Using daily diary data to examine the period prior to a suicide attempt: An observational single-case study

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ABSTRACT

Background: Prevention of suicide is an important public health issue. Applying Exponential Weighted Moving Average (EWMA) control charts to time-intensive diary data could improve our understanding of the processes leading up to a suicide attempt (SA). We explored daily reports of multiple psychopathological domains, and particularly changes therein, during a period directly preceding a SA.
Methods: We applied an observational single-case study design on a diary data from one participant (female, age between 20 and 30 years) who attempted suicide (and survived) during participation in another study. This study included 90 daily reports of depression and anxiety symptoms, psychotic experiences, thought disturbances and a proxy for passive suicide ideation (feeling life is worthwhile). We used EWMA control charts to explore whether structural changes in these psychopathological domains preceded the upcoming SA. We first investigated the overall domains and then zoomed in on individual items.
Results: We detected increases in depression and anxiety symptoms, psychotic experiences, and passive suicide ideation in a time window of 6 days directly preceding the SA. Although no changes in the overall dimension of thought disturbances preceded the SA, two specific items, impulsive thoughts and persistent thoughts, did increase.
Conclusion: We found changes in daily reports of several (sub)dimensions of psychopathology prior to the SA. Our findings show how applying EWMA charts to diary reports may be helpful to detect signs of an upcoming SA. Improving our ability to timely signal risk for SA may inform strategies aimed at its prevention.

Introduction

With a yearly estimation of nearly 1 million suicides worldwide (Bachmann, 2018; Hawton et al., Fazel), suicide is an urgent public health problem. Compared to the general population, suicide is much more common in people with mental illness (Bolton, et al., 2015). Our ability to prevent suicide deaths is limited (Sander et al., 2023). This might be partially attributable to our poor understanding of suicide-related behaviors and processes underlying the transition from suicide ideation (SI) to suicide attempt (SA) (Kleiman and Nock, 2018; Klonsky et al., 2018). Most research to date showing associations between suicide-related behaviors, mental disorders and other

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psychological processes come from cross-sectional studies, or from longitudinal studies with relatively large assessment intervals (e.g., weeks, months) (Coppersmith et al., 2022). Such designs do not optimally capture the volatile nature of SI (Kivelä et al., 2022) which has been shown to fluctuate at shorter periods of time (e.g., days or even hours) (Bryan et al., 2019; Forkmann et al., 2018; Kleiman et al., 2017). Fluctuations at such a micro-level can be captured through ambulatory assessments such as diary measurements (Czyz et al., 2019; Smit et al., 2023; Zuidersma et al., 2020). The time-intensive longitudinal data generated by such designs are suitable to detect short-term changes in SI that are thought to reflect shifts in real-time suicidal thinking (Ammerman and Law, 2022). As recently shown, unique individual trends (gradual and/or sudden changes) in SI may be detectable at an early stage using dynamics of time-series data (Nuij et al., 2023).

Recent studies have investigated the potential of statistical process control to detect significant changes in the mean of daily assessments of mental health states (e.g., restlessness) to foresee the recurrence of depressive symptoms (Schreuder et al., 2024; Smit and Snippe, 2022; Snippe et al., 2023). As a SA also represents an important mental health event, time-intensive longitudinal data may also offer important possibilities to better understand the process leading up to a SA. This, in turn, can inform and improve prevention strategies and may answer the need to develop sensitive tools and strategies to improve suicide risk detection (Bryan et al., 2023).

Symptoms of multiple psychopathological domains, including depression (Melhem et al., 2019) and anxiety (Bentley et al., 2016), have been associated with SA (Too et al., 2019; Wasserman et al., 2021). In addition, specific affective and anxiety symptoms were also found to predict suicide-related behaviors (Busby Grant et al., 2023). Psychotic experiences (PE) have also been examined as potential predictors of SI and SA (Gournellis et al., 2018), as individuals with PE have been found to be at increased risk for SI, SA and suicide death (Yates et al., 2019). PE are multidimensional (e.g., Wigman et al., 2011) and evidence on which PE subtypes show the strongest associations with SA remains inconclusive (Jay et al., 2023). Hielscher et al. (2021) found that the transition from SI to SA was associated with auditory hallucinations plus psychological distress, and Karcher et al. (2022) reported that in particular distressing PE were linked to suicidal ideation and behavior.

