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Patterns of Change in User-Generated Social Media Behavior among Service Members Who Die by Suicide

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BACKGROUND

Previous research funded by the Defense Suicide Prevention Office (DSPO) found that the content of Service members' social media accounts could differentiate between those who died by suicide and those who died by other causes (Hesse, Bryan, & Rose, 2015). Results suggested that the most useful indicators of suicide risk may vary during different timeframes preceding death. Data generated for the Hesse, Bryan, & Rose. study were reanalyzed in the present study using methods better suited to test temporal effects. These data were based on cases drawn from the Veteran's Affairs/Department of Defense Suicide Data Repository (n=700 Service members who died by suicide and n=700 demographically-matched controls). Nonlinear change processes among suicides and controls were modeled to identify signatures that may be unique to suicide, thereby enabling accurate classification of Service members (i.e., suicide versus control) as well as relative proximity to death.

HIGHLIGHTS

This report builds upon previous social media research aimed at exploring the potential to incorporate social media data into suicide prevention efforts. The present results indicate that, similar to previous findings, certain patterns of change in social media behavior can differentiate suicides from controls (i.e., who will die by suicide), and can provide clues regarding when death by suicide is likely to occur (i.e., 6 months in the future versus 1 day in the future).

Change patterns across five domains of risk were considered: triggers (stressful life events), cognitions (negative beliefs and thoughts), emotions (negative emotions or feelings), physical (somatic complaints and concerns), and behaviors (maladaptive coping strategies and actions).

Based on users' publicly available online data, several signatures of suicide were identified. Across all timeframes, suicide cases showed a change pattern in which posts describing triggers were followed by posts about emotion and cognition, suggesting a long-term signature of suicide. Three months to 1 month prior to death, posts about physical symptoms, emotions, and cognitions disappeared, suggesting a medium-term signature of suicide. Finally, more frequent posts about behaviors followed by fewer posts about cognitions emerged 1 month prior to suicide and strengthened as the date of death approached, suggesting an imminent signature of suicide.

REPORT DOCUMENTATION PAGE

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188		
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.			
1. REPORT DATE: 18052016	2. REPORT TYPE Technical Report 16-02		3. DATES COVERED: May 2015-May 2016
4. Patterns of Change in User-Generated Social Media Behavior among Service Members Who Die by Suicide	5a. CONTRACT NUMBER:		
	5b. GRANT NUMBER:		
	5c. PROGRAM ELEMENT NUMBER:		
6. AUTHOR(S): Craig J. Bryan, Jonathan E. Butner, Sungchoon Sinclair, AnnaBelle O. Bryan	5d. PROJECT NUMBER:		
	5e. TASK NUMBER:		
	5f. WORK UNIT NUMBER:		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Defense Personnel and Security Research Center Defense Manpower Data Center 400 Gigling Road Seaside, CA 93955	8. PERFORMING ORGANIZATION REPORT NUMBER PERSEREC: Technical Report 16-02		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITOR'S ACRONYM(S)		
	11. SPONSORING/MONITOR'S REPORT NUMBER(S):		
12. DISTRIBUTION/AVAILABILITY STATEMENT: (A) Distribution Unlimited			
13. SUPPLEMENTARY NOTES:			

ABSTRACT: This is a secondary analysis of a retrospective study examining social media posts made by military Service members 1 year prior to their deaths. The sample consisted of 700 randomly selected military Service members who died by suicide and a demographically-matched control group of 700 military Service members who died of causes other than suicide. Social media data were previously coded by staff and students at the University of Utah's National Center for Veterans Studies (NCVS). The present study used data analytic methods consistent with dynamic systems modeling and were aimed at identifying suicide-specific change processes that could predict manner of death (suicide vs. control) and the imminence of suicide death (6 months prior to 1 day prior). Findings identified long-term, medium-term, and imminent "signatures" of emerging suicide death, suggesting there may be observable change processes in social media behavior that could signal eventual suicide.

14. SUBJECT TERMS: suicide; social media; military; suicide data repository					
15. SECURITY CLASSIFICATION OF: UNCLASSIFIED			16. LIMITATION OF ABSTRACT:	17. NUMBER OF PAGES: 62	19a. NAME OF RESPONSIBLE PERSON: Eric L. Lang, Director
a. REPORT: UNCLASSIFIED	b. ABSTRACT: UNCLASSIFIED	c. THIS PAGE: UNCLASSIFIED			19b. TELEPHONE NUMBER (Include area code): 831-583-2846

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI td. Z39.18

PREFACE

In 2013, the Defense Personnel and Security Research Center (PERSEREC) began studying how publicly available social media data could inform suicide intervention and prevention strategies, with preliminary results suggesting that such data held considerable promise for detecting at-risk military Service members. The present effort expands on previous work by conducting secondary analyses of existing datasets in order to model the change processes evident in publicly available social media data that precede death by suicide. Results of the present study suggest that the online public behavior of military Service members who die by suicide show unique trajectories that may signal approaching suicide.

Based on the findings from this research, recommendations for integrating the present findings into intervention and prevention strategies will be offered. In addition, recommendations for next steps for continued research are discussed.

Eric L. Lang, Ph.D.
Director, PERSEREC

EXECUTIVE SUMMARY

INTRODUCTION

Suicide is a leading cause of death in the United States (Centers for Disease Control and Prevention, 2014), and is the second leading cause of death among members of the U.S. Armed Forces (Department of Defense, 2013). In Fiscal Year 2014, the Defense Suicide Prevention Office (DSPO) funded the Defense Personnel and Security Research Center (PERSEREC), a division within the Defense Manpower Data Center (DMDC), to conduct research on social networking posts made by military Service members who died by suicide. This initial research was completed in collaboration with the National Center for Veterans Studies (NCVS) at The University of Utah, with results suggesting that the content of social media networks could be used to predict suicide death among military Service members (Hesse, Bryan, & Rose, 2015). Results further suggested that observable patterns that differentiate suicides from controls might change over time. Additional research focused on understanding temporal change processes was therefore recommended. The objective of the present study is to understand better observable change processes leading up to suicide death among military Service members.

METHODOLOGY

This is a secondary data analysis of a dataset created during the initial phase of research (Hesse, Bryan, & Rose, 2015), which entailed a retrospective study that drew a random sample of 700 military Service members who died by suicide between January 1, 2010 and December 31, 2011, and a demographically matched control group of 700 military Service members who died by means other than suicide (e.g., accident, homicide, medical condition) during the same timeframe. The sample was drawn from the Suicide Data Repository (SDR). As reported by Hesse, Bryan, & Rose (2015) , the sample was predominantly male with a mean age of 30 years.

In the present study, 36 suicide risk factors were categorized into five conceptual domains: triggers, emotions, cognitions, behaviors, and physical symptoms. A dynamic systems modeling approach was used to identify change processes that lead up to suicide and that differentiate suicides from controls. Models were centered at 6 months, 3 months, 1 month, 1 week, and 1 day prior to death to determine signals of emerging suicide death at each of these timeframes. Simulations were run to test the algorithm and to illustrate change processes occurring among multiple variables.

FINDINGS

Long-term Signatures of Eventual Suicide

On average, during all relevant timeframes, suicide cases showed a temporal pattern in which posts about triggers preceded posts about emotions and cognitions; control cases did not show this same pattern. Posting about stressful life events immediately prior to posting about negative emotions and beliefs was therefore a useful signal for death by suicide. This signal strengthened as the date of suicide approached, suggesting that in addition to serving a long-term signature of suicide, this particular signal might also provide information about the imminence of suicide death.

Medium-term Signatures of Eventual Suicide

A three-way relationship among posts about physical symptoms, emotions, and cognitions was observed for both suicides and controls until approximately 3 months prior to death, at which time this relationship disappeared for suicide cases. By comparison, this relationship remained constant for the controls up until the day before death. Posts about physical or somatic complaints that were not temporally related to posts about negative beliefs and emotions therefore served as a second signal for eventual death by suicide. Because this signal emerged between one and 3 months prior to death, it may serve as a useful medium-term indicator of eventual suicide.

Imminent Signatures of Eventual Suicide

Approximately 1 month prior to death, a relationship between behavior and cognition emerged among suicide cases. Specifically, posts about maladaptive behaviors were followed by less change in posts about negative beliefs, which suggests a stabilizing effect of maladaptive behaviors on cognitions. This means that suicide is likely to occur within 1 month when a Service member posts about maladaptive behaviors and subsequently becomes more consistent in posting about negative beliefs. By contrast, in the absence of posts about maladaptive behaviors, increased consistency in posts about negative beliefs does not necessarily signal emerging suicide. Because this specific pattern emerged within 1 month of death and strengthened at 1 week and 1 day prior to the suicide, it may signal imminent risk for suicide.

DISCUSSION

The primary purpose of this study was to model temporal trajectories in social media behavior leading up to suicide, and to identify specific change processes that might differentiate suicides from controls. Similar to Hesse, Bryan, & Rose (2015), results of the current effort demonstrate that social media data can be used to determine who is likely to die by suicide. The present efforts build on the findings of

Hesse, Bryan, & Rose . by providing clues regarding the timing of a Service member's death by suicide (e.g., 6 months to 1 day later).

When examining change processes manifest on publicly available social media platforms, findings suggest that Service members who die by suicide differ in unique ways from Service members who die of other causes. Of note, those who died by suicide were more likely to post about a stressful life event first, then post about negative emotions and beliefs. In contrast, those who died of other causes tended to show the reverse pattern. This may suggest that suicide cases are more emotionally and cognitively reactive to life stressors.

Approximately 3 months prior to their deaths, suicide cases also tended to show a pattern in which posts about physical or somatic problems occurred independent of posts about negative beliefs and emotions. This may suggest disruptions in conscious awareness of the stress response among suicide cases, such that communications about physiological indicators of autonomic arousal (e.g., pain, insomnia) occur independent of internal psychological states.

Finally, in the month immediately preceding their deaths, suicide cases showed a unique change process in which posts about maladaptive behaviors (e.g., social withdrawal, alcohol use) were associated with subsequent stabilization of their negative belief system. In other words, as Service members posted more about maladaptive behaviors, the frequency of posts describing a negative worldview and self-perceptions tended to remain constant. This may suggest that, for Service members approaching death by suicide, increased engagement in maladaptive coping "backfires" and reinforces their negative worldview and sense of self.

RECOMMENDATIONS

Recommendations for Suicide Prevention and Intervention

(1) DSPO should explore options for integrating publicly available social media data into existing suicide prevention and intervention programs and strategies. Existing suicide prevention efforts are largely based on the dissemination of lists of risk factors and warning signs to military personnel and the general public, but do not explicitly highlight the potential role of social media behavior in suicide risk detection and prevention.

(2) DSPO should explore options for enhancing existing suicide prevention efforts by integrating information about suicide-specific change processes. The present results suggest that public health approaches to risk detection and identification may be enhanced by considering specific temporal sequences of certain risk factors and warning signs.

(3) DSPO should explore options for integrating results into suicide prevention efforts aimed at family members and friends of Service members who are

outside of the military, as these individuals are more likely to observe Service members' social media behavior than military leadership and peers.

(4) DMDC should explore options for assessing the incremental value of applying dynamical systems theory methods to other DoD datasets and databases, to include electronic health records.

Recommendations for Future Research

(1) Future research should be conducted with larger samples to replicate these findings and to examine potential differences among subgroups of social media users (e.g., differences by gender and age). For instance, additional subjects could be drawn from cohorts beginning with the 2012 calendar year. Including more recent generational cohorts would also provide information about the applicability of findings to newer and upgraded/updated social media platforms, as well as generalizability across age cohorts who may use social media in unique ways.

(2) Future research should include social media users with higher levels of privacy settings to determine if observed change patterns are generalizable to the larger community of social media users, as opposed to the subgroup who do not restrict public access to their data. Due to the privacy implications of such a study, alternative study designs would be required to include informed consent by social media users. Such research should also take into account the possibility that voluntary consent to participate in such research may influence online social media behavior in the short-term.

(3) Because many Service members who die by suicide demonstrate increased frequency of medical visits during the months immediately preceding their deaths, DSPO should explore options for applying the specific analytic methods used in the present study (i.e., dynamical systems theory) to DoD medical databases to assess if the modeling of nonlinear change processes provides incremental value in identifying Service members who die by suicide.

(4) Future research should aim to integrate automated detection methods with human detection methods. Whereas automated methods (e.g., natural language processing) are likely to provide scalability of risk detection across hundreds of thousands to millions of users, human coding procedures may provide greater semantic nuance (e.g., use of humor and sarcasm). Determining if the combination of these two methods can provide incremental utility relative to either method in isolation would therefore be of value.

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INTRODUCTION

Suicide is a leading cause of death in the United States, and is the second most common cause of death in the United States military (Department of Defense, 2013; Nevin & Ritchie, 2013; Ritchie, 2003). The rise in suicide rates in the U.S. military and general population during the past decade highlights the need for improved clinical and preventative efforts. From 2001 to 2010, only 45% of military personnel who died by suicide kept an outpatient medical appointment in the 30 days preceding their deaths (Trofimovich, Skopp, Luxton, & Reger, 2012), suggesting the majority of military personnel and veterans do not seek medical care immediately before their suicides. Furthermore, the majority of individuals who die by suicide deny or do not report suicidal intent in the time leading up to their deaths (Busch, Fawcett, & Jacobs, 2003; Coombs et al., 1992; Hall, Platt, & Hall, 1999; Kovacs, Beck, & Weissman, 1976). Early detection and identification strategies of individuals who are outside the health care system are therefore needed.

Another critical knowledge gap relates to temporal change processes that precede suicidal behavior. Implicit to the most contemporary models of suicide is a change process in which a person begins at a starting point (e.g., suicidal thoughts) and subsequently transitions to an end point (i.e., suicide attempt) at some later time. Although considerable theoretical and scientific work has focused on understanding why individuals die by suicide, few researchers have explicitly modeled change processes in order to characterize how suicidal behaviors emerge from suicidal thoughts and, more importantly, when suicidal behaviors will occur (Bryan & Rudd, in press). Suicide prevention necessitates intervention before the occurrence of lethal suicidal behavior; understanding the process of emergent suicide risk is therefore essential for knowing when and for whom to provide a potentially life-saving intervention.

In support of this, the Defense Suicide Prevention Office (DSPO) funded an initial effort to identify indicators of suicide risk using social media (Hesse, Bryan, & Rose, 2015). The present study used the same sample and indicators of suicide risk identified in this prior effort, but focused specifically on patterns of change in suicide risk indicators over time. Using a sample of 700 military personnel who died by suicide in 2010 and 2011, and a sample of 700 personnel who died by other means during the same time period, this effort aims to identify individuals at risk of suicide based on publicly available social media behavior. By focusing on change processes, the present work is intended to inform family members, friends, colleagues, and policy-makers about the typical time course that precedes death by suicide, as well as the specific combinations and patterns of risk factors may best indicate long-term, medium-term, and imminent risk of suicide.

