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Abstract

One of the greatest challenges to understanding, predicting, and preventing suicide is that we have never had the ability to observe and intervene upon them as they unfold in real-time. Recently developed real-time monitoring methods are creating new opportunities for scientific and clinical advances. For instance, recent real-time monitoring studies of suicidal thoughts show that they typically are episodic, with quick onset and short duration. Many known risk factors that predict changes in suicidal thoughts over months/years (e.g., hopelessness) do not predict changes over hours/days – highlighting the gap in our abilities for short-term prediction. Current and future studies using newer streams of data from smartphone sensors (e.g., GPS) and wearables (e.g., heart rate) are further expanding knowledge and clinical possibilities.

Our understanding of suicide – and our ability to predict and prevent it – has been hindered by a lack of information about the basic nature of suicidal thoughts and behaviors (STBs). One reason for this lack of information has been a gap in studies that assess STBs as they occur in everyday life. Fewer than 1% of all prospective studies of STBs have a follow-up time of a month or shorter [1]. Moreover, most prior studies use wide retrospective periods (e.g., by asking "did you have suicidal thoughts in the past year?"). Although such work is important, it precludes the ability to understand the dynamic nature of how STBs operate as they actually occur. Recent advances in real-time monitoring technology (also called ecological momentary assessment or experience sampling) have made it possible to gain never-before-available information about the nature of STBs by observing them as they occur in a variety of settings [2]. Although real-time monitoring has existed since the 1980s [3], it has recently become more accessible than ever because new smartphone-based real-time monitoring applications allow data collection using hardware the participant already owns. Accordingly, this is an ideal time to explore the current state of real-time monitoring methodology and the literature that uses it to assess STBs. The goals of this paper are to: (1) review recent studies that have used real-time monitoring to better understand STBs, and (2) discuss future directions for this exciting line of work.

Current studies

It is notable that, to date, only ten studies across ten manuscripts (one manuscript reported two studies [4] and one study was reported in two manuscripts [5,6]) have used real-time monitoring to assess STBs (**Table 1**). These studies primarily explore suicidal thoughts, not behaviors. Despite the small quantity and restricted focus, these studies contribute valuable new information about the feasibility of using real-time monitoring to study STBs, the basic nature of STBs, and short-term predictors of STBs.

Feasibility of real-time monitoring. Real-time monitoring of STBs has proven to be feasible in a number of ways. First, participants are compliant with the demands of real-time monitoring. All studies we identified report compliance rates above 50% (meaning that they complete >50% of prompted assessments), many >75%. Participants appear to be equally compliant throughout the duration of the study [5], although compliance tends to be higher during the middle of the day compared to the morning or night [7]. One study found that recent attempters completed fewer responses than psychiatric controls and lifetime attempters [5]. Thus, there may be utility in examining whether patterns of missing responses are meaningful (e.g., suicidal patients might not complete assessments when they are very distressed). Second, although some factors (e.g., caloric intake) change as a result of being assessed repeatedly, this is not the case with suicidal ideation. Repeatedly asking about suicidal ideation does not reduce or trigger it [8]. Third, and most illustrative of the importance of using real-time monitoring to assess suicidal thinking, participants report higher levels of suicidal ideation during momentary assessments than on weekly retrospective assessments [7]. Although real-time monitoring is feasible, before future lines of research are pursued, however, we must address ethical concerns regarding when and how to respond to participants indicating imminent risk.

Descriptive studies of suicidal ideation. Several recent studies have used real-time monitoring to provide information about several basic characteristics of suicidal thinking. First, the severity of suicidal ideation varies considerably over a short period of time. Two studies showed that there is nearly as much variability in reports of suicidal ideation from hour to hour as there is from person to person [4,9]. Second, episodes of suicidal ideation have a quick onset, with nearly one-third of all observations in one study differing by a standard deviation or more

from the prior rating just a few hours earlier [4]. Third, episodes of suicidal ideation tend to be brief, with participants reporting most episodes are shorter than an hour [10]. Fourth, thoughts of suicide are distinct from thoughts of nonsuicidal self-injury (NSSI), and co-occur less than half the time, even among those who frequently engage in NSSI [10].