Traditional approaches lack sensitivity (pooled sensitivity of 41 %) and possess poor positive predictive value (PPV), with *PPVs of only* 0.3 % in non-psychiatric and 3.9 % in psychiatric samples (McHugh et al., 2019). This means that these methods often fail to accurately identify individuals at imminent risk of suicide, limiting their effectiveness for timely intervention. In the attempt to better understand the transition from suicide *ideation* to suicide *attempt*, diary studies have provided new insights by examining the association between psychopathology and suicidal behaviors, in particular suicidal ideation (Kleiman and Nock, 2018), at a day-to-day level. Daily diary assessments can help to capture risk and protective factors, as well as their dynamic changes, in the flow of daily life. For example, the review by Kivelä et al. (2022) has shown that SI can vary greatly within short timeframes and that negative affect, hopelessness and burdensomeness are associated with these fluctuations in SI. Other studies also reported large within-person fluctuations in SI (Czyz et al., 2019) and found this to be a strong predictor of post-discharge suicide risk in patients independently of their mood (Bonilla-Escribano et al., 2023). The review by Gee et al. (2020) reported associations between daily negative affect, lack of social support, sleep disturbances and an individual's history of suicide and non-suicidal self-injury. In addition, this review also showed that negative affect was strongly associated with SI in patients with major depression (Gee et al., 2020). It has been found that young people reporting higher past-week SI also presented significantly less daily positive future thinking, even when controlled for previous-day average positive and negative affect (Kirtley et al., 2022).

However, daily diary studies examining PE and SI are very scant. The only study was conducted in a sample with psychotic disorders (Parrish

et al., 2021), and found that hearing voices, suspiciousness, mood and SI were associated with the experience of being a burden to others and feelings of belongingness, highlighted as two key risk factors for suicide-related behaviors by the Interpersonal Psychosocial Theory of Suicide (IPTS; van Orden et al. (2010)). Taken together, associations between suicidality and psychopathology seem to be more transdiagnostic than disorder-specific, asking for a transdiagnostic approach (Schechter and Goldblatt, 2020; Scott et al., 2021; Shah et al., 2022). In addition, the current lack of knowledge on the nature of early signs of imminent suicide risk (Kivelä et al., 2022) further supports a broad, transdiagnostic approach to identifying these.

In the current paper, we examined data of a participant diagnosed with depression who participated in a daily diary study and attempted suicide (and survived) during the data collection period. Our goal was to explore if systematic changes in a broad range of self-reported experiences, including affective and anxiety symptoms, PE, thought disturbances and passive SI (feeling life is (not) worthwhile), could be detected in the weeks or days prior to the SA.

Methods

Participant

The participant was one of the 96 participants of the *Mapping Individual Routes of Risk and Resilience* (Mirorr) study (Booij et al., 2018; Wigman et al., 2022). This study aims to examine the development and expression of psychopathology and consists of a daily diary study of 90 days as well as cross-sectional assessments at baseline and at 3 yearly follow ups. The inclusion criteria for the Mirorr study were: 1) aged between 18 and 35 years, 2) fluent in reading and speaking Dutch, 3) capable of following the research procedures and 4) provide informed consent. The exclusion criteria were: 1) a history of or current psychotic episode, according to the Diagnostic and Statistical manual of Mental Disorders 4 (DSM-4) criteria, 2) significant hearing or visual problems and 3) pregnancy, as stated on a general health questionnaire. The total sample was divided into four subgroups, with each subgroup representing different levels of severity for psychotic experiences (PEs). The subgroups are categorized as follows: "very low" risk ($n_{subgroup1}$=25), "low" risk ($n_{subgroup2}$=27), "moderate" risk ($n_{subgroup3}$=24), and "ultra-high" risk ($n_{subgroup4}$=20). These subgroups correspond to subsequent early risk stages for psychosis. Whereas individuals from subgroup 1 were recruited from the general population, individuals from subgroup 2–4 were receiving mental health care at time of inclusion (see protocol paper of the Mirorr study (Booij et al., 2018))

The participant of this single-case study was female, between 20 and 30 years old and had a middle level of education. She was in outpatient care for mental health assigned to subgroup 2 (low risk for psychotic disorder). At baseline, she presented with a diagnosis of depressive disorder, a history of suicidal ideation, suicidal planning, and non-suicidal self-injury. These were assessed using the Schedules for Clinical Assessment in Neuropsychiatry (mini-SCAN), a validated clinical diagnostic interview administered by a trained research assistant (Nienhuis et al., 2010).

Study design

This study has an observational single-case design using daily diary assessments. In these types of studies, many repeated measurements are obtained for a single individual which can then be analyzed statistically, allowing for statistical inferences for that specific participant (Zuidersma et al., 2020). Every evening for 90 consecutive days, she received a text message on her smartphone at the participant's chosen time. This text message contained a secure web link to the daily diary items on thoughts, feelings and behaviors of the past day. A window of 1.5 h was allowed to fill in the diary, and reminders were sent every 30 mins.

Measures

Baseline assessments

Psychological distress

The Depression, Anxiety and Stress Scales (DASS-21; Lovibond and Lovibond (1995)) was used to measure levels of depression, anxiety and stress. The DASS is composed of 21 items distributed over three subscales: depression, anxiety and stress. Each subscale contains 7 items, rated on a 4-point scale ranging from "never" (0) to "almost always" (3). The DASS has shown good psychometric properties in the Dutch population (Wardenaar et al., 2018). Together, these three scores reflect a measure of psychological distress (Peixoto et al., 2021).