BACKGROUND

Implicit to the notion of suicide prevention is a change process: suicide can only be prevented if its emergence from a prior (low risk) state can be known. Conceptual

INTRODUCTION

and empirical work in the field of suicide traditionally has not explicitly modeled change processes, which limits our understanding of how and when suicidal behaviors emerge from suicidal thoughts or impulses. Few contemporary models of suicide provide a clear framework for understanding *when* the transition from thought to action will occur or how this transition is expected to unfold. The process of emergent suicide risk (i.e., how an individual gets from ideation to attempt) therefore remains largely unaddressed.

One model that provides a framework for understanding the dynamic process of suicide risk over time is the fluid vulnerability theory (FVT; Bryan & Rudd, in press; Rudd, 2006). According to the FVT, suicide risk is inherently dynamic, and fluctuations in risk occur as a result of continually changing interactions that occur among multiple risk and protective factors. Many risk and protective factors for suicide also have stable properties that persist over time. Mood, for instance, fluctuates on a day-to-day basis. For individuals with major depression, however, these daily fluctuations might occur around a much lower level of mood as compared to someone without depression. Individuals with depression have ups and downs (this corresponds to the dynamic dimension of risk), but overall their mood is much lower than individuals without depression (this corresponds to the stable dimension of risk). Although individuals with recurrent depression have "good days" and "bad days," on the whole they tend to have lower mood. As a result, they are more likely to become suicidal and to engage in suicidal behaviors than individuals without depression.

The FVT further posits that risk and protective factors influence each other; change in one can affect change in another. Variables that are temporally related to each other can be described as *coupled.* A change in insomnia, for instance, can cause a change in mood. This would suggest an insomnia-mood coupling relationship in which the intensity of insomnia predicts the magnitude of (or "drives") subsequent changes in mood, such that current insomnia severity determines where mood is likely to be at the next time point. Coupled variables can also have transactional or reciprocal relationships over time; changes in insomnia may not only prompt a change in mood, but a change in mood might also prompt a change in insomnia. Insomnia therefore drives mood and mood, in turn, drives insomnia. This moment-to-moment interplay among multiple risk and protective factors is captured by the FVT's concept of the *suicidal mode,* a structural framework for understanding how cognitive, behavioral, affective, and physiological factors interact over time. Structurally, the suicidal mode is comprised of four interactive and mutually influential domains: cognitions, behaviors, emotions, and physical symptoms. Consistent with the FVT, these four domains have stable as well as dynamic features. Examples of stable versus dynamic features of these four domains are summarized in Table 1.

Table 1
Stable and Dynamic Characteristics of each Domain of the Suicidal Mode

Domain	Stable	Dynamic
Cognitive	• Internalized and implicit self-perceptions (e.g., shame, self-hatred, perceived defectiveness) • Cognitive inflexibility • Problem solving deficits • Pessimism	• Automatic thoughts and situational appraisals (e.g., hopelessness, feeling trapped, self-deprecation)
Behavioral	• Distress tolerance skills • Emotion regulation skills • Interpersonal communication skills • Coping style	• Substance use • Social withdrawal • Preparatory behavior or suicide rehearsal
Emotional	• History of psychiatric disorders • Emotional lability • Hypothalamic-pituitary-adrenal axis dysfunction	• Depression • Anger • Guilt
Physical Symptoms	• Demographics • Genetic vulnerabilities • Brain structure • Medical conditions	• Agitation • Insomnia • Pain • Muscle tension

According to the FVT, acute suicidal crises are activated by acute life stressors, also referred to as *triggers*. Stable risk factors serve to establish the individual's set point around which the individual fluctuates on a moment-to-moment basis, akin to the individual's point of equilibrium. Because the four domains of the suicidal mode are interactive, change in one domain is often associated with change in another domain. In other words, individuals who experience increased emotional distress in response to stressful life events also tend to experience changes in physiological arousal and cognitive appraisals. Individuals may also be driven to engage in certain behaviors in response to shifts in their internal psychological state. In this way, the FVT provides a model for understanding the downward spiral or snowball effect that many suicidal individuals experience when describing the sequence of thoughts, emotions, physical sensations, and behavioral responses leading up to a suicidal crisis. By extension, it also provides a model for understanding the upward spiral associated with recovery from a crisis.

To illustrate the importance of considering both stable and dynamic dimensions of risk, consider two different hypothetical trajectories of suicide risk preceding a Service member's death by suicide (see Figure 1). Both trajectories are similar in that suicide risk fluctuates over time, although the week-to-week ebb and flow of risk is more pronounced for Trajectory A than for Trajectory B. These fluctuations represent the dynamic nature of suicide risk. Of note, during the first 13 weeks, Trajectory A has a higher average level of risk than Trajectory B, but from weeks 14 to 22, the average risk levels for both trajectories are fairly similar. After week 23, Trajectory A again has a higher average risk level. In the final 2 weeks of life,

however, Trajectory B suddenly increases and catches up to Trajectory A. Although there are periods where Trajectory A and Trajectory B seem very similar to each other in terms of suicide risk, we can see that Trajectory A has an overall higher level of risk. This reflects the stable dimension of suicide risk: Trajectory A tends to have persistently elevated risk in spite of short-term fluctuations.
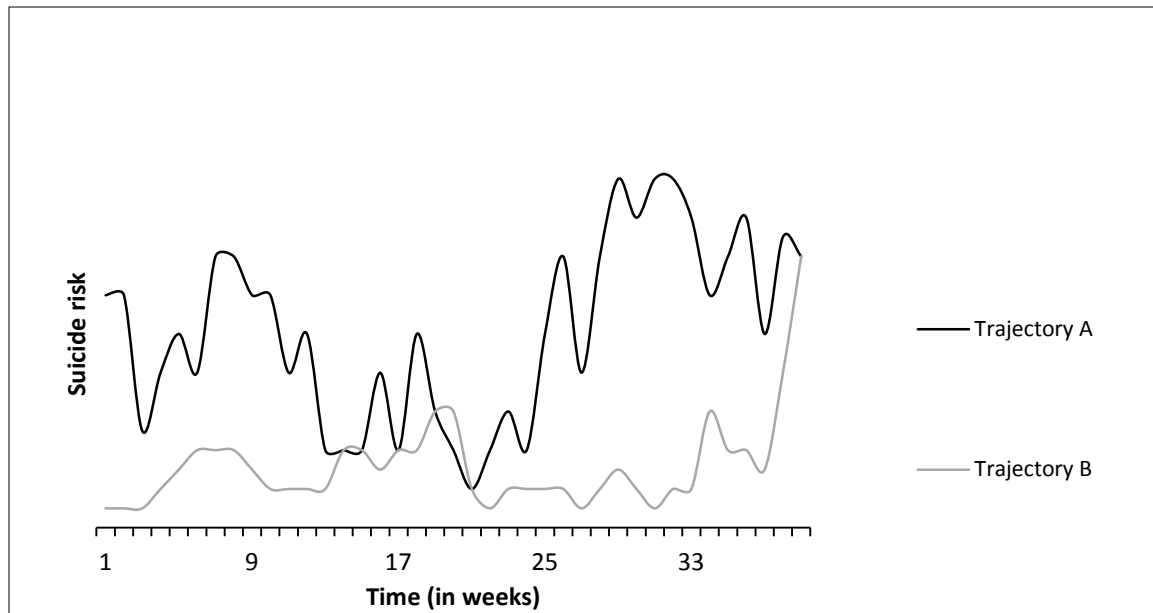
Figure 1 Two Hypothetical Trajectories of Suicide Risk Leading up to a Service Member's Death by Suicide

When considering these temporal patterns, it is likely that the suicide in Trajectory B would be described as impulsive because it is characterized by a sudden departure from the low risk set point. Interestingly, the suicide that results from Trajectory A might also be described as unexpected or impulsive because the level of suicide risk at which the suicide occurred was lower than the trajectory's peak level of risk, which occurred several weeks earlier. Why did the suicide not occur during the highest risk period of time, as traditional approaches to conceptualizing suicide risk would posit?

One approach to answering this question is examining the change process itself. The two trajectories illustrated in Figure 1 suggest different change processes, which might suggest that each trajectory has different warning signs. Alternatively, there may be a common change process across both trajectories that remains hidden because we are not focusing on the unique temporal patterns that may exist among multiple risk variables. For example, insomnia that precedes change in depression may serve as a warning sign for suicide, but depression that precedes change in insomnia may not. In both cases, insomnia and depression are implicated, but the specific temporal pattern of change matters much more. In this case, suicide emerges from a change process in which insomnia drives change in depression, but does not emerge from a change process in which depression drives

change in insomnia. The specific direction of influence among multiple risk factors therefore matters. In some cases, this temporal interplay may be relatively fixed over time, consistent with the stable dimension of suicide risk; in other cases, this interplay may come and go over time, consistent with the dynamic dimension of suicide risk. Consideration of both stable and dynamic change processes is a core assumption of the FVT, and can be applied to the analysis of social media data.

From a prevention and intervention perspective, the application of the FVT provides a basis for triaging an individual's risk and implementing suicide prevention interventions that match the individual's point along the trajectory to suicide. Individuals with change patterns suggesting they are on a trajectory towards suicide but are as-yet relatively far from this event (e.g., 12 months prior to death) may benefit from a relatively low-intensity intervention that enacts a small but important change in their overall trajectory. In contrast, individuals with change processes suggesting they are on a trajectory towards suicide and are very near to this event (e.g., 1 month or less prior to death) may require a more intensive and aggressive intervention such as outpatient psychological treatment. By extension, individuals reporting or displaying suicide risk factors who manifest change processes suggesting they are *not* on a trajectory to suicide may be targeted for non-crisis interventions that may be better suited to their unique needs. In summary, the FVT provides a conceptual basis for determining who should get which interventions at which times.

SUICIDE WARNING SIGNS

Because of its emphasis on the role of temporal dynamics in the emergence of suicidal behaviors, fluid vulnerability theory provides a practical model for identifying and conceptualizing "warning signs" for suicide, which serve as indicators of short-term (i.e., within days or weeks) elevations in suicide risk (Rudd et al., 2006). There is emerging consensus that factors such as insomnia, agitation, and social withdrawal may signal suicide risk even in individuals who deny suicidal ideation or intent. Recent scientific progress indicates that the expression of suicide-specific beliefs such as perceived burdensomeness, perceived distress intolerance, and self-hatred are better predictors of suicide attempts among military personnel than self-reported suicide ideation (Bryan et al., 2014). Despite these advances, the fact remains that there are no scientific studies that have identified reliable warning signs for suicide within timeframes of greatest interest and relevance to clinicians and preventionists (e.g., days to weeks). This is arguably the most significant gap in our current understanding of suicidal behaviors, and is the single largest barrier to effective suicide prevention efforts.

The concept of the warning sign has been widely implemented by the general community to prevent a wide range of diseases and health issues. Warning signs are publicized under the assumption that identifying and disseminating warning signs improves public awareness, leading to early detection and intervention, and

ultimately resulting in improved outcomes within the targeted domain. For example, standardized warning signs for a heart attack are widely available and commonly known among the public (Carter, 2004; Lee, 2004). In the case of suicide prevention, the identification and dissemination of suicide warning signs would ideally lead to a reduction in deaths by suicide. The remarkable inconsistency with which supposed suicide warning signs have been identified and disseminated hampers effective prevention (Mandrusiak et al., 2006).

The lack of knowledge about suicide warning signs is attributable to several factors including the proliferation of empirically supported risk factors, overemphasis on methods requiring honest self-disclosure of suicidal ideation or intent, and limited understanding about the typical course of a suicidal episode. The present research effort aims to mitigate these problems by analyzing data that do not require self-identification of suicide risk (i.e., social media data) and by using contemporary data analytic methods that explicitly model temporal processes

The Problem of Risk Factor Proliferation

Of the hundreds of suicide risk factors and warning signs that have been empirically identified and/or disseminated to the public, it is currently unknown which carry the greatest weight and should therefore be emphasized in education and community-based programs. Our best clinical and prevention approaches are based on lists of risk factor with predictive timeframes that can extend to 20 years later (e.g., Brown, Beck, Steer, & Grisham, 2000), but the notion of the warning sign implies short-term or imminent risk, on the order of hours to days or weeks. Knowledge about which variables serve as useful indicators of risk during different timeframes of interest (e.g., 1 week, 1 month, 3 months, 6 months, or 12 months prior to suicide) is therefore needed to identify high-risk individuals, and to more accurately and appropriately triage risk. Social media data may present a solution to this problem because it can provide information about a wide range of risk factors during different timeframes in "real time."

The Problem of Self-reported Suicidal Ideation or Intent

A second problem is the overemphasis on self-report methodology for predicting future suicidal behaviors. Individuals are not always aware of their suicide potential even in the presence of underlying risk factors, which limits their ability to accurately report risk to others and limits opportunities for early and effective intervention. A much greater challenge relates to motivational issues that influence the individual's willingness to honestly and accurately self-disclose suicide risk to others. Accurate self-disclosure of suicide risk is an issue of particular concern among military populations due to considerable mental health stigma and fear of negative career impact secondary to disclosure. Research has consistently shown that the majority of suicide decedents do not report, or in some cases deny, suicidal ideation or intent immediately prior to their deaths (Busch, Fawcett, & Jacobs, 2003; Coombs et al., 1992; Hall, Platt, & Hall, 1999; Kovacs, Beck, & Weissman,

1976). Similar data have been reported among military and veteran samples (Department of Defense, 2013; Department of the Army, 2011; Poulin et al., 2014). In previous PERSEREC social media research (Hesse, Bryan, & Rose, 2015), researchers found that only 7 out of 222 suicide cases (3.2%) disclosed suicide ideation on their social media profiles during the year preceding their deaths. By comparison, 6 of 244 non-suicide cases (2.5%) disclosed suicide ideation on social media during the same timeframe. Self-report of suicidal thoughts and intentions on social media platforms may therefore have limited utility for risk detection purposes. Identifying unique change processes among other indicators of risk (e.g., mood, substance use) could therefore provide clues about the emergence of suicide without relying on the accurate self-disclosure of suicide risk. Because social media users often post content about a wide range of suicide risk factors, social media platforms provide a uniquely large amount of information about multiple indicators of risk.

The Problem of Risk Trajectories

Very little is known about the trajectory of the suicidal crisis over time. Is there an identifiable stage characterized by signs or symptoms that precede later suicide? What is the typical course of transition from suicide ideation to behavior? How do we know when a suicidal crisis has truly "resolved"? Because the overwhelming amount of suicide research to date relies on single time point measurement and/or infrequent assessments of risk, our ability to understand changes in suicide risk status in "real time" is considerably reduced. Methods that repeatedly assess variables of interest with sufficient frequency are needed to map out better the ebb and flow of suicide risk over time. Because many social media users engage in online behaviors on a daily, weekly, or monthly basis, social media provides a unique dataset with sampling frequencies that are sufficiently high to model risk trajectories with much greater nuance and precision than the typical study.

