) associated with the Hopelessness and Interpersonal Theories. We also wanted to see if these risk factors are associated with short-term changes in suicidal ideation. There were several surprising findings. We learned that these risk factors, long believed to be fairly stable over short periods of time (i.e., a meta-analytic review found that the median time between assessments of suicidal ideation was 24 months; Ribeiro et al., 2016), actually vary quite dramatically over short time periods of hours and days. We also found that higher levels of hopelessness, burdensomeness, and loneliness tended to co-occur with higher levels of suicidal ideation. When examining prospective, short-term associations, only hopelessness across both studies and burdensomeness in Study 1 (it was not included in Study 2), but not loneliness, at T predicted higher levels of suicidal ideation at T + 1 (about 4–8 hr later). When we controlled for suicidal ideation at T, however, only suicidal ideation at Time T was significantly associated with suicidal ideation at T + 1. These analyses suggest that hopelessness, burdensomeness, and loneliness are most useful in identifying suicidal ideation as it occurs but are less useful in predicting suicidal ideation over a very short period. This is generally compatible with Ben-Zeev et al.'s (2012) paper-based short-term retrospective real-time monitoring study that showed hopelessness was not associated with likelihood of suicidal ideation at T + 1 when accounting for presence or absence of suicidal ideation since T.

There are two important points to consider when interpreting the findings on short-term changes in suicidal ideation. First, there are limitations of using one-item measures to assess hopelessness, burdensomeness, and loneliness. It is unclear to what extent a one-item measure might correspond with larger, established measures of these constructs. This limitation is not unique to this study

or these constructs, however. It is inherent in any study measuring the same construct repeatedly each day, necessitating a very brief assessment. Supporting our approach, Fraser et al. (2014) showed that a two-item measure of hopelessness correlated strongly with the full hopelessness scale ($r = .93$); however, more work validating the appropriateness of a one-item measure of these variables is needed, and recent work on the use of single-item measures of suicide-related variables has illustrated the potential error introduced with such an approach (Millner, Lee, & Nock, 2015). Second, null findings should be considered within the context of the effects that these studies could detect. Both studies were sufficiently powered to detect moderate-to-large effects, like those in the cross-sectional analyses. The studies were not sufficiently powered to detect small effects like those that might have been found in the prospective analyses, especially those predicting suicidal ideation at T + 1 adjusting for suicidal ideation at T. This means that we were unable to determine whether hopelessness, loneliness, and burdensomeness did not predict suicidal ideation over time at all or if these effects were simply weakened beyond the size that we could reasonably detect in this study.

There are two points to consider regarding interpreting our findings within the context of the theoretical models tested. First, the interpersonal theory specifies that suicidal ideation is not the result of the main effects of hopelessness, burdensomeness, and thwarted belongingness, but rather the three-way interaction between them. Due to the limitations of both samples' size, we were not able to test this interaction. Future studies with much larger samples are needed to test these effects.⁴ Second, the interpersonal theory makes specific predictions regarding passive versus active ideation, where perceived burdensomeness and thwarted belongingness should be associated with passive suicidal ideation (Van Orden, 2010, 2015). We were unable to fully test these predictions in this study because our assessment of suicidal ideation did not readily lend itself to such a distinction.

These findings do not necessarily refute either theory tested in this study, but suggest that the constructs included in these models may tell us more about: (a) longer-term risk for suicidal ideation,

⁴ We would expect a three-way interaction to produce a small effect. Our power analyses indicated that we would have needed 50 participants \times ~270 responses per participant or over 90 days of responses (three times Study 1's length) at our response rate to detect a small effect ($d = .20$).