Diary measurements

All diary items, listed in Appendix 1, were assessed on a 100-point visual analogue scale (0= "not at all", 100= "very much"), except auditory and visual hallucinations which were scored on a 7-point Likert scale (1 = "not at all", 7 = "very much"). These items cover a broad range of symptoms, emotions and experiences to reflect depression, anxiety, psychotic experiences, thought disturbances and life worthiness considered from a transdiagnostic perspective. A list of all diary items used in the Mirorr study may be found elsewhere (Booij et al., 2018).

Depressive symptoms

We used the average score of six items that each reflected different subdimensions of depressive symptoms: 1) Energy levels, 2) Enthusiasm, 3) Cheerfulness, 4) Apathy, 5) Tiredness, 6) Feeling down. Before averaging, we reversed the scores (i.e., 100-score) of subdimensions 1–3 to have the same valence as subdimensions 4–6.

Anxiety symptoms

We used the average score of three items that each reflected different anxious subdimensions: 1) Anxiousness, 2) Restlessness, 3) Worriedness.

Psychotic experiences

We used seven items that each reflected different subdimensions of PE: 1) Suspiciousness, 2) Persecution, 3) Thought broadcasting, 4) Dissociation, 5) External locus of control 6) Auditory hallucination, 7) Visual hallucination. We used the average score of items 1–5 to reflect daily levels of psychotic experiences. Because auditory and visual hallucinations (items 6 and 7) are less frequent in subclinical populations (Waters et al., 2014), they were scored on a 7-point Likert scale. Because of their low prevalence, these two items were not included in the average score of the other psychotic experiences but reported separately.

Thought disturbances

We used the average score of four items that each reflected different subdimensions of thought disturbances: 1) Impulsive thoughts, 2) Persistent thoughts, 3) Running thoughts, and 4) Thought expression.

Life worthiness

To avoid psychological burden of daily measurements on willingness to live or die (Bonilla-Escribano et al., 2023), we used one item on life worthiness as a reversed expression of passive suicidal ideation. In this study, willingness to live was conceptualized in terms of the self-reported feeling of life worthiness phrased as "I found my life was worthwhile today" a proxy of passive suicidal ideation.

Additional interview

After completing the initial EWMA analyses with participant data, the participant was approached for an additional interview (Appendix 2) to further explore the period preceding the suicide attempt, which the participant agreed to. Given the sensitive nature of this event, we are very grateful for this to the participant. This semi-structured interview was designed to collect detailed qualitative data regarding the participant's thoughts, feelings, and experiences (i) of the week prior to the attempt and (ii) at the day of the attempt. Special attention was paid to maintaining a supportive and safe atmosphere throughout the interview to encourage open and honest responses. Prior to conducting the interview, additional written informed consent was obtained from the participant.

Statistical analyses

Reliability

Because the data concerns repeated assessments within one participant, we used the within-level omega (ω) estimation of reliability for composite scores (Dunn et al., 2014; Geldhof et al., 2014). Specifically, we used the total sample of Mirorr (N = 96) to estimate the within-level ω for the composite scores: depressive and anxiety symptoms, psychotic experiences and thought disturbances. Within-level ω refers to the degree to which a composite score (average of a set of items) is consistently measuring the same latent construct in the same participant over time (within-level ω). As Cronbach's alpha (Ursachi et al., 2015) is a specific case of the omega reliability measure (Geldhof et al., 2014), similar rules of thumb for interpretation can be followed, with values between 0.6–0.7 considered acceptable, 0.7–0.8 considered good, 0.8–0.9 considered excellent, and values between 0.9–1.0 potentially indicating redundancy in the chosen items (Tavakol and Dennick, 2011; Ursachi et al., 2015). We used *omegaSEM* from the *multilevelTools* package in R (Wiley, 2024) to calculate within-level ω.

Exponential Weighted Moving Average charts (EWMA)

EWMA is a technique that has recently been shown to be suitable to detect structural changes in time-intensive reports of mental states to signal a transition to recurrence of depression (Smit and Snippe, 2022; Snippe et al., 2023). Originally used in industry to timely signal deviations in the production process, EWMA can also be used to detect one's deviation from their own pattern of experiences in real-time (Montgomery, 2019). Considering expected person-specific fluctuations in mood and affect, EWMA charts signal the moment when these experiences go 'out of control' (i.e., out of one's normal range) in real-time.