THE PRESENT STUDY

The primary aim of the present study is to improve the identification of Service members who eventually die by suicide by using social media data and advanced data analytic methods designed to address the limitations noted earlier. To achieve this aim, we used data extracted from social media accounts of Service members who had died by suicide and Service members who had died for reasons other than suicide. By including data from Service members who had died by suicide as well as non-suicide causes, the present study was able to identify change processes that may be unique to suicide.

The analytic approach adopted in the present study was based on dynamical systems theory (Butner, Gagnon, Geuss, Lessard, & Story, 2015). Dynamical systems theory is an especially well-suited analytic approach for the present study because it assumes *emergence* of a construct or behavior over time; in the present study, the emergent behavior of interest was death by suicide. Emergence assumes

that a Service member's behavior over time is the result of complex interactions among the Service member's many risk factors, and that the Service member's behavior cannot be easily deduced from any risk factor alone. Emergence also assumes that variability in the outcome (i.e., manner of death) is a function of stable temporal patterns, the ability to move among different stable patterns, and naturally-occurring fluctuations over time that occur as a result of perturbations that act upon Service members. Dynamical systems theory therefore assumes that the change process entails both stable and dynamic dimensions; it is therefore an analytic approach that is consistent with the fluid vulnerability theory of suicide. In the present study, we modeled the stable and dynamic change processes observed within the content of Service members' social media profiles to determine if there are change patterns that are unique to suicide during different timeframes leading up to a Service members' death. The identification of suicide-specific change processes on social media could potentially advance our ability to identify at-risk Service members and match them to an appropriate level of intervention.

METHOD

PARTICIPANTS

Participants included Service members who died between January 1, 2010, and December 31, 2011, and whose information were contained in the Suicide Data Repository (SDR), a database containing data from the National Death Index and the Defense Casualty Analysis System. A total of 700 records of Service members who died by suicide and a total of 700 records of Service members who died by a manner other than suicide were extracted. Records in which the manner of death was difficult to determine (e.g., accidental discharge of firearms, accidental poisoning or overdose) were excluded from the study to minimize the possibility of misclassification of cases.

Of the 1,400 participants in the sample, 315 had publicly available social media data that could be used for data analyses. A detailed description of the sample's demographics can be found in an earlier report (Hesse, Bryan, & Rose, 2015), but in summary the sample was predominantly male (93.1%) and ranged in age from 17 to 68 years old, and approximately half (44.6%) were identified as White. Participants represented all branches of Service: 60.4% Army, 14.8% Air Force, 11.9% Navy, 11.1% Marine Corps, and 1.8% Coast Guard. In terms of Service component, 42.9% were Regular, 32.5% were Reserve, and 24.6% were National Guard. The majority (90.6%) were enlisted rank.

DATA COLLECTION AND CODING PROCEDURES

As reported in Hesse, Bryan, & Rose (2015), personally identifiable information (PII) was collected from the National Death Index, Defense Casualty Analysis System, and personnel files from the Defense Manpower Data Center (DMDC). PII was sent to a social media vendor to conduct searches for publicly available online content from social networks (e.g., Facebook), microblogs (e.g., Twitter), and blogs. For this effort, publicly available refers to information returned in searches that is not meaningfully restricted. No usernames or passwords were provided to the vendor; therefore, none of the information used in this report was secured behind a password or required log-in or special access. The vendor used PII to gather as much publicly available content as possible through multiple mechanisms, including search engines, custom web crawlers, and social media aggregators. After the data were aggregated, the vendor leveraged its proprietary identity resolution process to indicate how the returned data are matched to the individual they searched. All of the data collected were posted by subjects during the year prior to their death.

De-identified social media reports were sent to researchers at the National Center for Veterans Studies (NCVS) located at The University of Utah. Researchers coded all social media posts to determine the presence or absence of 36 risk factors for suicide. Detailed descriptions and examples of each risk factor can be found in

METHOD

Hesse, Bryan, & Rose, 2015. The 36 indicators were organized into five variables consistent with the fluid vulnerability theory of suicide (Rudd, 2006): triggers, cognitions, behaviors, physical symptoms, or emotions. Due to low frequency counts for each of the 36 risk factors, factor analyses were unable to be conducted. Use of the five risk variables was therefore based on previous theoretical and conceptual work as opposed to the psychometric properties of the data set. The risk factors assigned to each of the five risk variables are listed in Table 2.

Table 2
Risk Factors Assigned to each of the Five Domain Risk Variables, as Described by the Fluid Vulnerability Theory

Cluster	Risk Factors
Triggers Descriptions of stressful situations or life circumstances	• Interpersonal or relationship problem • Significant loss • Legal or disciplinary issue • Financial problem • Employment problem • Reintegration or adjustment problem
Cognition Descriptions or verbalizations of beliefs, assumptions, and/or subjective appraisals of the self, others, or a situation	• Wish for death • Suicide ideation • Thwarted belonging or isolation • Perceived burdensomeness • Meaninglessness or lack of purpose • Self-hatred • Hopelessness • Trapped or helplessness • Unbearability
Behavior Descriptions of maladaptive actions that are directly observable and/or entail motor activity	• Nonsuicidal self-injury • Suicide rehearsal or preparation • Suicide attempt • Alcohol use • Drug use • Medication misuse • Withdrawing from others • Verbal or physical aggression or violence
Physical Symptoms Descriptions of somatic complaints or health-related issues	• Insomnia • Hypersomnia • Agitation • Concentration problems • Physical problems or pain
Emotion Descriptions of feelings or negative internal affective states or experiences	• Anger • Sarcasm • General distress • Guilt • Anxiety • Depression • Shame • Loneliness

Seventeen coders were trained to identify each of the 36 risk factors using a coding manual and continual oversight and monitoring for quality assurance. The specific training and coding procedures, described elsewhere (Hesse, Bryan, & Rose, 2015), yielded interrater reliability estimates (i.e., kappa coefficient) greater than 0.90 for 34 of the 36 risk factors. Overall, kappa estimates ranged from 0.67 to 1.00 (M=0.97, SD=0.06, median=0.99). To minimize bias, coders and all researchers at the NCVS were blind to manner of death.

As expected for multiple domains of suicide risk, the five variables of interest had moderate to high intercorrelations (see Table 3). None of the five variables were significantly correlated with manner of death (rs<|0.09|).

Table 3
Intercorrelations Among the Five Risk Variables

	Cognition	**Behavior**	**Trigger**	**Physical**	**Emotion**
Cognition	1.00				
Behavior	0.45**	1.00			
Trigger	0.64**	0.52**	1.00		
Physical	0.38**	0.53**	0.54**	1.00	
Emotion	0.64**	0.69*	0.77**	0.74**	1.00

*p<.05, **p<.01

DATA PREPARATION PROCEDURES

Using the R software, we read and merged two separate data files. The first data file contained the coded variables and dates of each social media post, and the second data file contained dates of death for each participant. A series of multilevel modeling (MLM) analyses were used to establish the parameters and significance values of each analysis to create the network modeling. MLM analyses were selected to account for variability *within* individual users as well as variability *between* individual users. In other words, individual users could make multiple posts over time; multiple posts made by a given user are therefore related to each other (e.g., what a user posts at any given time often depends on what was posted previously). MLM takes into account the temporal relationships that might exist among posts within users and separates those effects from the temporal relationships that differ among unique users. Formatted and string values of the suicide variable were coded as 1 for people who died by suicide and 0 for those who did not die by suicide. Next, we created five variables corresponding to the suicidal mode clusters: trigger, cognition, behavior, physical, and emotion.

A new data set was created by merging each participant's variables of interests with their dates of death. Within this merged data set, a new variable (*date_diff*) was created indicating the difference date between date stamp variable and death date variable, such that a value of 0 indicated the post occurred on the day of death, negative values indicated posts that occurred prior to death, and positive values

indicated third party posts that occurred after death. Using the date difference variable, we identified entries with dates that occurred after the date of death, entries that occurred more than 1 year before the date of death, and erroneous dates. These entries were omitted from data analyses in order to restrict information to only those posts that occurred during the 12 months leading up to participants' deaths. We further restricted the database to include only social media posts generated by the user themselves; posts generated by third parties were omitted. This restriction was imposed because the primary goal was to model trajectories to suicide as they emerged within the suicidal person. The ordering of individual social media posts was sorted in ascending order within each individual. The raw change score from one time point to the next (future minus current) was then calculated for each risk variable.

To generate parameters and to test effects where the model was allowed to differ as a function of how many days before the day of death, we used Statistical Package for the Social Sciences (SPSS) 20.2 to restructure this new data file into the actor-partner interdependence model (APIM) format (Campbell & Stanton, 2015; Cook & Kenny, 2005). The APIM format allows for the simultaneous consideration of actor and partner effects. Actor effects denote the effect of a variable on itself over time (e.g., cognition score predicting subsequent change in cognition score) whereas partner effects denote the effect of a variable on other variables (e.g., cognition score predicting subsequent change in emotion score).

In our figures we exemplify these analyses through testing of the differences of the model on the day of death, 1 day before death, 1 week before death, 1 month before death, 3 months before death, and 6 months before death. A log transformation of our time variable, *date_diff*, was performed because we hypothesized that the temporal relationships among variables could change dramatically as the date of suicide approached. Specifically, we reasoned that change could occur more rapidly immediately prior to suicide as compared to several months prior to suicide. Because log transformations of zero and negative values are not possible, we converted *date_diff* into a logged form using a linear transformation ($lndate\_diff$ = ln($date\_diff$*(- 1) +1), which essentially flips the sign from negative to positive and reassigns the date of death to a value of 1. This resulted in the following log-transformed values for centering time: day of death (0), 1 day prior (0.693), 1 week prior (2.079), 30 days prior (3.434), 90 days prior (4.511), and 182 days prior (5.209). To conduct analyses with respect to each of these timeframes, we re-centered each entry's log-transformed date by subtracting its log-transformed value from the relevant reference point. For example, to center at 90 days prior to death, we computed $lndate\_diff\_90$ = $lndate\_diff$ - 3.434.

STATISTICAL ANALYSES

To analyze the five dimensions simultaneously, we created a new dependent variable named *change,* and an indicator for each of the five cluster variables

(*trgind, cgnind, bhvind, phyind, emtind*). As the dependent variable, *change* reflects the raw difference score between the next time point and the current time point for each of the five variables. The indicator variables are used to specify each actor and partner effect. For example, when *trgind* equals 1, the resulting coefficients indicate that the effects being tested are predicting change in the trigger domain as the outcome. Likewise, when *trgind* equals 0, the resulting coefficients indicate that the effects being tested are not predicting change in the trigger domain as the outcome. Indicator variables therefore enable simultaneous modeling of multiple outcomes in a single equation. As noted earlier, actor effects correspond to change within a variable being predicted by itself, whereas partner effects correspond to change within a variable being predicted by a different variable. Finally, we suppressed the intercept option for the MLM analyses, thereby creating 5 distinct two-level equations for each cluster variable, with the coefficients for the indicator variables serving as the intercepts for each equation.

Because the primary aim was to model change within and between individual users over time, we specified our MLMs such that the change in score over time (level 1) was nested within each individual (level 2). This yielded the following level 1 equation:

Level 1

$$Change = \beta_{1(Trgind)} + \beta_{2(Cogind)} + \beta_{3\ (Bhvind)} + \beta_{4\ (Phyind)} + \beta_{5\ (Emtind)} + r$$

This level 1 equation represents change over time within each individual user as the outcome of our five risk variables. We also specified five level 2 equations that were identical to each other in structure. One of the five level 2 equations is displayed here:

Level 2

$$
\begin{aligned}
\beta_{1(Trgind)} = \ &\gamma_{1,0} + \gamma_{1,1\ (Trigger)} + \gamma_{1,2\ (Cognition)} + \gamma_{1,3\ (Behavior)} + \gamma_{1,4\ (Physical)} + \gamma_{1,5\ (Emotion)} \\
&+ \gamma_{1,6\ (Suicide)} + \gamma_{1,7\ (Trigger*Suicide)} + \gamma_{1,8\ (Cognition*Suicide)} \\
&+ \gamma_{1,9\ (Behavior*Suicide)} + \gamma_{1,10\ (Physical*Suicide)} + \gamma_{1,11\ (Emotion*Suicide)} \\
&+ \gamma_{1,12\ (lndate\_diff)} + \gamma_{1,13(Trigger*lndate\_diff)} + \gamma_{1,14\ (Cognition*lndate\_diff)} \\
&+ \gamma_{1,15\ (Behavior*lndate\_diff)} + \gamma_{1,16\ (Physical*lndate\_diff)} \\
&+ \gamma_{1,17\ (Emotion*lndate\_diff)} + \gamma_{1,18\ (Suicide*lndate\_diff)} \\
&+ \gamma_{1,19\ (Trigger*Suicide*lndate\_diff)} + \gamma_{1,20\ (Cognition*Suicide*lndate\_diff)} \\
&+ \gamma_{1,21\ (Behavior*Suicide*lndate\_diff)} + \gamma_{1,22\ (Physical*Suicide*lndate\_diff)} \\
&+ \gamma_{1,23\ (Emotion*Suicide*lndate\_diff)} + \omega_1
\end{aligned}
$$

This level 2 equation enables us to examine different change processes across the two manners of death (suicide vs. non-suicide) at different time frames prior to the date of death. Because standardized coefficients are difficult to compute and interpret within an MLM framework, unstandardized regression coefficients are reported in the following sections. To assess for the potential impact of multicollinearity among predictors, variance inflation factors (VIFs) for all of the

predictor terms were calculated at the mean-centered time. VIFs ranged from 1.07 to 7.63, below the typical threshold for concern (i.e., VIF>10).

Upon obtaining the results of the MLM analyses, we ran a series of simulations to determine how the change process might unfold under conditions that mimic real life, in which a specific user's group (i.e., suicide or control) and location in the timeline relative to death is unknown. The final results of the MLM analyses (including all effects, whether statistically significant or not) were used for the simulations, which were run for each risk variable pair (i.e., one variable entered as the predictor and the other as the outcome) separately for suicides and controls. To do this, we fixed the values for each variable to its mean with the exception of the variable of interest. We then entered the maximum observed value for the variable of interest and allowed the equation to play forward several steps, updating the value for each variable at each step. This process enabled us to examine the expected "ripple effect" that a particular variable might have on itself and all other variables over time.