Although suicidal ideation tends to be episodic, with quick onset and short duration, some people do experience persistent, low-level suicidal ideation. In some studies, >50% of random momentary assessments of suicidal ideation had a non-zero response [4,11,12]. This stands in contrast to studies that ask participants to actively report when they are suicidal and find only about one episode of suicidal ideation each week [10]. This discrepancy could be due to momentary reports picking up on low-level ideation that participants do not notice or would not consider worthy of reporting, or the low-level ideation on momentary reports might represent a baseline and participant-initiated reports might represent deviations from that baseline.

This descriptive work aligns well with prior theory. A tenant of the Fluid Vulnerability Theory is that suicidal ideation fluctuates close to a baseline with episodic peaks representing suicidal crises [13,14]. The short-term fluctuations described above fit well with this model. This work is also in line with intensive retrospective studies using timeline-followback approaches that report nearly the same level of within-person variability as several of the real-time monitoring studies cited above [15].

Predictors of short-term change. Several studies have examined predictors of short-term change in suicidal ideation. One study found that suicidal ideation was associated with average daily affect intensity, but was unassociated with within-day variability or magnitude of change in affect [16]. Some affective states, like sadness, predict time-lagged changes in suicidal ideation (i.e., affect at T, predicting ideation at T+1, adjusting for ideation at T)[6,11]. Other affective states, like hopelessness and loneliness, correlate with momentary suicidal ideation and predict it a few hours later, but do *not* predict time-lagged changes [4,11]. This suggests that there is an important distinction between correlates of ideation, predictors of ideation, and predictors of change in ideation. Moreover, it highlights the importance of identifying factors that predict short-term change in ideation, given that these factors would be very important targets for treatment.

Future directions

Beyond echoing the call for more research using real-time monitoring [17,18], several specific areas of research are needed to "move the needle" on suicide research and prevention.

Larger, longer studies. All but one study discussed here had a sample size under 100 and no study was longer than four weeks. Although a benefit of repeated-measures data is needing fewer participants because each provides multiple data points, this benefit fades when examining between-persons (i.e., level-2) data, where there is only one measurement per person. Some caution the use of level-2 predictors at all with <50 participants [19]. Studies were smaller and shorter than needed because real-time monitoring previously required separate, expensive devices, making larger studies prohibitively expensive. Moreover, power analyses are complicated because commonly-used tools (e.g., G*Power) cannot produce estimates for studies using multi-level data. Recently, however, affordable smartphone-based real-time monitoring apps have become available. Moreover, several R packages are now available that can determine needed sample sizes and sampling frequency for real-time monitoring studies [20,21]. We also created a website for power analyses that does not require knowledge of R (https://goo.gl/5texAe). Thus, available technology now meets the need for larger studies over longer time periods. Larger studies can examine trait-level moderators of momentary responses

(e.g., do people with poor emotion regulation respond to daily stress with more severe suicidal ideation?). Longer studies can tease apart whether constructs vary at the level of the person, day, or time period. For example, if someone reports high stress at every assessment during a 14-day study, it is unclear whether this person habitually reports high stress or if the study is picking up on a stressful period that might not be present during a 14-day period a few weeks later.

Studies conducted during critical high-risk time periods. Although most studies discussed in this paper utilize participants at high-risk for suicide (e.g., those with a prior suicide attempt), with only one exception [6], there has been no exploration of specific time periods when these people are at the highest risk. For example, is well known that one of the highest-risk time periods for suicide is the month after discharge from inpatient psychiatric care [22]. Despite understanding that this period is so risky, it is not clear why it is so risky. Real-time monitoring is particularly well poised to explore this and other critical high-risk periods for suicide such as immediately after a job loss [23] or divorce [24] or within the first year after separation from the military [25].