We first tested structural changes in the mean levels of the above-described psychopathological dimensions prior to a suicide attempt (i.e., depressive and anxiety symptoms, psychotic experiences, thought disturbances and passive suicidal ideation). Next, we examined each item within the dimensions to see if potential effects would be driven by particular items. These changes are plotted in EWMA charts, which have time on the *x*-axis and EWMA scores on the *y*-axis. An EWMA score at moment ($EWMA_t$) is calculated by updating the previous measurement of the mean ($EWMA_{t-1}$) of a psychopathology dimension (Y) by assigning weights (λ) to both the measurement of the psychopathology dimension in the current day (Y_t) and the previous measure of the mean ($EWMA_{t-1}$) as follows:

$$EWMA_t \ = \ \lambda \times Y_t + (1 - \lambda) \times EWMA_{t-1} \qquad (1)$$

Lambda (λ) determines how much weight is given to the current observation. The higher λ, the more weight is assigned to recent observations (as default, we used λ of 0.1 (Smit and Snippe, 2022; Snippe et al., 2023). There are two phases in EWMA charts: a calibration and a monitoring phase. Based on the calibration phase, we calculated the person-specific parameters (i.e., mean (μ) and standard deviation (σ)) to produce a personalized Upper Control Limit (UCL, Eq. (2)) and Lower Control Limit (LCL, Eq. (3)). These limits create a bandwidth within which EWMA scores psychopathology dimensions are expected to vary for that individual. We used a similar approach as (Smit and Snippe,

2022; Snippe et al., 2023) and selected the first 4 weeks (28 days) for the calibration phase. In the monitoring phase, we then monitor each $EWMA_t$ score to detect structural changes signalized by the values moving outside the control limits bandwidth.

$$UCL_t = \mu + L\sigma \sqrt{\{[\lambda / (2 - \lambda)][1 - (1 - \lambda)^{2t}]\}} \quad (2)$$

$$LCL_t = \mu - L\sigma \sqrt{\{[\lambda / (2 - \lambda)][1 - (1 - \lambda)^{2t}]\}} \quad (3)$$

The appropriate value of L depends on λ and on the desired in-control Average Run Length (ARL0). The ARL0 is the expected number of days before the occurrence of false positive (i.e., an EWMA measurement is detected outside the control limits bandwidth when the EWMA measurement is in fact within the bandwidth). Again, following recommendations (Smit and Snippe, 2022; Snippe et al., 2023) we used ARL0 of 370 days. Given that we used a lambda of 0.1, this corresponds with an L of 2.7. Prior to EWMA analysis, we calculated the mean and standard deviation of the calibration phase scores of each psychopathological dimension under study. Next, we used these values to standardize each dimension of psychopathology. This procedure ensures a standard bandwidth limit for multiple variables which allows us to directly compare multiple psychopathological (sub)dimensions on the same chart. We used the publicly available R-code developed by Schat and colleagues (Schat, 2021) to produce the EWMA charts. For a full tutorial on analyzing EMA data using EWMA control charts see (Smit et al., 2023).

Results

Participant description. According to the cut-offs proposed by Lovibond and Lovibond (1995), the participant had moderate levels of depression (score of 15) and anxiety (score of 12), but normal levels of stress (score of 14) at baseline. Overall, the participant had moderate levels of psychological distress (total score of 41). The participant did not report any auditory hallucinations and reported 2 visual hallucinations (score of 5 on a 7-point Likert scale) after SA.

Additional interview

The participant stated that there was not really one specific trigger for the SA, but that several things came together at that moment. She had been experiencing suicidal thoughts already for several years. She had a concrete plan in mind, though she did not act upon it. She had been experiencing much distress and anxiety at school, and although she had hoped this would decrease after finishing school, these feelings instead persisted. She reported feeling lonely, anxious and stressed, and not having many social contacts except her parents. Experiencing her professional training as very distressing, she stopped this and moved back in with her parents. She also reported how it was difficult to find adequate mental health care, including a fitting diagnosis. Prior to the SA, she was enrolled for a new treatment for which she did not feel well enough, and felt somewhat doubtful about its effectiveness; however, she was afraid to mention this. For this new treatment group therapy, she was asked to sign a non-suicide contract, a commitment which she experienced as extremely stressful and burdensome. In addition, two individuals in her direct environment had committed suicide in the past few years. She stated that the SA was not an impulsive action; she had made the decision and needed only to determine the moment. She had made up her mind several days prior to the SA on the specific day. She had saved up her medication for several days, which also increased her symptoms during this time. The night before the planned day, she had slept very poorly. At this day of the SA, she felt very nervous and panicky. The time around the actual SA is difficult to remember. After taking the medication, she managed to make some phone calls, which resulted in her being brought to the hospital in time.

Data description

Of the 90 measurement points, there were 10 missing values during data collection (4 non-consecutive missing values during the calibration phase and 6 non-consecutive ones during the monitoring phase) resulting in 80 valid values. SA happened on day 60 of dairy data collection. (i.e., data point 54). Directly after the SA, the participant was hospitalized and did not complete diary data for 3 days (i.e., 3 missing days after SA, which were included in the graph as a white gap). After that, she resumed the diary study again of her own volition.