For example, to determine how cognition was related to change in emotion, the values for the emotion, behavior, trigger, and physical symptoms variables were set to their mean values and entered as variables into the regression equation. Cognition was then set to its maximum value (i.e., a value of 1). The equation was solved and the resulting values for all variables were saved. These saved values were then entered into the equation and the resulting values for all variables were saved again. This process was iterated several times to describe the expected pattern among multiple adjacent posts. The results of these simulations were graphed in order to illustrate how the change process associated with different combinations of variable pairs unfolds over time.

RESULTS

Results of the MLM models at each of the relevant timeframes are summarized in Tables 4 through 8 on the following pages. To facilitate ease of interpretation, we also display temporal patterns graphically through a series of network representations of the simple slopes centered at a series of relevant time frames as subjects approach death. To generate these network representations, the arrows indicate how each variable uniquely predicted change in itself (i.e., actor effects) and in other variables (i.e., partner effects). Grey arrows indicate negative relationships, such that when the predictor variable has higher values the change is more negative or less positive at the next time point, whereas black lines indicate positive relationships, such that when the predictor variable has higher values the change is more positive or less negative at the next time point. For example, the grey arrow from triggers that loops back to itself represents how triggers predict subsequent change in triggers. Though the model allowed for all possible relationships, only relationships significant at the level of a two-tailed $\alpha=.05$ are shown. Given that we allowed these relationships to be moderated by the manner of death and the temporal proximity to death, this model allowed for the evolution of how the temporal dynamics changed as one approached the date of death.

Unfortunately, there is currently no standard effect size statistic for MLMs, and of those that have been proposed, problems have been noted for each. Nonetheless, in an attempt to quantify the degree of fit of our model to the data, we computed a pseudo-R^2 statistic, one of several possible effect size statistics that have been proposed for MLMs, using the predicted values and the residuals in the sums of square formula. The derived pseudo-R^2 value of 0.45 indicated a very good model fit and suggested that approximately 45% of the total variance in the data were accounted for by the model. Although the pseudo-R^2 can be interpreted in a manner that is similar to that of the traditional R^2 value for linear regression, it should be noted that the pseudo-R^2 value is an imperfect statistic. It should therefore be interpreted as a "best estimate" rather than a definitive value.

Overall, each risk variable (trigger, cognition, behavior, physical, and emotion) predicted change in itself for both the suicide and control groups. These effects are designated by the statistically significant negative coefficients for the actor effects, and are graphically represented by grey, circular loops attached to each risk variable in the figures. This finding indicates that each risk variable demonstrates stability over time by fluctuating around a set point. In other words, when a risk variable is higher than its set point, it tends to decrease at the next time point. Likewise, when the risk variable is lower than its set point, it tends to increase at the next time point. Taken together, this means that triggers, cognitions, behaviors, physical symptoms, and emotions tend to gravitate towards points of stability, similar to how water tends to flow downhill towards a basin. In contrast to these common change features across groups, several statistically significant differences between the two groups were observed at different time points.

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RESULTS

As early as 6 months prior to death, suicide cases showed a pattern characterized by posts about triggers preceding change in emotion and cognition. Both suicide and control cases also showed a pattern in which posts about physical symptoms, cognitions, and emotions tended to occur in close temporal proximity. At approximately 3 months prior to death, however, posts about physical symptoms no longer occurred in close proximity to posts about cognition and emotion among suicide cases. At approximately 1 month prior to death, a temporal relationship between posts about behaviors and cognition emerged among suicide cases. Specifically, posts about behaviors were associated with stabilization in cognition posts. This relationship strengthened in magnitude at 1 week and 1 day prior to death by suicide. Each of these findings will be discussed in greater detail in the following section.

CHANGE PATTERNS OBSERVED AT ALL TIMEFRAMES

In both groups, triggers, emotions, and cognitions demonstrated coupling patterns during most timeframes leading up to death, suggesting that these three clusters were consistently related to each other over time (see Table 4 and Figure 2). However, the nature of this temporal coupling differed in the suicide group as compared to the control group. In the suicide group, the direction of the black arrow flowed from trigger to emotion (black dashed ovals in Figure 2), indicating that descriptions of stressful events that are followed by expressions of negative emotions is a signal for the suicide group. This pattern emerged 6 months prior to death and persisted up until the day before the suicide. By contrast, when a temporal relationship among triggers and emotions occurred in the control group, the direction of the black arrow flowed in the opposite direction, from emotion to trigger (solid black ovals in Figure 2), indicating that expressions of negative emotions that are followed by descriptions of stressful events may be a signal for the control group. The suicide group also demonstrated a reciprocal relationship between triggers and cognitions at all time points except 1 day prior to death (grey dashed ovals in Figure 2). This pattern was not observed in controls.

Table 4
Results of Multilevel Models, Centered 6 Months Prior to Death

Outcome	Predictor	Control		Suicide	
		B	SE	B	SE
Trigger	(Intercept)	0.01**	0.00	0.01**	0.00
	Cognition	0.05**	0.01	-0.00	0.02
	Behavior	-0.00	0.01	-0.01	0.01
	Trigger	-0.86**	0.01	-0.93**	0.01
	Physical	0.00	0.01	0.00	0.01
	Emotion	0.012*	0.01	0.01	0.01
Cognition	(Intercept)	0.00**	0.00	0.00	0.00
	Cognition	-0.92**	0.01	-0.99**	0.01
	Behavior	0.01	0.00	0.00	0.00
	Trigger	0.04**	0.01	-0.01	0.01
	Physical	4.88	0.01	0.01	0.01
	Emotion	0.01**	0.00	0.01**	0.00
Behavior	(Intercept)	0.03**	0.00	0.02**	0.00
	Cognition	-0.01	0.02	0.08*	0.03
	Behavior	-0.88**	0.01	-0.87**	0.01
	Trigger	0.01	0.01	0.01	0.02
	Physical	0.00	0.01	-0.02	0.01
	Emotion	-0.00	0.01	0.01	0.01
Physical	(Intercept)	0.01**	0.00	0.01**	0.00
	Cognition	0.04**	0.01	0.03	0.02
	Behavior	1.45	0.01	0.00	0.01
	Trigger	0.01	0.01	-0.01	0.01
	Physical	-0.88**	0.01	-0.83**	0.01
	Emotion	0.02**	0.01	0.01	0.01
Emotion	(Intercept)	0.04**	0.00	0.02**	0.00
	Cognition	-0.06*	0.02	-0.02	0.03
	Behavior	0.00	0.01	0.01	0.01
	Trigger	0.09**	0.01	0.02	0.02
	Physical	0.06**	0.02	0.04**	0.02
	Emotion	-0.91**	0.01	-0.91**	0.01

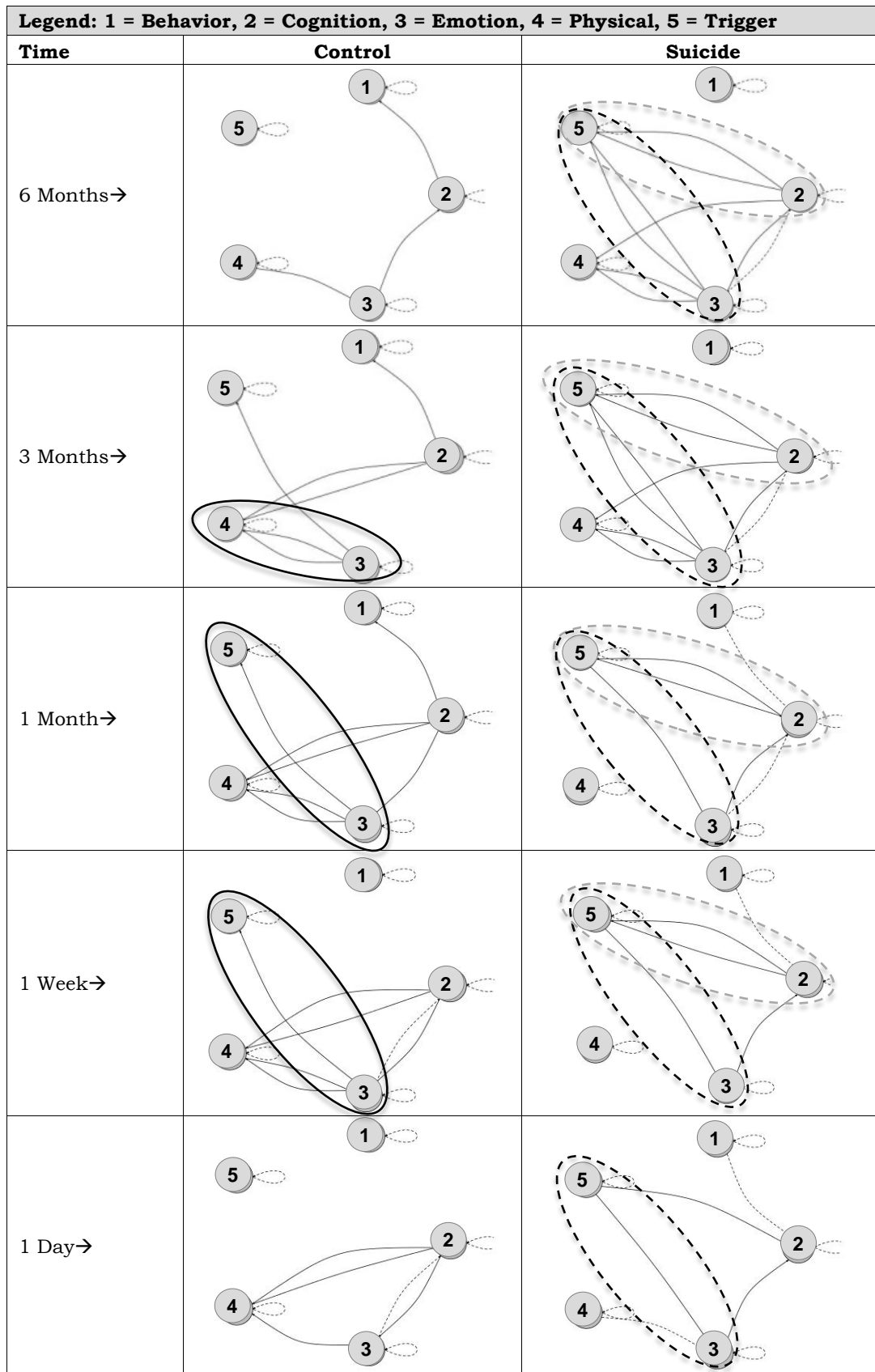*p<.05, **p<.01

RESULTS

Figure 2 Stable Temporal Patterns Among Suicides and Controls

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Taken together, these two change patterns suggest that suicide cases are more likely to demonstrate a change pattern wherein they describe stressful events and then express negative beliefs or perspectives about themselves or the world soon afterwards. In addition, suicide cases who express negative beliefs tend to subsequently post more descriptions of stressful events. Because these two distinct patterns were observed as early as 6 months prior to death and continued to be observed until the day of death, they may indicate stable or long-term signatures of suicide, regardless of how close the individual is to his or her death.

Results of relevant simulation runs are graphically displayed in Figures 3 and 4. As can be seen, following a post about a life stressor, suicide cases are more likely to post about negative emotional content in the next post (Figure 3, (a) Suicide), but this same pattern is not seen in controls (see Figure 3, (b) Control). The magnitude of this effect among suicide cases is approximately twice as large during the day prior to death as compared to 6 months prior to death. Posting about negative emotions immediately following a post about stressful life events therefore becomes much more common as a suicide case approaches death; this pattern therefore signals a trajectory towards suicide.

(a) Suicide   **(b) Control**
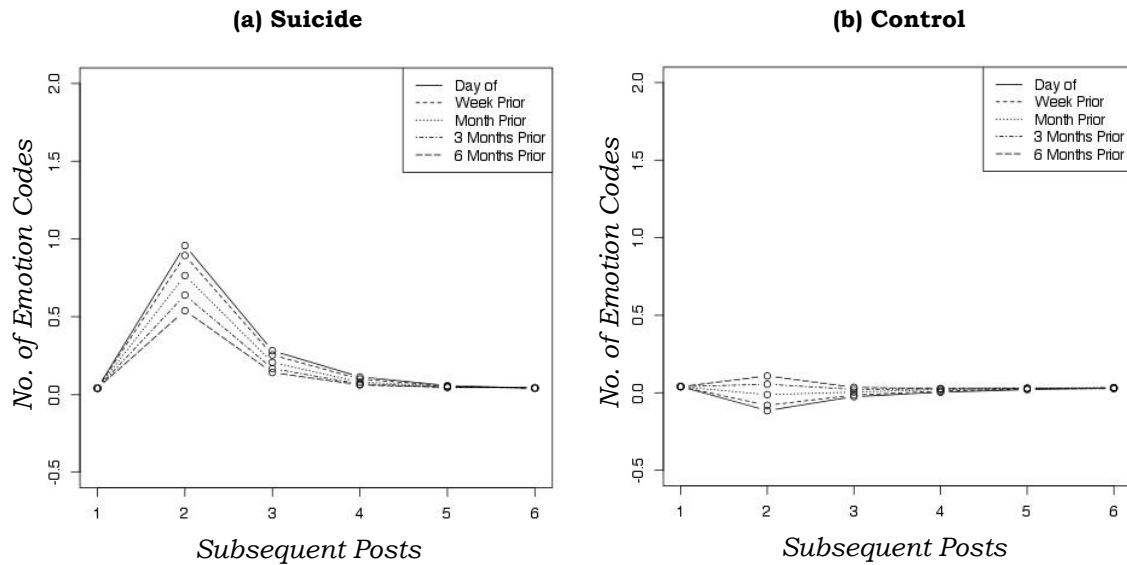
Figure 3 Results of Simulations Predicting Posts with Emotion Content Following a Post Containing Trigger Content

A similar pattern was observed for the relationship among triggers and cognition (Figure 4). Note that the difference in the magnitude of this effect over time was more pronounced than for the previous trigger/emotion simulations, as indicated by the larger "gaps" between the peaks associated with each timeframe (Figure 4, (a) Suicide). This suggests that posts about life stressors that are immediately followed by posts about negative beliefs may be somewhat more informative regarding the imminence of suicide than posts about life stressors that are immediately followed by posts about negative emotions.
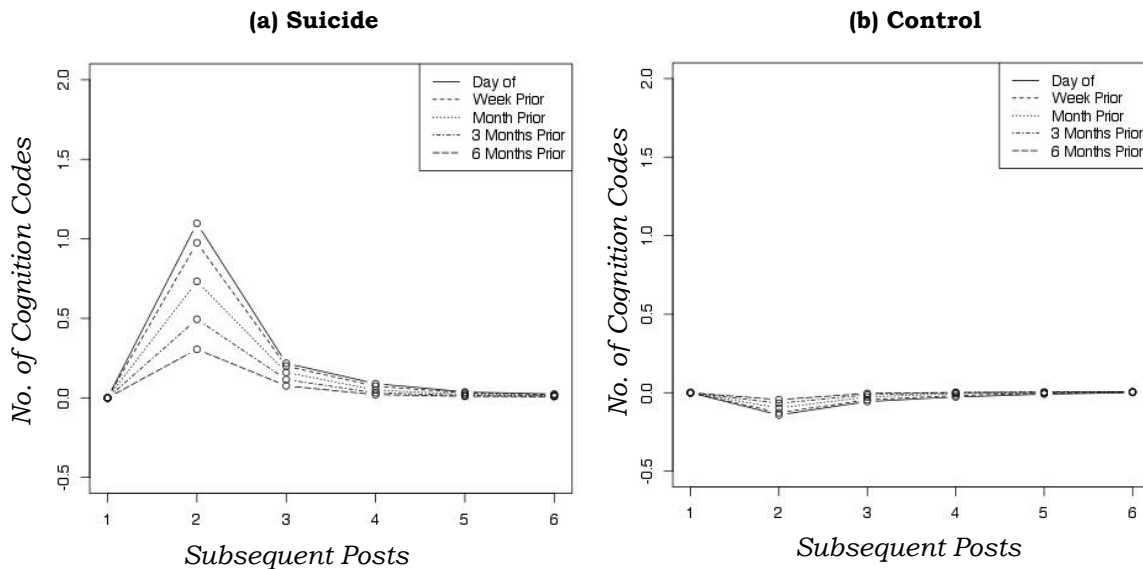
Figure 4 Results of Simulations Predicting Posts Containing Cognition Content Following a Post Containing Trigger Content

These general patterns were illustrated by case 53, who died by suicide on 5/2/2010 (see Appendix A). Approximately 4 months prior to death (post #13), case 53 stated that he was being disciplined for missing a CQ shift (trigger). Soon after (posts #16 and 17), he expressed frustration and general distress (emotion). Later in his timeline, approximately 1 month up to 1 week prior to death, case 53 described triggers and expressed negative cognitions and emotions in quick succession: marital problems (post #24), anger (post #26), self-criticism (post #27), marital problems (post #30), broken guitar and anger (post #31), anger (post #33), and marital problem and self-criticism (post #37).