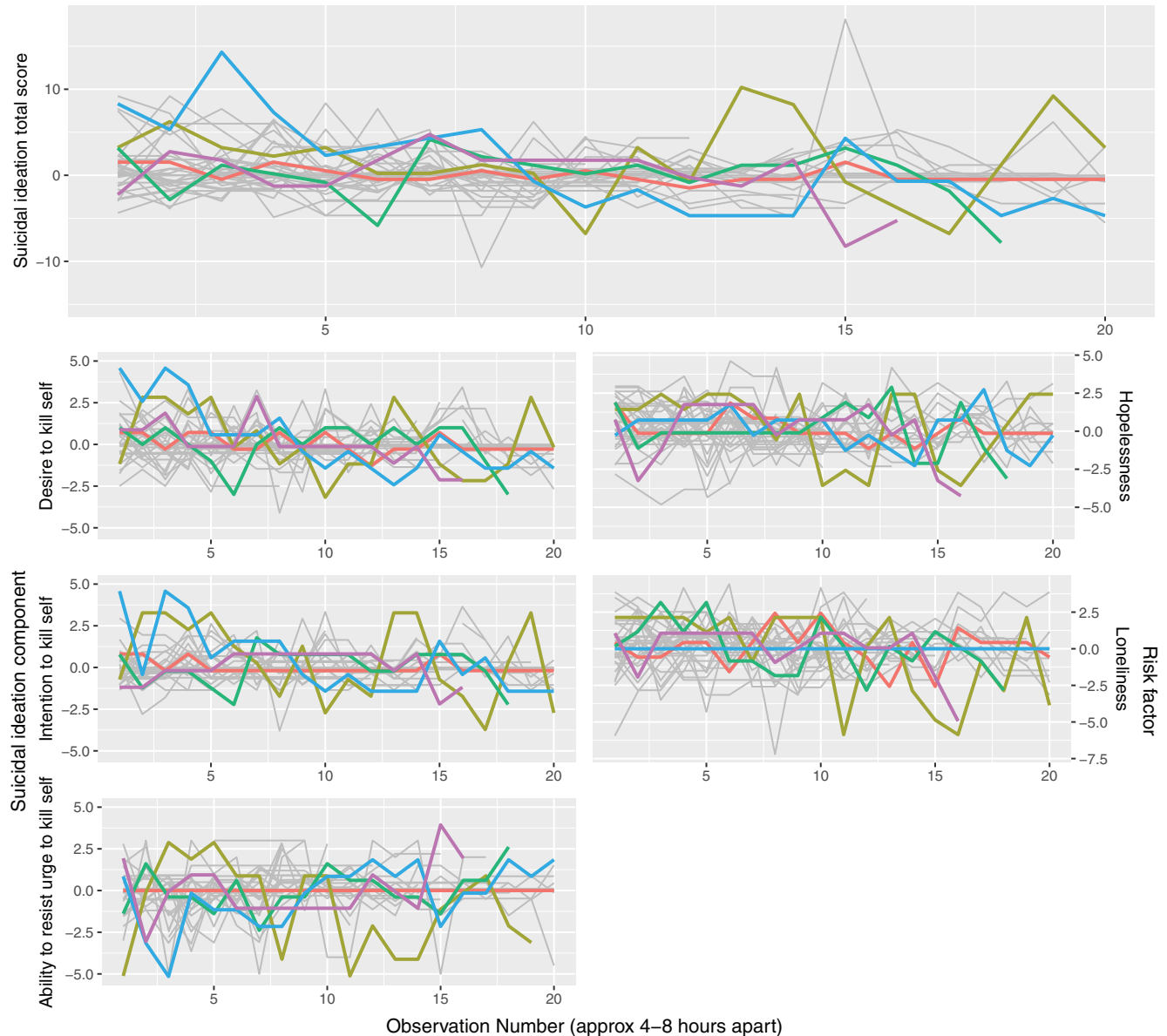


Figure 3. Time series plots of all study variables (Study 2). All variables are group-mean centered. Colored (thicker) lines were participants randomly selected (to enhance clarity of the figure). See the online article for the color version of this figure.

and (b) what factors co-occur with suicidal ideation, but (c) may be limited in their ability to predict imminent, short-term changes in suicidal ideation. This is in line with published work, especially on the hopelessness theory, that finds hopelessness predicts risk for death by suicide over time periods as long as multiple decades (Beck, Brown, & Steer, 1989; Beck, Steer, Kovacs, & Garrison, 1985; Brown, Beck, Steer, & Grisham, 2000). This means that other variables likely predict short-term changes in suicidal ideation. For example, research by Bagge and colleagues (Bagge, Glenn, & Lee, 2013; Bagge et al., 2014) highlights the role of recent negative life events in the emergence of suicidal behavior and it may be that the occurrence of negative life events is also relevant to the emergence of suicidal ideation. Moreover, although

we found that hopelessness, loneliness, and burdensomeness co-occurred with suicidal ideation but did not predict changes in suicidal ideation 4–8 hr later, it is still unknown to what degree these variables predict suicidal ideation in the range of time between right now and 4–8 hr from now. For example, it might be that these variables are useful for predicting ideation 1–2 hr from now but not much later.