Reliability

Within-level ω was acceptable to excellent in all psychopathology dimensions (within-level ω range: 0.60–0.84, see Appendix 3). This means that the items were consistently measuring the same latent construct over time.

EWMA charts of daily reports of psychopathology

As said, EWMA charts signals the moment when experiences go 'out of control' (i.e., out of one's normal range, determined by the upper and lower control limits) in real-time. We detected significant changes of psychopathology dimensions in a time window of 6 daily diary measures (=6 days) prior to SA (see Fig. 1). Specifically, a decrease in life worthiness was detected 6 days prior to SA and an increase in the dimensions of depressive and anxiety symptoms was detected 5 days prior to SA. Additionally, an increase in psychotic experiences was detected 3 days prior to SA. We only detected an increase in the dimension of thought disturbances on the dairy measure after SA. NB: Visual inspection suggest the trend in those dimensions started roughly 3 days before they reached significance.

When investigating specific items within each domain (Fig. 2 E-U), we detected changes in multiple subdimensions of depressive symptoms (increases in tiredness, feeling down, as well as decreases in cheerfulness, enthusiasm and energy levels), anxiety symptoms (increases in anxiousness and restlessness), psychotic experiences (increases in dissociation, suspiciousness and persecution) and thought disturbances (increases in impulsive thoughts and persistent thoughts). Increases apathy in the dimension of depressive symptoms and running thoughts in the dimension of thought disturbances were detected only after the SA. We did not detect any changes in thought broadcasting and external locus of control in the dimension of psychotic experiences. Similarly, there were no significant changes in thought expression in the dimension of thought disturbances.

Discussion

In this observational single-case study, we used time-intensive daily diary data to examine structural changes in daily reports of several psychopathological domains prior to a suicide attempt in a young adult female outpatient diagnosed with depression. In a time-window of 6 days prior to the SA, we detected increases in subdimensions of depressive symptoms (tiredness, feeling down, cheerfulness, enthusiasm and energy levels), anxiety symptoms (anxiousness, restlessness, worriedness), psychotic experiences (dissociation, suspiciousness and paranoid ideation) and a decrease of life worthiness (i.e., passive suicidal ideation). We only detected structural changes in the overall levels of thought disturbances *after* the SA; however, we did detect changes in some specific domains of thought disturbances prior to the SA (i.e., impulsive thoughts and persistent thoughts).