The trigger → emotion sequence can also be seen in case 839, who died by suicide on 12/11/2011 by self-inflicted gunshot wound (see Appendix A). Approximately 2 months prior to his death, case 839 posted about an unspecified stressor (trigger; post #1) then shortly after posted that he was "feeling fussy" (emotion; post #3) because he missed his significant other (emotion; post #4). The trigger → emotion and trigger → cognition sequences were also apparent just 2 days prior to his death, when he reported a breakup with his significant other (trigger) and described feeling like "a total mess" (emotion; post #31). In the very next post (post #32), he expressed loneliness (emotion) and then two posts later (post #34) expressed self-hatred (cognition).

Of note, the trigger → emotion and trigger → cognition sequences could be seen in case 53 as early as 5 months prior to death, but the date of his suicide approached, two notable changes occurred. First, the gap between posts about triggers and emotions/cognitions shortened. Second, these sequences increased in frequency, such that 1 week prior to his death there was a "flurry" of posts about triggers, emotions, and cognitions within a very brief period of time. Case 53 therefore shows an intensification in these specific sequences as his suicide death approaches.

Intensification of the trigger → emotion and trigger → cognition sequences also occurred in case 839 during the 2 days immediately preceding his death as compared to 2 months prior to his death.

In contrast to the temporal pattern observed among suicide cases, control cases did not show this same pattern on average. This is demonstrated by case 83, who died subsequent to an accidental fall on 1/3/2011 (see Appendix A). Approximately 3 months prior to death, case 83 posted repeatedly about an ongoing conflict with her significant other, along with other life stressors. For example, she made several posts on 9/28/2010 describing general distress (emotion; posts #1, 2, 3, and 6) prior to posting about a relationship problem (trigger; post #6 and 8). She then made several more posts about sadness (emotion; post #9) and her "breaking" heart (emotion; post #10). A few days later, she expressed loneliness (emotion) and isolation (cognition) over the course of two consecutive posts (posts #19 and 20), then the next day posted about a relationship problem (post #26). She did not post any emotion or cognition content during the next several posts. Although the trigger → emotion and trigger → cognition sequences were evident in case 83, the reverse sequences, emotion → trigger and cognition → trigger, were more pronounced.

CHANGE PATTERNS OBSERVED 3 MONTHS PRIOR TO SUICIDE

An important difference between the suicide and control trajectories emerged 3 months prior to death (see Table 5). In both groups there was a 3-way coupling relationship among physical, emotion, and cognition (black solid ovals in Figure 5). After 3 months prior to death, however, the relation of the physical cluster with the emotion and cognition clusters disappeared in the suicide group. By contrast, the three-way coupling relationship remained in the control group up until the day before death. This suggests that individuals who die by suicide within the next 1 to 3 months tend to post about physical or somatic complaints independent of posts about negative thoughts and emotions. Posts about physical symptoms therefore do not necessarily occur immediately before or after posts about negative thoughts and emotions. This pattern suggests a medium-term indicator of suicide risk.

RESULTS

<div align="center">

Table 5
Results of Multilevel Models, Centered 3 Months Prior to Death

</div>

Outcome	Predictor	Control		Suicide	
		B	SE	B	SE
Trigger	(Intercept)	0.01**	0.00	0.01**	0.00
	Cognition	-0.00	0.02	0.05**	0.01
	Behavior	-0.01	0.01	0.00	0.01
	Trigger	-0.93**	0.01	-0.85**	0.01
	Physical	0.00	0.01	0.00	0.01
	Emotion	0.01	0.01	0.01*	0.01
Cognition	(Intercept)	0.00	0.00	0.01**	0.00
	Cognition	-0.99**	0.01	-0.94**	0.01
	Behavior	0.00	0.00	-0.00	0.00
	Trigger	-0.01	0.01	0.06**	0.01
	Physical	0.01	0.01	-0.00	0.01
	Emotion	0.01**	0.00	0.01**	0.00
Behavior	(Intercept)	0.02**	0.00	0.03**	0.00
	Cognition	0.08*	0.03	-0.01	0.02
	Behavior	-0.87**	0.01	-0.87**	0.01
	Trigger	0.01	0.02	-0.00	0.01
	Physical	-0.02	0.01	-0.00	0.01
	Emotion	0.01	0.01	-0.00	0.01
Physical	(Intercept)	0.01**	0.00	0.01**	0.00
	Cognition	0.03	0.02	0.03**	0.01
	Behavior	0.00	0.01	-0.00	0.01
	Trigger	-0.01	0.01	0.01	0.01
	Physical	-0.83**	0.01	-0.85**	0.01
	Emotion	0.01	0.01	0.01**	0.00
Emotion	(Intercept)	0.02**	0.00	0.04**	0.00
	Cognition	-0.02	0.03	-0.05**	0.02
	Behavior	0.01	0.01	0.01	0.01
	Trigger	0.02	0.02	0.10**	0.01
	Physical	0.04**	0.02	0.04**	0.02
	Emotion	-0.91**	0.01	-0.93**	0.01

*p<.05, **p<.01
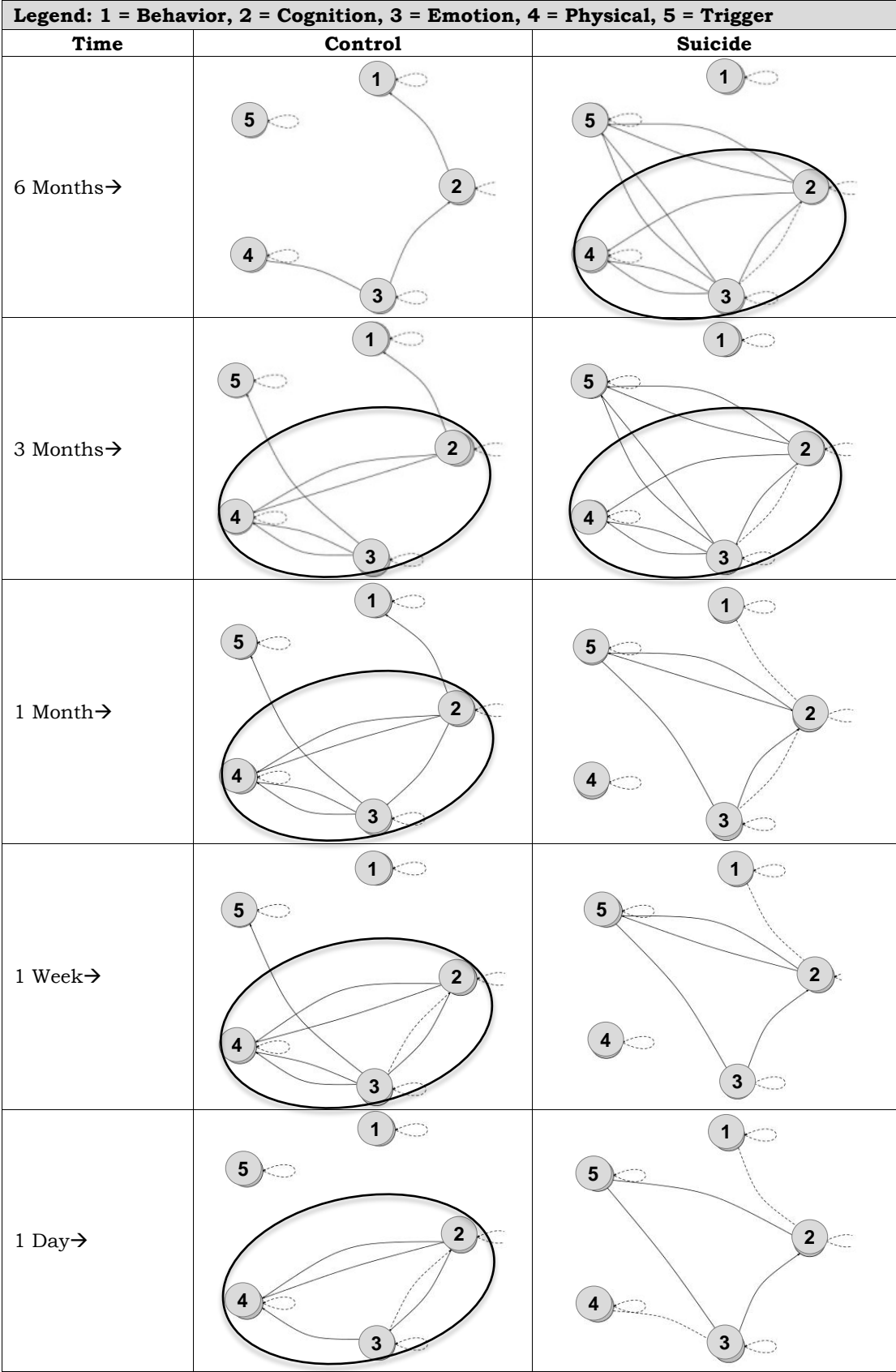
Figure 5 Temporal Patterns Between Suicides and Controls Observed 3 Months Prior to Death

RESULTS

Results of relevant simulation runs are graphically displayed in Figure 6. Whereas suicide cases show minimal change in posts containing negative emotions following posts containing negative beliefs (Figure 6, (a) Suicide), this relationship is very strong among controls (Figure 6, (b) Control). This suggests that a cognition/emotion coupling may signal individuals who are relatively unlikely to die by suicide, especially in the near-term.

(a) Suicide   **(b) Control**
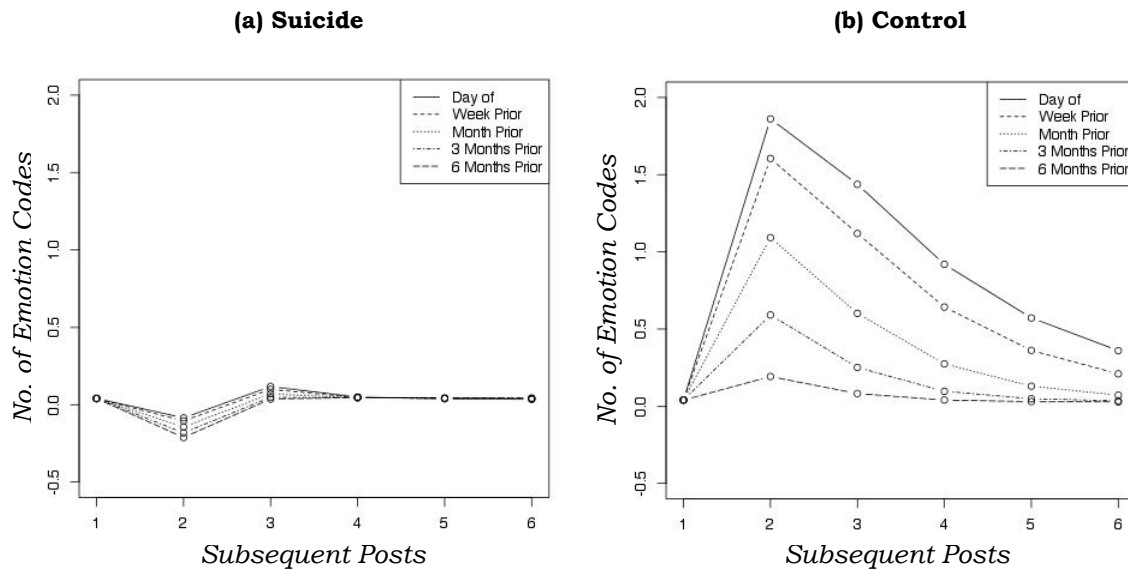
Figure 6 Results of Simulations Predicting Posts Containing Emotion Content Following a Post Containing Cognition Content

The absence of the cognition → emotion sequence was evident in case 53 (Appendix A). Of all the publicly available posts for this suicide case, cognition content was first observed in post #27 and the next instance of emotion content occurred four posts later (post #31). Cognition content was next observed in post #37, but no instances of emotion content were observed in any of case 53's remaining posts.

Case 839 also demonstrated an absence of the cognition → emotion sequence. For example, he expressed self-hatred (cognition) in post #34 but did not post any emotion content in any remaining posts leading up to his suicide.

Finally, case 28 expressed isolation (cognition) at two different points (posts #1, 12), but these posts were not followed by emotion content. Case 28 also expressed purposelessness (cognition) in post #24, but this, too, was not followed by posts containing emotion content.

CHANGE PATTERNS OBSERVED 1 MONTH PRIOR TO SUICIDE

Another notable difference between suicides and controls emerged 1 month prior to death (see Table 6).