Use of passive data from smartphones and wearables. Beyond self-report (or "active") data, many real-time monitoring applications are able to collect streams of passive data from the smartphone's sensors, including GPS, call logs, and app usage. These data are valuable because they assess participants' actual behaviors without adding burden to the participant. Researchers have explored other areas (e.g., depression [26,27]) using passive data, but no such work has been done on suicide. It is also possible to combine smartphone data with data from wearable devices. Although there are some research-grade wearables, movement, heart rate, and sleep can be reliably gleaned from consumer-grade wearables that are affordable and may already be owned by participants (e.g., Fitbits). These devices provide objective indicators of sleep (although accuracy is not as high as gold-standard devices [28,29]) and distress in ways not possible with a smartphone device [30]. The most promising use of these new streams of data is combining features from these streams of data (e.g., phone calls made, time asleep, amount of steps taken) in a digital phenotyping/footprinting [31,32] approach that uses classification methods like latent class/profile analysis to identify whether there are unique groups of individuals at risk for suicide [33].

Conclusions

Real-time monitoring is a feasible way to better understand STBs by examining them as they occur in everyday life. The studies reviewed here provide at least two broad pieces of information about STBs that we could not glean from other methodologies. First, suicidal thoughts are episodic, with quick onset and short duration. Second, some factors that predict changes in suicidal ideation over weeks, months, and years do not predict changes over hours and days. Future studies will be able to further expand what we know about STBs by using streams of data from smartphones sensors and wearable devices.

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Table 1. Summary of real-time monitoring studies of suicidal thoughts and behaviors

Citation	Sample	Length in days	Monitoring type	Compliance rate	Main findings
Ben-Zeev, et al. [12]	Inpatients w/serious mental illness (*n*=27)	6	Smartphone (6x/day)	Not reported	SI co-occurs with violent behavior.
Ben-Zeev, Young, & Depp [11]	Depressed inpatients (*n*=30)	7	Pager + paper diary (~6x/day)	Not reported	Boredom, tension, sadness predict time-lagged SI.
Hallensleben et al. [9]	Suicidal or depressed inpatients (*n*=20)	6	Smartphone (10x/day)	>80%	SI fluctuates considerably over time.
Husky et al. [5]	Recent attempters (*n*=42), lifetime attempters (*n*=20), affective (*n*=21). healthy (*n*=13) controls	7	PalmPilot (5x/day)	73.8% (recent attempters), 81.1%-85.7% (others)	Recent attempters completed fewest responses. Compliance did not decline during study.
Husky et al. [6]	Follow-up of 42 recent attempters [5]	7	PalmPilot (5x/day)	73.8%	SI more likely when people were alone. Sadness, anxiety, and happiness predict time-lagged SI.
Kleiman et al. [4]	Adults w/recent SA (Study 1; n=54), Suicidal inpatients (study 2; *n*=36)	28 (Study 1) Length of treatment (Study 2)	Smartphone (4x/day)	62.75% (Study 1) 62.0% (Study 2)	SI fluctuates considerably over time. Hopelessness and loneliness correlate with SI but do not predict time-lagged SI.
Law et al. [8]	Adults w/BPD (129 received SI assessment, 129 did not)	14	PalmPilot (5x/day)	62.9%	Those who received assessment of SI did not differ from those who did not in odds of SI/SA at end of study.

Links et al. [16]	Adults w/BPD (*n*=82)	21	Pager + paper diary (6x/day)	58.1%	Daily negative mood intensity was associated with daily SI.
Nock, Prinstein, & Sterba [10]	Self-injurious adolescents (*n*=30)	14+	PalmPilot (2x/day)	83.3% completed >28 responses	Participants reported 1.1 episode of SI per week. 73.1% of episodes lasted <1 hour. SI and NSSI thoughts do not often co-occur.
Torous et al [7]	Outpatients (*n*=30)	30	Smartphone (3x/day)	77.8% (overall), 75.5% (morning), 84.2% (afternoon), 75.5% (evening)	Momentary SI was significantly higher than SI assessed retrospectively at end of study.

Note. SI = suicidal ideation, SA = suicide attempt, BPD = Borderline Personality Disorder, NSSI = Non-suicidal self-injury.