Our findings fit with literature revealing that higher levels of multiple psychopathological domains are associated with increased risk for SA (Bentley et al., 2016; Borges et al., 2010; Bryan et al., 2019; Hielscher et al., 2021; Too et al., 2019). Together, this underscores the need for a transdiagnostic perspective for monitoring different stages of suicide behavior (Schechter and Goldblatt, 2020). Of particular note, we found that our proxy measure of passive SI (life worthiness) showed a large
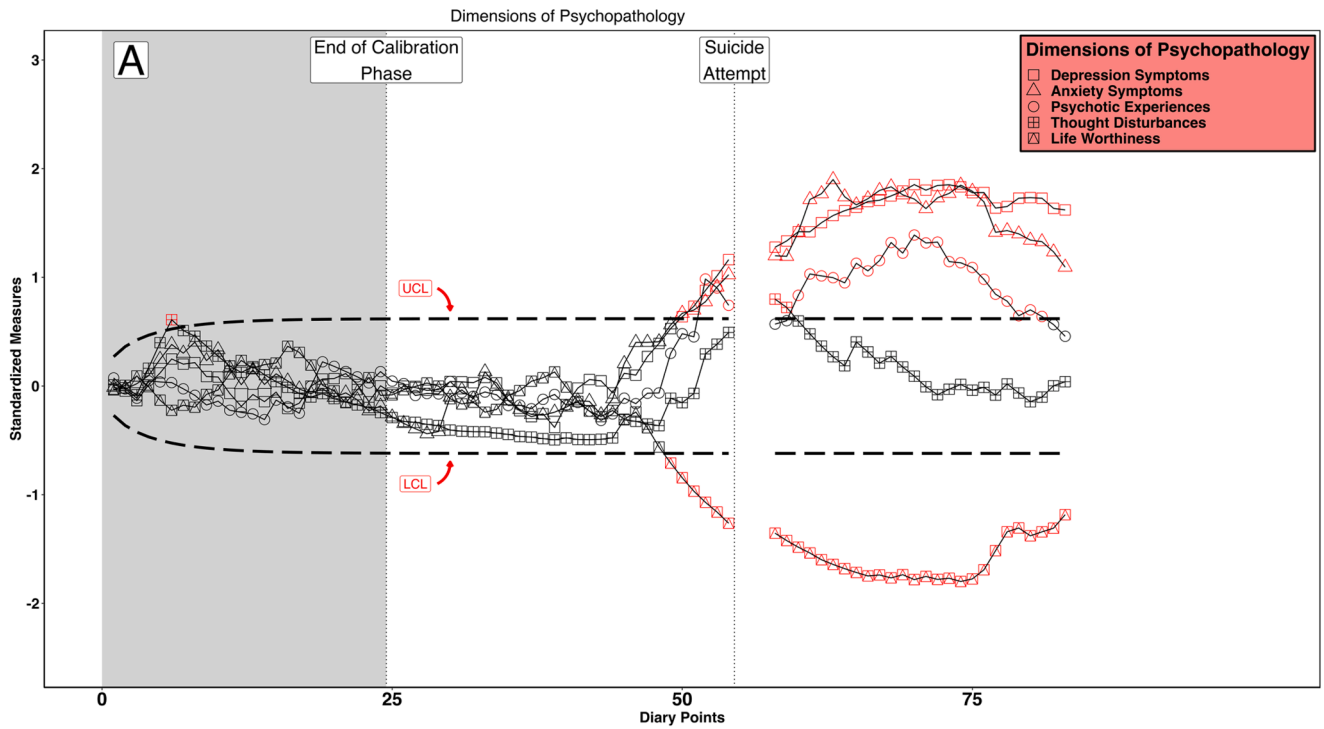
Fig. 1. Exponential Weighted Moving Average (EWMA) chart for psychopathological dimensions. Chart A shows all psychopathological dimensions, namely depression and anxiety symptoms, psychotic experiences, thought disturbances and life worthiness. Gray area is the calibration phase for Upper (UCP) and Lower (LCL) Control Limits. x-axis: measurement number (0–83), y-axis: standardized psychopathological dimensions. Suicide attempt at measurement point 54. There were 3 missing values after SA due to hospitalization (represented as a white gap).
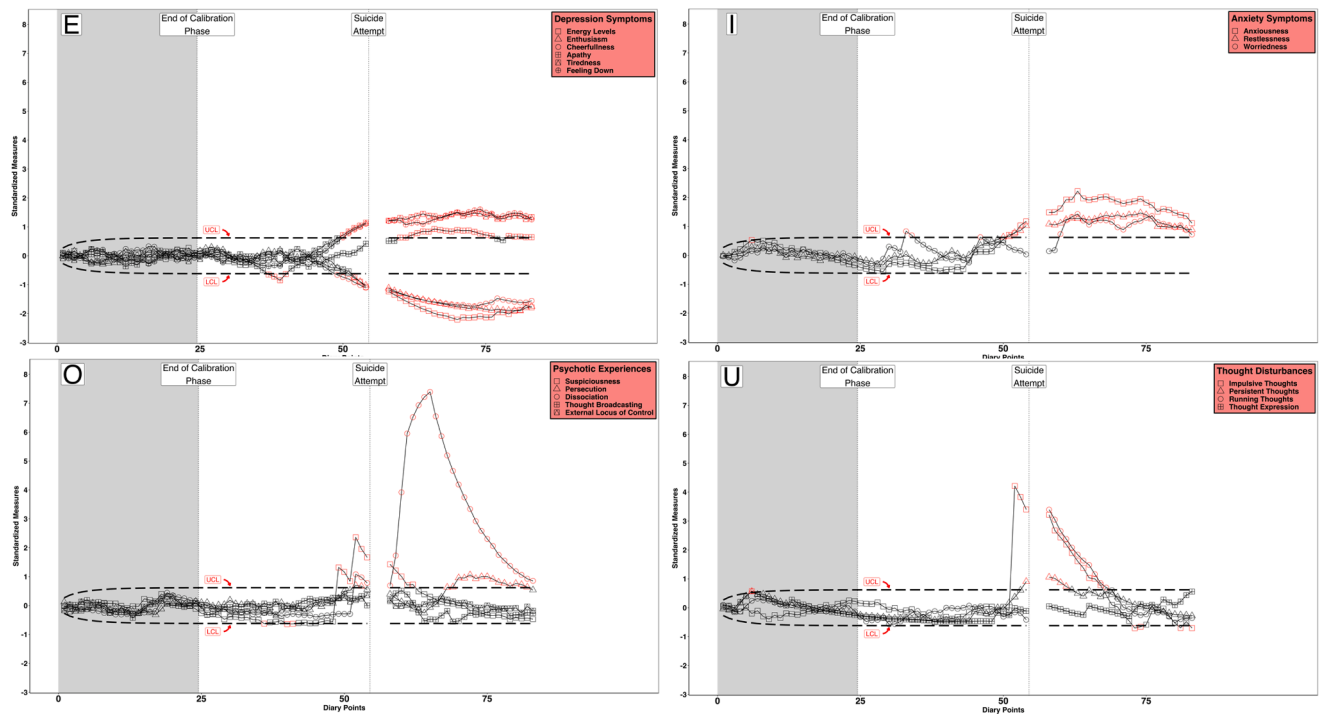
Fig. 2. Exponential Weighted Moving Average (EWMA) charts for specific items. Charts E-U show specific items within each dimension of respectively depression, anxiety, psychotic experiences, and thought disturbances). Gray area is the calibration phase for Upper (UCP) and Lower (LCL) Control Limits. x-axis: Diary Points (0–83), y-axis: standardized measures per item. Suicide attempt diary point 54. There were 3 missing values after SA due to hospitalization (represented as a white gap).