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Table 6
Results of Multilevel Models, Centered 1 Month Prior to Death

Outcome	Predictor	Control		Suicide	
		B	SE	B	SE
Trigger	(Intercept)	0.01*	0.00	0.02**	0.00
	Cognition	-0.01	0.02	0.05**	0.01
	Behavior	-0.02	0.01	0.01	0.01
	Trigger	-0.98**	0.01	-0.83**	0.01
	Physical	0.01	0.01	0.00	0.01
	Emotion	0.02**	0.01	0.01	0.01
Cognition	(Intercept)	0.00**	0.00	0.01**	0.00
	Cognition	-0.81**	0.01	-0.98**	0.01
	Behavior	-0.00	0.01	-0.02*	0.01
	Trigger	-0.01	0.01	0.10**	0.01
	Physical	0.04**	0.01	-0.01	0.01
	Emotion	-0.01	0.01	0.02**	0.01
Behavior	(Intercept)	0.02**	0.00	0.03**	0.00
	Cognition	0.09**	0.03	0.01	0.02
	Behavior	-0.91**	0.02	-0.87**	0.01
	Trigger	0.00	0.02	-0.02	0.01
	Physical	-0.02	0.02	-0.01	0.02
	Emotion	0.01	0.01	-0.00	0.01
Physical	(Intercept)	0.01**	0.00	0.02**	0.00
	Cognition	0.17**	0.02	0.01	0.01
	Behavior	-0.01	0.01	-0.00	0.01
	Trigger	-0.01	0.01	0.01	0.01
	Physical	-0.84**	0.01	-0.82**	0.01
	Emotion	0.03**	0.01	0.00	0.01
Emotion	(Intercept)	0.03**	0.00	0.04**	0.01
	Cognition	0.11**	0.03	-0.04*	0.02
	Behavior	0.02	0.02	0.01	0.02
	Trigger	0.01	0.02	0.12**	0.02
	Physical	0.06**	0.02	0.00	0.02
	Emotion	-0.90**	0.01	-0.93**	0.01

*p<.05, **p<.01

One month prior to death, a significant relationship between behavior and cognition emerged among suicide cases, with the direction of the effect suggesting that suicides tend to post about maladaptive behaviors then show *less* change in their posts expressing negative beliefs (black solid ovals in Figure 7). This relationship strengthened as the suicide approached. Controls also showed a significant

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relationship between behavior and cognition, but the direction of the effect suggested that controls tended to post about negative beliefs first, then show *more* change in maladaptive behaviors (black dashed ovals in Figure 7). In other words, the direction and nature of the change process differentiated suicides and controls. This indicates that descriptions of maladaptive behaviors tend to *stabilize* negative beliefs for suicides, but only in the period of time immediately preceding their death, which suggests a near-term signal for suicide.
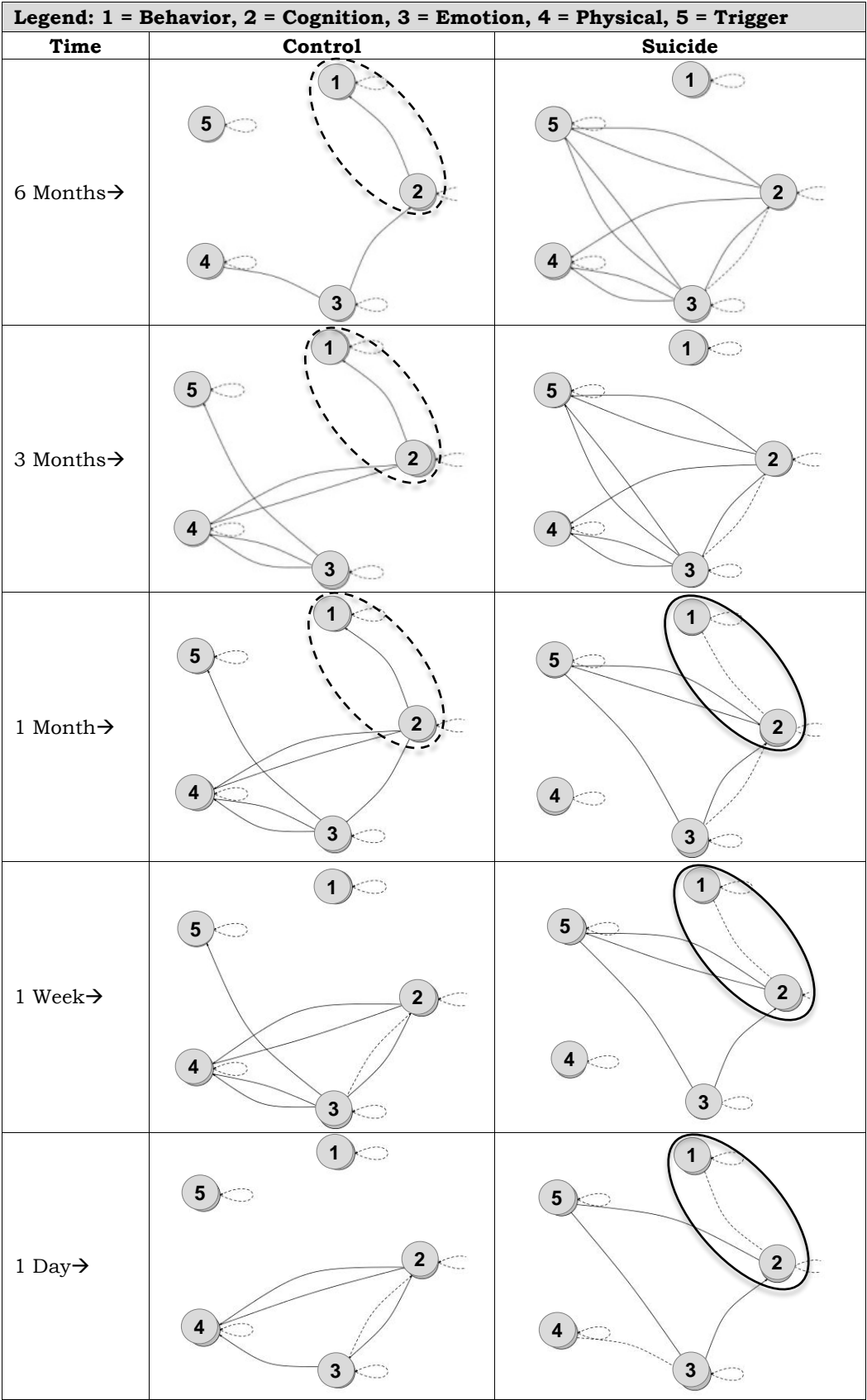
Figure 7 Temporal Patterns Between Suicides and Controls Observed 1 Month Prior to Death

RESULTS

Results of relevant simulation runs are graphically displayed in Figure 8. Whereas suicide cases show less change in posts containing negative beliefs following posts describing maladaptive behaviors (Figure 8, (a) Suicide), there was no such relationship among controls (Figure 8, (b) Control). This suggests that a stabilizing behavior/cognition coupling may signal individuals who are very close to dying by suicide.
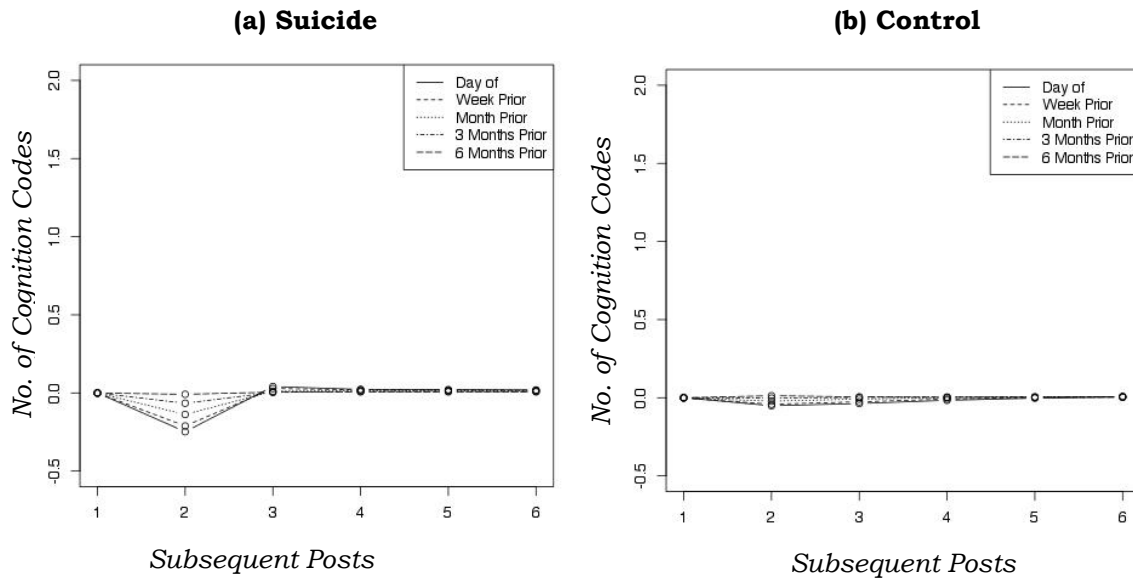
Figure 8   Results of Simulations Predicting Posts Containing Cognition Content Following a Post Containing Behavior Content

This pattern was evident in case 28 (Appendix A), who died by suicide on 7/12/2010. In the final week of his life, case 28 referenced alcohol use (behavior) in 3 out of his last 11 posts without any posts containing cognition content. This contrasts with the pattern previously demonstrated by case 28 when discussing alcohol use. Approximately 6 months prior to his death, case 28 expressed isolation (cognition; post #1) several posts prior to referencing alcohol use (behavior; posts #5 and #7). Case 28 did not post cognition content for several posts until he posted song lyrics containing themes of isolation (post #12). He then posted about alcohol use again (posts #13 and 14), but did not post cognition content again for many posts. Approximately 2 months prior to his death, case 28 again posted about isolation (post #18), then posted about alcohol use (post #24), but did not post cognition content again afterwards. In summary, case 28 shows a weak cognition → behavior sequence, but during the final week of his life his behavior posts were *not* preceded by cognition posts. In this final week of life, cognition posts therefore stabilized relative to behavior posts.

CHANGE PATTERNS OBSERVED 1 WEEK AND 1 DAY PRIOR TO SUICIDE

The stabilizing effect of behavior on cognition reported in the previous section continued to strengthen during the week and day before death (see Table 7), suggesting that as a suicide case entered the final days of his or her life, posts

about negative beliefs were less likely to be observed after posts about maladaptive behaviors (see Figure 7). The strength of this relationship therefore might serve as a final "alarm" for imminent suicide.

Table 7
Results of Multilevel Models, Centered 1 Week and 1 Day Prior to Death

Outcome	Predictor	1 Week Prior to Death				1 Day Prior to Death			
		Control		Suicide		Control		Suicide	
		B	SE	B	SE	B	SE	B	SE
Trigger	(Intercept)	0.01**	0.00	0.02**	0.00	0.02**	0.01	0.02**	0.01
	Cognition	-0.02	0.04	0.05**	0.02	-0.02	0.06	0.05	0.03
	Behavior	-0.03	0.02	0.02	0.02	-0.04	0.03	0.03	0.02
	Trigger	-1.01**	0.02	-0.80**	0.02	-1.05**	0.04	-0.77**	0.02
	Physical	0.02	0.02	-0.00	0.02	0.03	0.03	-0.00	0.03
	Emotion	0.03*	0.02	0.01	0.01	0.04	0.02	0.01	0.01
Cognition	(Intercept)	0.01*	0.00	0.01**	0.00	0.01*	0.00	0.01**	0.00
	Cognition	-0.67**	0.02	-1.03**	0.01	-0.53**	0.04	-1.08**	0.02
	Behavior	-0.01	0.01	-0.03**	0.01	-0.01	0.02	-0.05**	0.02
	Trigger	-0.02	0.02	0.14**	0.01	-0.03	0.02	0.19**	0.02
	Physical	0.06**	0.01	-0.02	0.01	0.08**	0.02	-0.03	0.02
	Emotion	-0.02*	0.01	0.02**	0.01	-0.03*	0.01	0.03*	0.01
Behavior	(Intercept)	0.02**	0.01	0.02**	0.01	0.02*	0.01	0.02**	0.01
	Cognition	0.10	0.05	0.02	0.03	0.11	0.08	0.03	0.04
	Behavior	-0.94**	0.03	-0.86**	0.02	-0.97**	0.04	-0.85**	0.03
	Trigger	-0.00	0.03	-0.03	0.02	-0.01	0.05	-0.05	0.03
	Physical	-0.02	0.03	-0.02	0.03	-0.02	0.04	-0.03	0.04
	Emotion	0.02	0.02	-0.01	0.02	0.03	0.03	-0.01	0.03
Physical	(Intercept)	0.01**	0.00	0.02**	0.00	0.01	0.01	0.03**	0.01
	Cognition	0.28**	0.04	-0.01	0.02	0.39**	0.05	-0.04	0.03
	Behavior	-0.02	0.02	-0.01	0.02	-0.03	0.03	-0.01	0.02
	Trigger	-0.01	0.02	0.01	0.02	-0.01	0.03	0.02	0.02
	Physical	-0.85**	0.02	-0.77**	0.02	-0.86**	0.03	-0.73**	0.03
	Emotion	0.05**	0.01	-0.01	0.01	0.06**	0.02	-0.03	0.02
Emotion	(Intercept)	0.03**	0.01	0.03**	0.01	0.03**	0.01	0.03**	0.01
	Cognition	0.21**	0.06	-0.04	0.03	0.31**	0.10	-0.03	0.05
	Behavior	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.04
	Trigger	-0.01	0.04	0.15**	0.03	-0.02	0.06	0.17**	0.04
	Physical	0.07*	0.03	-0.04	0.03	0.08	0.04	-0.09	0.05
	Emotion	-0.90**	0.02	-0.93**	0.02	-0.90**	0.04	-0.93**	0.03

This pattern was evident in case 28, described in the previous section.

DISCUSSION

The present study builds on previous research efforts by DSPO suggesting that the content of Service members' social media data could differentiate between those who died by suicide and those who died of other causes (Hesse, Bryan, & Rose, 2015). In contrast to this previous work, which used logistic regression methods to predict manner of death (suicide vs. control), the present study used regression methods to model nonlinear change processes associated with each manner of death, under the assumption that some variables may push Service members towards suicide whereas other variables may pull them away from suicide. The present study and Hesse, Bryan, & Rose are therefore similar in that both used analyses focused on the same end point (i.e., suicide or non-suicide death). The present study differs from Hesse, Bryan, & Rose by also focusing on mapping the specific pathways or roads traveled along the way to this end point. By mapping the ways in which the road that heads towards suicide differs from the road that heads towards non-suicide death, we can predict which group a Service member belong to (i.e., which road are they on?) and also predict how close they are to the end point (i.e., where on the road are they currently located?). Understanding how an individual post fits within the larger context of the Service member's pattern of online behavior over time could therefore provide additional information about the likelihood of suicide death and the relative imminence of this outcome.