These studies must be viewed in the context of several important limitations. First, because we had no reported suicide attempts during the study period, we were unable to predict suicidal behaviors. Second, although this sample was robustly powered to detect Level 1 (i.e., observation-level) effects, it was not sufficiently powered to explore Level 2 (i.e., person-level) effects that might

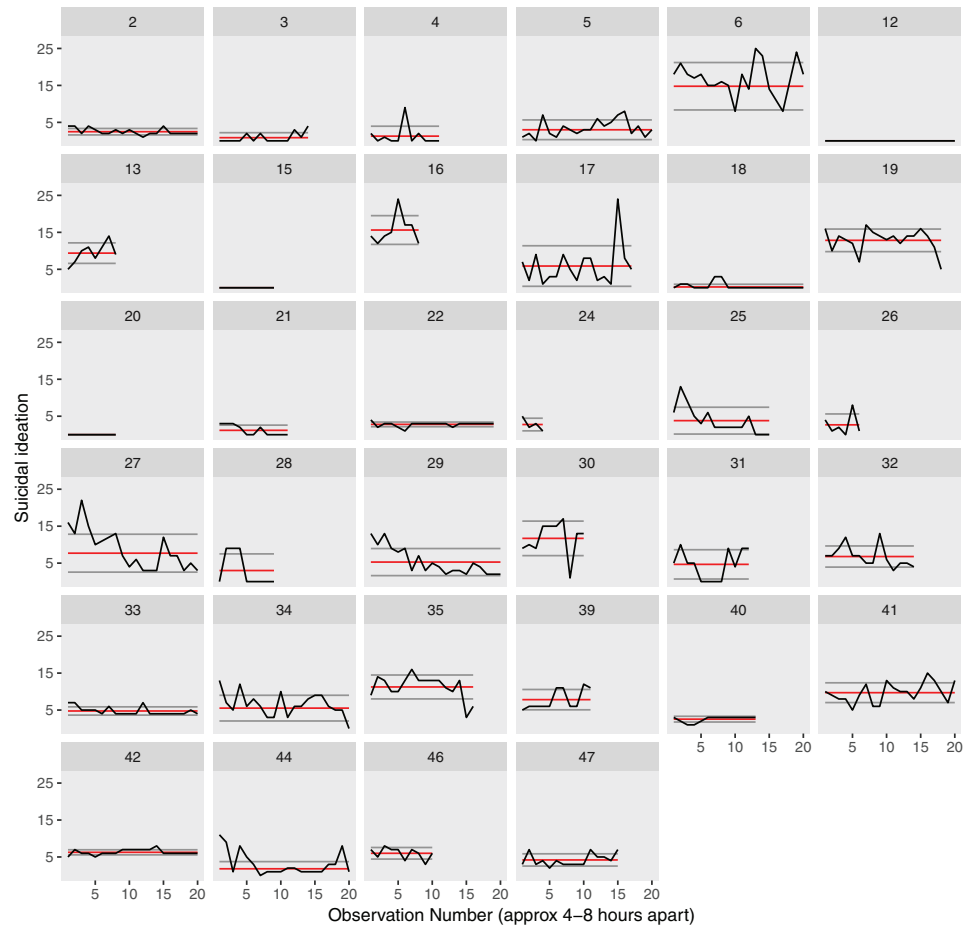


Figure 4. Individual time series plots of raw suicidal ideation scores (Study 2). See the online article for the color version of this figure.

have played a role in predicting short-term variability in suicidal ideation. Larger studies are needed to examine Level 2 predictors of suicidal ideation. Third, although 28 days (Study 1) and an inpatient hospitalization (Study 2) was enough time to see consid-

erable variability in suicidal ideation, it is unknown if individual patterns in short-term variability change over long periods of time (e.g., months or seasons). This is compatible with work that found suicidal ideation varied by semester at the group-level among

Table 4
Results of Multi-Level Regression Analyses Testing Association between hopelessness, loneliness, and Suicidal Ideation (Study 2)