drop before the SA. This mirrors prior research demonstrating that perceiving 'no reason to live' is a dynamic variable that strongly increased prior to a SA (Bagge et al., 2022). Although other ambulatory assessment studies have also reported that changes in intensity, duration and recently short-term fluctuations in SI all are risk markers for a SA in individuals with a history of SA (Bonilla-Escribano et al., 2023; Czyz et al., 2019), we found a systematic deviation from the participant's normal range of feelings of life worthiness rather than increased fluctuations. Tentatively, this could suggest that *any* meaningful change in individual's experiences may reflect increased risk for an upcoming SA, regardless of the way it is conceptualized (e.g., as increased fluctuations or as a systematic deviation from one's normal range of experiences). However, to support such a claim, multiple conceptualizations should first be systematically compared, and similar changes that are *not* followed by a SA (i.e., false positives) should be investigated as well. Moreover, using different methods such as first-person accounts might enhance the understanding of suicidal processes (Bantjes and Swartz, 2019; Marsh et al., 2021). Results from the additional interview revealed the importance of the two key factors of the Interpersonal Psychosocial Theory of Suicide (van Orden et al., 2010), such as feelings of loneliness and social withdrawal (captured in the construct of thwarted belongingness) and high distress (captured in the construct of perceived burdensomeness). The IPTS highlights that when co-occuring, these two key components can lead to a *desire* to engage in suicidal behavior. However, this must be combined with an increased *capability* to engage in this type of behavior for someone to make the transition from SI to SA; this heightened capability was reflected in both the increased impulsivity prior to the SA and the participant's history of previous SA. Our finding of increasing levels of depressive and anxiety symptoms prior to the SA is in line with recent evidence demonstrating that these are risk factors for the onset of both SI and SA in youth (Busby Grant et al., 2023). Our results also partially fit with a study of Bagge et al. (2017), who retrospectively analyzed signals of an upcoming SA within a period of 48 h prior to the SA, and found that affective changes were early signs of a SA for some, but not all, suicide attempters and that these changes increased the risk when occurring 2–1 h prior the SA. However, participants in the study by Bagge et al. (2017) reported their mental states retrospectively, i.e., after a SA, while in our study the participant reported her current mental states *prior* to the SA. Therefore, our study was probably less influenced by potential biases derived from the intense psychological distress following SA.

Additionally, three days prior to the SA, we observed an increase of the overall levels of psychotic experiences. Paranoid ideation, dissociation, and suspiciousness became out of control six, four, and two days, respectively, before the SA. Previous research has shown that paranoid ideation is a significant source of psychological distress in non-psychotic patients, and associated with increased risk for suicide even in individuals who do not meet diagnostic criteria for a schizophrenia spectrum disorder (Freeman et al., 2019; Wastler and Núñez, 2022). On the other hand, dissociative disorders, dissociative experiences and suspiciousness have found to be strongly associated with SI and SA, and regarded as potential transdiagnostic contributing factors to transitioning from SI to SA. Therefore, its inclusion could improve detection of early signs of risk for SA (Calati et al., 2017; Jay et al., 2023), even in individuals who do not primarily present with psychotic problems. We additionally observed a strong increase in impulsive thoughts three days prior to SA and a lower, but significant, increase in persistent thoughts one day prior to the SA. This partially mirrors the findings by Bonilla-Escribano et al. (2023), who reported that, at a group-level, cognitive instability (intruding and racing thoughts), was associated with higher variability of SI in a sample of suicidal attempters. Nevertheless, because of different measures and designs, direct comparisons should be made with caution, especially when comparing results from studies performed at either group-level or individual-level. Although the technique we applied has the advantage to estimate personalized parameters of expected variability, further research is needed to fully understand the

volatile nature of SI and how it may lead to SA.

We found concurrent and multiple changes preceding the SA in specific affective, anxiety, psychotic and cognitive symptoms all previously reported risk factors for suicide (Borges et al., 2010). Not all these symptoms appeared to follow a similar changing pattern. While depressive/anxiety symptoms and life worthiness showed a more gradual trend, persecution and impulsive thoughts peaked more abruptly and closer to the SA. Given the dynamic nature of mental disorders (Nelson et al., 2017; Wichers, 2014) and the high inter-individual differences in their etiology, risk-related factors and trajectories of symptoms (Zuidersma et al., 2020), we cannot conclude whether our results are definitive or exclusive proximal warning signs for SA. This is especially true given the single-case design which does not allow for generalization to other individuals or even to other SA.