To illustrate this possibility, consider the situation in which one desires to travel from work to home in a busy city via taxi. There are many possible routes that can be taken to get from one point to the other, but the specific route that ultimately emerges may be influenced by contextual factors. For instance, one might encounter unexpected traffic or construction, prompting one to change course in a different direction. In addition, one's options might also be limited by one-way streets. Each obstacle and barrier, by itself, does not provide much information about whether you are at work or home, but they do provide a lot of information about the specific path one is likely to take from work to home. Of note, these obstacles and barriers will play a different role if one is trying to go in the reverse direction, from home to work. This is because traffic and construction patterns differ according to the time of day, and because one-way roads that are unusable when traveling in one direction are usable in the other direction. In isolation, risk indicators (e.g., hopelessness, depression) may play a similar role: providing relatively little information at any given time about whether a Service member is in the suicide or control group, but shaping the specific pathway a Service member travels with respect to suicide. To address this problem, the present study used an analytic approach informed by dynamical systems theory (Butner et al., 2015), which provides a basis for examining change processes among multiple variables over time.

The present study was based on the same dataset used by Hesse, Bryan, & Rose, which contained information about the presence of 36 predictor variables in total. The present study differed from Hesse, Bryan, & Rose by collapsing these 36

variables into five conceptually meaningful and theoretically driven variables: triggers, cognition, emotion, physical, and behavior. This data reduction method was used to address the problem of data sparseness that characterized each individual risk indicator, and enabled us to consider variables that might be more intuitive and practical from a public health perspective. For example, public education aimed at identifying and differentiating between discrete, albeit related, cognitive patterns (e.g., hopelessness, but not feeling trapped) is much more challenging than public education aimed at identifying "negative cognitions" more generally (e.g., either hopelessness or feeling trapped). Our reduction of 36 risk indicators into 5 conceptually meaningful variables therefore increased the interpretability of results from a human factors and public education perspective while also preserving the scientific foundation for interpreting these results.

MAIN CONCLUSIONS OF THE PRESENT STUDY

Despite these limitations, the present study provides important and practical clues about the overall trajectory pattern that emerges among Service members who die by suicide, with results suggesting several signatures that are specific to the emergence of suicide. Critically, these signatures of eventual suicide are only apparent when considering change processes over time among multiple variables simultaneously, a finding that supports the utility of the approach and aligns with the fluid vulnerability theory's hypothesis that suicide risk entails both stable and dynamic features (Bryan & Rudd, in press; Rudd, 2006).

With respect to the stable dimension of risk, all five risk variables showed patterns of temporal stability around their individual set points, meaning that posts containing high amounts of risk variable content tended to be followed by posts containing less risk variable content. Likewise, posts containing low amounts of risk variable content tended to be followed by posts containing more risk variable content. In other words, social media posts containing content about triggers, cognitions, emotions, physical symptoms, and behaviors remained fairly constant over time, neither increasing nor decreasing among suicide cases. A similar pattern of stability was found for controls. Although the suicide group tended to show somewhat higher set points than the control group for all five clusters, these differences were very small in magnitude, such that they are of limited practical utility. Taken together, these findings indicate that Service members who die by suicide tend to "settle in" to reasonably stable patterns of posting on social media platforms, but these patterns of stability do not differ sufficiently from the patterns of stability observed among controls to be of practical use as a signal for suicide risk. When considering the dynamic interplay among multiple risk variables during different timeframes relative to death, however, several notable differences between suicides and controls became apparent. Of the many differences between the suicide and control trajectories, the ones that stand out suggest the possibility of long-term, medium-term, and near-term "signatures" of eventual suicide.

DISCUSSION

Long-Term Signatures of Suicide. Suicide cases were characterized by a change pattern in which triggers drove change in emotion and cognition. In other words, suicides tended to post about stressful life situations first, and then posted content describing negative emotions or beliefs. This coupling relationship strengthened as the suicidal user approached his or her death by suicide, which suggests the magnitude of change in emotion and belief following a trigger can serve as an indicator of proximity to death by suicide. The strengthening of this change process over time further suggests a *destabilizing* pattern (Butner et al., 2015) of triggers on cognitions and emotions over time, such that triggers were associated with greater variability (i.e., less stability) in cognition and emotion as the user approached his or her suicide. In contrast to suicides, a reverse pattern of temporal coupling was much more common among controls: posts containing negative emotions tended to be posted first, followed by posts containing descriptions of stressful life events.

Because this particular signature occurred across all of the time points considered during the 12 months preceding participants' death, it may be understood best as a stable indicator of suicide. In sum, posts about life stressors that are consistently followed by posts about negative emotions and/or negative beliefs may be good *long-term* signatures of eventual suicide.

Medium-Term Signatures of Suicide. The second major difference between suicides and controls emerged within the 3 months prior to death. Up to the third month prior to death, a reciprocal coupling relationship of the physical variable with the cognition and emotion variables was observed among suicide cases. Approximately 1 month prior to death, however, these coupling relationships disappeared among suicides. In other words, posts about physical or somatic problems, negative emotions, and negative beliefs that occur in close temporal proximity to each other, regardless of order, suggest either a non-suicide control trajectory or a distal suicide trajectory. This is consistent with a *stabilizing* pattern over time (Butner et al., 2015), in which cognition and emotion was associated with less variability (i.e., more stability) in physical, and physical was conversely associated with less variability in cognition and emotion as the participant approached his or her suicide. Similar coupling relationships were observed among controls within 3 months of death, although evidence for *destabilization* over time characterized this group. This was especially true for the effect of cognition on subsequent change in physical.

Taken together, these results suggest that posts about physical or somatic problems that are not immediately preceded or followed by posts about negative emotions or beliefs may signal risk for suicide within the next month. The reliability of this signal increases as time passes, whereas posts with physical or somatic themes become increasingly unrelated to previous or subsequent posts about negative emotions and cognitions among suicides, and for n controls there is a tendency for posts about negative cognitions to increasingly precede posts with physical or somatic themes. Posts about somatic or physical health complaints that

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occur independent of posts about negative emotions and beliefs may therefore be a good **medium-term** signature of eventual suicide.

Near-Term Signatures of Suicide. The final notable difference between suicides and controls emerged within the final month of life. Beginning approximately 1 month prior to death, a coupling relationship between behavior and cognition emerged among suicides. A coupling relationship between these two variables was also observed in the control group up until 1 day prior to death, but the nature of this coupling was very different for suicides and controls. For suicides, the coupling relationship flows from behavior to cognition and follows an *antiphase* pattern, which means that more frequent posts about maladaptive behaviors are followed by *fewer* posts about negative beliefs. In other words, when the behavior variable increases, the cognition variable decreases soon afterwards. For controls, however, the coupling relationship of these two variables flows in the opposite direction (from cognition to behavior) and follows an *in-phase* pattern, which means that more frequent posts about negative cognitions are followed by more posts about maladaptive behaviors: when the cognition variable increases, the behavior variable also increases soon afterwards.

The antiphase pattern among suicides strengthens as the Service member approaches his or her death by suicide, indicating a stabilizing effect of maladaptive behaviors on negative beliefs. This stabilizing effect was evident across the entire 12-month period of study, but was especially pronounced during the final month, week, and day of life preceding death by suicide. This might suggest a reinforcing effect of maladaptive behaviors on the suicidal individual's negative perceptions about themselves and the world. The antiphase relationship between behavior and cognition might serve as an *imminent or near-term* signature of eventual suicide.

LIMITATIONS OF THE PRESENT STUDY

Although the present study was designed to address several important limitations of previous DSPO research, the present study is not without its own limitations that warrant discussion. First, the data used for the present study were limited to only those deceased Service members who (a) had social media accounts, (b) used these social media accounts with some amount of frequency, (c) did not restrict public access to these social media accounts and (d) had social media accounts that were not deleted after their deaths. Conclusions based on the present study should therefore be made within the limits of these parameters. It is possible, for instance, that Service members who use privacy control features on their social media accounts (e.g., limiting access to other, "friended" users) behave in different ways from those who do not use any privacy control features. Additional research is therefore needed to determine the generalizability of results to the larger community of social media users.

Another limitation of the present study relates to the restriction of data to the calendar years 2010 and 2011. Although these data are less than 5 years old,

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DISCUSSION

online social networks are characterized by rapid change and innovation. As a result, patterns of user behavior on social media platforms such as Facebook or Twitter may differ today as compared to 5 years ago. In addition, many social network platforms that are very popular today did not exist or were not in widespread use from 2010-2011 (e.g., Snapchat, Instagram). Conversely, other social media platforms in use 5 years ago are rarely used today and/or no longer exist (e.g., Myspace). The present study should therefore be considered preliminary until it can be replicated using data obtained from a different period of time and/or different social media platforms.

A third limitation relates to the relatively small sample size. Although sufficient to detect meaningful results, larger samples are needed to examine more nuanced temporal patterns. For instance, change patterns associated with suicide may differ between men and women in meaningful ways. Similarly, differences in temporal trajectories may vary across different age groups. Larger samples are therefore needed to determine if the observed change processes are influenced by other relevant factors and variables.

Fourth, results of the present study are based on a sample comprised entirely of deceased Service members. Change processes associated with suicide were therefore identified in comparison to change processes associated with other manners of death as opposed to change processes associated with living controls. It is possible, for instance, that Service members who died as a result of a disease behave in different ways on social media than Service members who do not die. Conclusions must therefore be made within the context of deceased Service members.

Finally, the present study did not employ cross-validation procedures to test the accuracy of the predictive model in an independent sample or a subsample of participants. Cross-validation was not used for two primary reasons, the first of which was the small sample size. Cross-validation in a subset of participants could have reduced our ability to detect meaningful patterns. Second, the primary purpose of this study was to determine if data analyses based on a dynamic systems approach could predict manner of death and imminence of death; it was not to establish a predictive model for implementation in actual social media networks. In other words, the primary purpose was "proof of concept," not algorithm development. Nonetheless, cross-validation would have been a useful method for testing the validity of obtained results. Future studies are therefore needed to further test the method used and evaluate the results.

SUMMARY OF CONCLUSIONS

Results of the current project provide further support for the utility of social media networks as a tool for identifying and detecting military personnel at risk for suicide. In contrast to previous research, however, the present study focused on comparing the change patterns leading up to suicide to the change patterns leading

up to non-suicide deaths. Results of the present study suggest that information about eventual suicide can be enhanced by considering the specific *content* of social media posts as well as the specific temporal *sequencing* of such data. Modeling of nonlinear change processes may provide unique opportunities for (a) identifying Service members at risk for dying by suicide and (b) determining how close they are to suicide. The present results therefore provide a foundation for using social media data to determine *who* will die by suicide as well as *when* their suicide is likely to occur. To achieve this objective, additional research is needed to confirm and build upon these promising initial results.

RECOMMENDATIONS FOR SUICIDE PREVENTION AND INTERVENTION

(1) DSPO should explore options for integrating publicly available social media data into existing suicide prevention and intervention programs and strategies. Existing suicide prevention efforts are largely based on the dissemination of lists of risk factors and warning signs to military personnel, but do not explicitly highlight the potential role of social media behavior in suicide risk detection and prevention.

(2) DSPO should explore options for enhancing existing suicide prevention efforts by integrating information about suicide-specific change processes. The present results suggest that public health approaches to risk detection and identification may be enhanced by considering specific temporal sequences of certain risk factors and warning signs.

(3) DSPO should explore options for integrating results into suicide prevention efforts aimed at family members and friends of Service members who are outside of the military, as these individuals are more likely to observe Service members' social media behavior than military leadership and peers.

(4) DMDC should explore options for assessing the incremental value of applying dynamical systems theory methods to other DoD datasets and databases, to include electronic health records.

RECOMMENDATIONS FOR FUTURE RESEARCH

(1) Future research should be conducted with larger samples to replicate these findings and to examine potential differences among subgroups of social media users (e.g., differences by gender and age). For instance, additional subjects could be drawn from cohorts beginning with the 2012 calendar year. Including more recent generational cohorts would also provide information about the applicability of findings to newer and upgraded/updated social media platforms, as well as generalizability across age cohorts who may use social media in unique ways.

(2) Future research should include social media users with higher levels of privacy settings to determine if observed change patterns are generalizable to the larger

community of social media users, as opposed to the subgroup who do not restrict public access to their data. Due to the privacy implications of such a study, alternative study designs would be required, to include informed consent by social media users. Such research should also take into account the possibility that voluntary consent to participate in such research may influence online social media behavior in the short-term.

(3) Future research should include studies aimed at determining if change processes can differentiate Service members who die by suicide from Service members who do not die during the same time period.

(4) Because many Service members who die by suicide demonstrate increased frequency of medical visits during the months immediately preceding their deaths, DSPO should explore options for applying the specific analytic methods used in the present study (i.e., dynamical systems theory) to DoD medical databases to assess if the modeling of nonlinear change processes provides incremental value in identifying Service members who die by suicide.

(5) Future research should aim to integrate automated detection methods with human detection methods. Whereas automated methods (e.g., natural language processing) are likely to provide scalability of risk detection across hundreds of thousands to millions of users, human coding procedures may provide greater semantic nuance (e.g., use of humor and sarcasm). Determining if the combination of these two methods can provide incremental utility relative to either method in isolation would therefore be of value.