Dependent variable	SI at T				SI at T + 1				SI at T + 1, controlling for SI at T			
	B	95% CI (B)	SE	p	B	95% CI (B)	SE	p	B	95% CI (B)	SE	p
Fixed parts												
(Intercept)	5.65	4.22–7.08	.73	<.001	5.38	3.92–6.85	.75	<.001	2.27	1.47–3.08	.41	<.001
Hopelessness	.92	.76–1.08	.08	<.001	.43	.22–.64	.11	<.001	–.03	–.24–.19	.11	.806
Loneliness	.16	.01–.31	.08	.041	.05	–.15–.25	.10	.654	–.10	–.29–.09	.10	.316
SI at T									.59	.50–.68	.05	<.001
Random parts												
σ^2		7.696				9.154				8.541		
$\tau_{00, \text{subject}}$		18.158				17.341				2.686		
N_{subject}		.36				.33				.33		
ICC_{subject}		.702				.654				.239		
Observations		.642				.468				.468		
R^2/Ω_0^2		.762/.762				.668/.668				.686/.686		
Deviance		3252.977				2463.136				2378.612		

Note. CI = confidence interval; SI = suicidal ideation; T = time T; ICC = intraclass correlation.

college students, with ideation being the highest during the summer semester (Van Orden et al., 2008). Thus, studies with longer follow-up periods are needed to examine these long-term patterns in short-term variability. Fourth, the EMA compliance rates in both studies (62.75% in Study 1 and 62.0% in Study 2), although similar to some related EMA studies (e.g., 58.1% in a sample of individuals with borderline personality disorder; Links et al., 2007), are still somewhat low. This compliance rate is a limitation because it is unknown if these prompts were missed truly at random or if there might be some factor (e.g., high distress) that is leading to a missed prompt. Finally, it is unknown to what extent participants might have been reactive to the multiple assessments, leading to artificial inflation in ratings of suicidal ideation and risk variables. This issue of measurement reactivity is one that exists in all real-time monitoring studies and is unfortunately understudied (cf. Wray, Merrill, & Monti, 2014). Nevertheless, EMA studies of factors that are expected to have little variability (e.g., pain reports among individuals experiencing chronic pain) find that reports are relatively stable across EMA periods (Peters et al., 2000).

One final point that warrants discussion is the notable consistency in findings across the two independent samples reported here. We found that the ICCs in both studies were overlapping suggesting that the variability we observed in Study 1 was a replicable phenomenon in Study 2. Moreover, the ICCs for suicidal ideation were similar to those identified in retrospective studies of ideation within a 24-hr period (Bagge et al., 2014). We found that the interpretations regarding the predictive findings were similar in both studies as well (because the measures were on different scales, interpreting of overlapping confidence intervals is less informative).

There are at least three key clinical implications from these findings. First, these findings imply that no single data point should be used in making clinical decisions. For example, because suicidal ideation can change considerably over just a few hours, clinicians monitoring those believed to be at high risk for suicide (e.g., those on inpatient units) should make discharge decisions based on repeated assessments of suicidal ideation that are below threshold for discharge. This may help reflect the reality that someone currently experiencing low levels of ideation may not necessarily stay that way, especially after being discharged. This is important given the high risk associated with the time immediately after discharge, the first four weeks of which present a higher risk of suicide than the entire 48 remaining weeks in the first year after discharge combined (Bickley et al., 2013; Meehan et al., 2006). Second, given that suicidal ideation varies so quickly, interventions should be designed to teach suicidal individuals how to cope with (and possibly anticipate) these quick changes in ideation. Third, given that suicidal ideation and its risk factors change so rapidly and given that we could assess these changes in ideation using smartphone EMA, it may be that smartphone-based ecological momentary interventions are a fruitful path for intervention into suicide risk.

The strongest implication from this work is that assessing suicidal ideation and its risk factors over long periods of time at infrequent intervals does not accurately reflect the reality of how quickly and frequently suicidal ideation and its risk factors fluctuate over just a few hours. Had we assessed suicidal ideation weekly or even daily, we would have missed these important fluctuations. Thus, it is imperative that future studies assess suicidal ideation in real time. Beyond capturing the reality of how suicidal ideation changes dynamically in the wild, real-time monitoring technology can enhance our

ability to identify which factors best predict suicidal thoughts and behaviors in the hours and minutes before they arise, and ultimately to test interventions targeting key risk factors in the attempt to prevent suicidal behaviors before they occur.

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