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APPENDIX A:

ILLUSTRATIVE CASES

APPENDIX A

CASE 28

Date of death: 7/12/2010

Manner: Suicide (gunshot wound)

Post #	Date	Post Content
1	12/24/2009	"and still you feel the lonliness is better replaced by this..."
2	12/24/2009	sevendust....nuff said [posted weblink]
3	12/24/2009	nervous as hell now lol...shoot me now
4	12/24/2009	Is gonna kill dan if this goes wrong lol...
5	12/24/2009	"...and its all acceptable under the giant umbrella of the huuuuugggeeee sorry I was drunk rule..."
6	12/24/2009	dont we all
7	12/24/2009	sayin hello to his old pal whiskey....
8	12/24/2009	god man...im gonna be [redacted] in april, gettin up there...
9	12/24/2009	lmao...man if im grown up, u must be getting geriatric
10	12/24/2009	thanks garrett, hope you have a good xmas as well, make the lil ones happy
11	12/24/2009	cant wait to hear his mother suddenly start talking with a rhode island accent as soon as we get to her sister's house in rhode island tomorrow
12	12/25/2009	"lookin at u makes it harder...but i know ull find another...that doesn't always make you wanna cry...started with a perfect kiss then...we could feel the poison set in...perfect couldn't keep this love alive" to all the girls i know that are sad about bein alone on xmas, and steady thinking about their exes..you can sit and dwell on a past you cant change or mold your future, be happy and be u
13	12/25/2009	buzzin on chianti wine, what to do next...
14	12/26/2009	has to be up early for the pats game tomorrow, dad doesnt wanna miss the tailgate...beer better be free ☺
15	12/26/2009	damn....ah well and we will
16	12/26/2009	we'll miss the tailgate if we take the train so...
17	12/26/2009	my dad's at the helm man...im just chillin starboard lol
[...]	[...]	[...]
18	5/4/2010	"We cant all be happy, you know....but the worst part is the loneliness...the knowledge that you'll never have anyone to be close with, to share with, to love...me, i have up trying a long time ago, maybe thats why im here...but the pain is the worst part, the mental torment, and the realization that you are in fact solitary, alone.." ~ [name], ADMAX Florence Colorado, the most secure Supermax in the world
19	5/4/2010	thought it was sad when i read it
20	5/4/2010	not me this guy lol
21	5/4/2010	Up to stamford for a meeting with some pentagon people...fun fun
22	5/4/2010	im goin there next year to be my buddy, who is a major, his lead aide/bodyguard

Post #	Date	Post Content
23	5/5/2010	That i am lol….nada bro workin up at millstone now, workin and chillin, u still at the depot?
24	5/5/2010	bored with it all…there's got b more than this..only time i feel lifelike is with the aid of alcohol…lost and lonely…save me please, save me…
25	5/5/2010	hahaha…heard this in a song on my godawful road trip to and from stamford yesterday…me and my buddy were like wow this song is the cherry on top of it all lol
26	5/5/2010	is all ADHD at the present time, cant stop cleanin…Cinco de Mayo at Bank Street Café tonight! Cheap drinks and good times…Ridin Dirty bitches!
27	5/5/2010	yes i am mr [name] its a cool place now, lot different than it was…and chris my boy, its my turn to be goin out while you're workin! hahahhahaa
28	5/6/2010	hahahha…arent we all
29	5/6/2010	always man….its my new home base..and hell yeah last night was fun as hell!!
[…]	[…]	[…]
30	7/1/2010	I promised myself, that i'm gonna die for something that counts
31	7/6/2010	busy ass morning, gonna be up for over 25 hours, well depending on how long court lasts…
32	7/6/2010	im fightin a speeding ticket
33	7/7/2010	got my ticket reduced yesterday, but was up for 28 hours straight, off to take my car to a checkup, then to the gym and finally washing my car….god I cant wait to sip that first ever so sweet sip of alcohol later
34	7/7/2010	come up here and drink w me chica lol
35	7/7/2010	no alcohol in like 5 days bro, im fiendin! and Court, thats awesome, we def gotta meet up and chill at some point.
36	7/7/2010	sweeeeeeetttttt!, i'll tie myself up to make it easier for ya
37	7/7/2010	haha damn right…the only two CLASSICS at this point in time
38	7/7/2010	People live in terrible times, but you must believe you can survive ~ The Expendables
39	7/7/2010	"Lookin at me like I killed Kenny"
40	7/9/2010	"A life, Jimmy, you know what that is? It's the sh*t that happens while you're waiting for moments that never come." [name] one day at a time, make the most of each one, u'll realize you have more than you think you do, it aint about where you are, its all about the people you're with
41	7/9/2010	rootin through a massive box of dvds tryin to find Gracie vs. Japan for mr. joey thorough, needless to mention its in the garage and im sweatin like an 80 year old man holdin a sauna hostage
	7/12/2010	**Case 28 died of self-inflicted gunshot wound**

CASE 53

Date of death: 5/2/2010

Manner: Suicide (hanging / suffocation)

Post #	Date	Post Content
1	12/18/2009	My flight leaves at 6am to go home. Yay
2	12/18/2009	the wife would kill me
3	12/19/2009	FUCK MY LIFE. Delayed until tomorrow at 3pm.
4	12/19/2009	its just as cold here
5	12/19/2009	Im in [redacted] right now :P
6	12/19/2009	if I can get a flight
7	12/19/2009	alright I suppose, you?
8	12/19/2009	[youtube link posted]
9	12/20/2009	Lol no. I plan on going back maybe when I get done my training, a lot of people haven't gotten to meet her yet.
10	12/20/2009	Flights seem to be onetime.
11	12/21/2009	Well fuck that idea. Should have a flight tomorrow.
12	1/8/2010	So thought I was guna get stuck on base for a long time, thank god for the people who fuck up more than me.
13	1/9/2010	I missed a Cq shift and I left my locker unsecure and my Plt Sgt said i was going to be fucked for a month.
14	1/9/2010	my phone is no longer in service, leave a message here if you wanna get a hold of me.
15	1/10/2010	I feel liberated without a phone. So ya'll can fuck off
16	1/13/2010	Busy as Hell. I got the APS spot so now I have to baby sit 79 screaming children.
17	1/14/2010	I got 4 days of freedom coming up starting tomorrow. Oh this is going to be nice. Oh and we arent allowed to smoke anymore as a part of punishment. I WANT TO SMOKE.
18	1/17/2010	…This is what happens when you let boys from the south into a Bass Pro shop. [video clip posted]
19	1/17/2010	The big on is [name] and the guy in the Black is [name]
20	1/17/2010	…Now they are both doing it. [video clip posted]
21	1/17/2010	…I just wanted a hug [video clip posted]
22	1/22/2010	This whole being in charge of a platoon thing… FUCKING SUCKS
23	1/23/2010	Thats fine in the real army, not here. Its a bunch of kids who want to fuck around and not do what they are told. Imma work it out though and when my time is up im going to leave behind a squared away platoon.
24	4/21/2010	So much for being married. Gotta try everything at least once.
25	4/21/2010	…lol?
26	4/21/2010	Here is a piece of advice, dont grow up to be like your sister.
27	4/21/2010	reject.

Post #	Date	Post Content
28	4/21/2010	Shit no, im perfec, I dont know what you're talkin about.
29	4/21/2010	what are you black?
30	4/21/2010	You know shit is getting bad when every time you lay nuts to your wife you get a massive headache.
31	4/22/2010	Brand new Guitar and its already fucked up ☹ BUUULLLLLLLSSSSHHHHHHHIIIIIIIIIIIITTTTTTTT
32	4/22/2010	Truss rod, im getting abuzzing on almost all my frets. watching a vid on youtube on how o fix it.
33	4/22/2010	Fuck me, So i adjust the truss rod, still nothing, raise the bridge, tune the bitch and the action is waaaayyy to high, lower the bridge, tighten up the truss rod and retune it... damnnit
34	4/23/2010	Cant sleep...tomorrow is guna suck
35	4/23/2010	I thought this state was suppose to be warm
36	4/24/2010	huh...
37	4/25/2010	You know its sad when you ask your so called wife, "Should I really have to live with a guy who wants to fuck my wife?" And she cant give a simple yes or no answer. For any normal couple...thats usually never an issue. What really sucks is...who seems like the most important man in her life right now? SURE AS FUCK ISN'T ME.
38	4/26/2010	...huh
39	4/27/2010	So I got up this morning and decided I wanted to get me 8 new staples in my head, it was fuckin awesome I would add a pic but FB is gay
40	4/27/2010	I didnt actually plan on it [name], my head kinda hurts now but its not too bad. I was kneeling down kinda like wtf watching the blood come out of my head, it was pretty badass
41	4/27/2010	This was at home and its pretty much summed up by me not payin attention and something heavy falling on my head. I give the ER 5 stars. I was in and out in under 2 hours.
42	4/27/2010	Thats a picture of my head ^
	5/5/2010	**Case 53 died of suicide by hanging / self-strangulation**

CASE 83

Date of death: 1/3/2011

Manner: Accident (fall)

Post #	Date	Post Content
1	9/28/2010	Being in love isn't easy, it's full of Heartbreak and happiness, Joy and Loss. When you decide to remain together after everything, you've found true love.
2	9/28/2010	Not sure where to go from here. I do and is a lot of appts. and "housecleaning" I guess.
3	9/28/2010	It was and is jsut wrong the way it all happened. Not wanting to talk on here. Just gone, come home and gone and kids knew. the pain is unbearable and the hurt.
4	9/29/2010	People make mistakes and say or do things they did not mean to. Are you that perfect that you cannot forgive them or yourself?
5	9/29/2010	Alot accomplished today and back to the ole grind in am.
6	9/30/2010	Just blown away as all just keep walking away from the truth and what they live and never face it head on. And just walk away from all responsibilities as usual the situations at hand they never dealt or wanted to deal with.
7	9/1/2010 to 9/30/2010	[daily inspirational posts from website]
8	10/1/2010	it is nearly impossible to be mean to someone who is trying so hard to make things right with you but in the meantime has lied, stole, and cheated and just left ya!!!! That means they have issues not you. They are not willing to face the real truth and what they live and deal with and then cannot face the fact and willingly know that the others who were told know.
9	10/1/2010	Sad is not the word, nothing can describe my feelings right now =C
10	10/2/2010	When your heart is breaking remember: don't cry over someone who won't cry over you.
11	10/3/2010	Forgetting someone is not as easy as walking out of the door.
12	10/4/2010	If you loved me you wouldn't have left me, if you were sorry you wouldn't have done it again and if you cared you wouldn't have hurt me in the first place.
13	10/4/2010	I am willing to admit to my mistakes, but I am also willing to correct the ones I can and learn to forgive myself for the ones I can't.
14	10/4/2010	SSDD
15	10/4/2010	Is just frustrated…. Garage repairs want alot of money to fix and not use what is here and available from the purchase.
16	10/4/2010	Need the rollers, the springs, and drums installed I guess.
17	10/4/2010	Got another guy coming out Sat.
18	10/4/2010	Ok enlighten me..
19	10/4/2010	misses the 1 person that made her the happiest, but also broke her heart

Post #	Date	Post Content
20	10/5/2010	Lord, I asked for you to come and take my heavy burdens. I ask you to carry them for me as they are too heavy. Please keep me daily, Lord in your perfect peace.
21	10/5/2010	Thanks [name] if ya only knew.....
22	10/5/2010	... Is stressed , mad, nervous, exhausted and just wants 2 do nothing but sleep!!
23	10/5/2010	Don't judge me unless you have looked through my eyes, experienced what I have, and cried as many tears as me. Until then back-off, cause you have no idea.
24	10/6/2010	Hell I ain't no redhead…
25	10/6/2010	[name], who knows…
26	10/5/2010	Not too sure what to think with all the drama.. But my hubby came home tonite, is washing clothes and laying in recliner. Yes I said what I had to say and it hurt and the tears rolled.
27	10/6/2010	Did you ever sit and wonder to yourself, "What the hell just went wrong here?"
28	10/6/2010	Asking for Forgiveness is easier than asking Permission!!!!
29	10/7/2010	FOOD FOR THOUGHT-ALWAYS THINK AND ANALYZE BEFORE TAKING ACTION. YOU MAY HURT MORE THAN 1 PERSON WITHOUT REALIZEING IT.
30	10/7/2010	[posts link]
31	10/7/2010	Unfortunately most women won't re post this. I'm strong willed, independent, and outspoken. I make mistakes. I am sometimes out of control and at times hard to handle – but if you can't handle me at my worst then you sure don't deserve me at my best. If you're a HANDFUL.. then post it on ur stattus.
[...]	[...]	[...]
	1/3/2011	**Case 83 died of an accidental fall**

CASE 839

Date of death: 12/11/2011

Manner: Suicide (gunshot wound)

Post #	Date	Post Content
1	10/5/2011	Like I really need anymore tonight!!!!!!
2	10/5/2011	I love you MY Baby!!!
3	10/7/2011	Extremely fussy an tryin' to be a good kid tonight, lets see how this works out for me!!!!!
4	10/7/2011	Ummmm….NO, just missin' MY Baby!!!
5	10/7/2011	So lovin' my lil sis!!!!!!!
6	10/7/2011	[posts image]
7	10/9/2011	Italian Pork Chops(using MY Babys marinade) friend potatoes an green beans, so wish MY Baby was here right now!!!! But no worries I will be there soon!!!! I love you my Baby!!!!!
8	10/9/2011	Unfortunately Im thinking this is gonna be a LONG night!!!! BAD GUT feelin'!!!!!!
9	10/9/2011	Really Hooker? Shush!!!!!!!!!
[…]	[…]	[…]
10	11/24/2011	Love watchin' MY Baby sleep, she looks so heavenly….I Love her soooo MUCH!!!!!
11	11/24/2011	Guess I should give thanks for the fact that not everyone is allowed to own automatic weapons right now
12	11/24/2011	Im not? Always & Forever
13	11/26/2011	Less you really an truly know me you dont need to be tryin to talk shit bout me unless you actually have some kind of real facts….SHUT YOUR FUKKIN MOUTHS!!!!!
14	11/26/2011	you shush!!!!! LOL
15	11/28/2011	Jus heard a lil voice that said somethin' that really made my day!!!!!!
16	11/12/2011 to 11/30/2011	[posts links to daily horoscope and websites]
17	11/30/2011	So missin' MY Baby, feels like its been forever since I was home. Cant wait til Monday when she gets here!!!!
18	12/2/2011	I wanna frog!!!!!
19	12/2/2011	English hooker!!!!!
20	12/2/2011	According to google translate, you called me a pig!!!!! LMFAO!!!
21	12/2/2011	[posts link to video]
22	12/2/2011	So just wanna curl up with MY Baby right now, but guess its nap time til she gets off work so I can see her beautiful face an actually get some sleep!!!! Love her so much an dont have a clue where I would be with out her!!!!!
23	12/4/2011	OMFG!!!!! Tonight is draggin', so cant wait, 16 more hours and Manda will be here. So excited right now, feel like a fat kid waitin' on cake, LOL!!!! I love her more than anything.

Post #	Date	Post Content
24	12/4/2011	Santa, I don't want much for Christmas, I just want the woman I love more than anything in my arms for the rest of my life. This is what I want: Call me selfish, call me foolish! But this is my only wish, Im thinking I've spent enough Christmas's alone Santa, so if you promise me this I guess I can be a nice boy from here on out!!!!!!
25	12/4/2011	Amanaka's Ipo Mua Loa!!!!!!
26	12/5/2011	Lazy day with MY Baby!!!!
27	12/5/2011	So yea its snowing again an the weather report is calling for 1-3"s…WTF???? Guess its a good thing me an My Baby are just gonna cuddle up on the couch an relax tonight!!!
28	12/5/2011	Would gladly trade ya [name]
29	12/6/2011	Chilling with my baby!!!!
30	12/7/2011	Sweet dream My Baby, I love you, Always and Forever!!!!!!
31	12/8/2011	My Baby just left and Im a total mess right now, I miss her so much already!!!!
32	12/9/2011	Has officially decided that I FLIPPIN' HATE goin' to bed and waking up with out MY Baby!!!! Slept like shit last night without her!!! Miss her so much!!!!
33	12/9/2011	I know right???
34	12/9/2011	I am an always have been my own worst enemy an possibly just fukked up the BEST thing that ever happened to me!!!!!
35	12/9/2011	P Always & Forever
36	12/9/2011	Always & Forever
37	12/9/2011	[link to song lyrics]
38	12/9/2011	FUK IT!!!!
39	12/10/2011	So do not have enough alcohol for the night
	12/11/2011	**Case 839 died of self-inflicted gunshot wound**