Our approach, however, does present one possible example to meet the need of innovative approaches, strategies and sensitive tools to detect rapid symptom intensification associated with suicide in clinical settings (Bryan et al., 2023, 2019), which remains a relevant issue in suicide prevention. Diary studies are regarded as adequate to examine SI and to identify associations among symptoms beyond simple co-occurrences (Kivelä et al., 2022). Nevertheless, their suitability to investigate early signs of an upcoming SA has been discussed (Ammerman and Law, 2022; Bagge et al., 2017) and literature suggests the need for adapting (Bonilla-Escribano et al., 2023) diary assessment protocols to enhance suicidal risk assessment and preventive interventions. In this context, our study supports the recently proposed use of EWMA as a suitable idiographic method to determine whether and when a specific person's affective and cognitive states start to deteriorate in real-time (Snippe et al., 2023). Visual inspection indicated a trend emerging three days prior to our first detected change. This observation raises the prospect that employing a less conservative approach in future research could potentially enable the detection of these changes even earlier (e.g., using lower values of ARL0). However, this premise should be taken with caution as a less conservative approach may lead to false positives (detecting a change that does not result in increased risk for SA).

The present study has several limitations that should be kept in mind. First, the data we used were convenience data, as the SA was an unforeseen event in a larger study. In addition, while the sinlge-case design allows for inferences at the individual level, it does not allow for inferences to the group level (i.e., generalizing to other individuals or other SA). Therefore, generalization of our conclusions is limited. In particular, no assessment can be made regarding how commonly out-of-control scores would be detected in people who did not attempt suicide (i.e., false positive rate). Second, we did not assess some suicide-related factors other than psychopathology that have been reported in earlier ambulatory assessment studies, such as sleep disturbances, appetite, social connectedness, and decreased fear of death and increased pain tolerance (Bonilla-Escribano et al., 2023; Kivelä et al., 2022). Instead, we focused solely on psychopathological dimensions and explored these in-depth. Third, we assessed passive SI through a single item (feeling life is worthwhile) that was considered a reversed proxy of passive SI. However, our results support the construct validity of the life worthiness item in which low scores preceded a SA. Fourth, our focus was on simple trends (e.g., shifts in the mean) and potential presence of change of more complex measures (e.g., autocorrelations) cannot be ruled out. However, it has recently been argued that relatively complex measures of affect dynamics may not have higher predictive value than relatively simple measures like mean scores (Dejonckheere et al., 2019). Fifth, despite the limitations of averaging (e.g., items differing in variance), we chose to average item scores per domain to limit the number of variables to examine.

This study also has important strengths. Given the unpredictable and sensitive nature of an event like a SA, it is difficult to collect data prior to its occurrence. These data therefore offer a unique possibility to explore in-depth the process leading up to a SA. Moreover, the observed

structural changes in psychological dimensions align with the occurrence of a suicide attempt and hospitalization for mental health issues, further supporting the external validity of the study. The Exponentially Weighted Moving Average (EWMA) chart is particularly adept at detecting small, persistent shifts in processes over time, making it valuable for monitoring subtle changes in mental health status. This is especially relevant given the dynamic and volatile nature of SI. Daily diary data studies are needed to apply this innovative approach, as these studies can provide the high-resolution, time-intensive data that reflect the individual's day-to-day experiences and emotional states. By integrating EWMA control charts with daily diary data, this study aims complement traditional predictive methods, offering opening up possibilities for a more nuanced and responsive strategy for suicide risk assessment. Future studies can combine insights from our retrospective, data-driven approach with a more theory-driven approach, where the assessed constructs are grounded in theories on SI, such as the IPTS.

Conclusion

Keeping the limitations in mind, our findings reinforce recent recommendations to develop measures that focus on a transdiagnostic scope of short-term predictors and correlates of suicide risk (Bagge et al., 2022; Kivelä et al., 2022), enabling the monitoring and timely detection of increased suicide risk by clinicians. In conclusion, we found changes in daily reports on several (sub)dimensions of psychopathology prior to a SA and showed how applying EWMA charts to diary reports may be helpful to detect warning signs of an upcoming SA.

CRediT authorship contribution statement

Daniel Núñez: Writing – review & editing, Writing – original draft, Project administration, Conceptualization. **Esdras Raposo de Almeida:** Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Arnout C. Smit:** Writing – review & editing, Supervision, Methodology. **Evelien Snippe:** Writing – review & editing, Supervision, Methodology. **Merel K. Muller:** Writing – review & editing, Investigation, Data curation. **David van den Berg:** Writing – review & editing. **Yuan-Pang Wang:** Writing – review & editing, Supervision. **Wim Veling:** Writing – review & editing, Supervision. **Sanne H. Booij:** Writing – review & editing, Data curation. **Johanna T.W. Wigman:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

All authors declare that they have no conflicts of interest to disclose.

Author contributions statement

All authors provided substantial contributions to the work's conception or design, drafting or reviewing the work, and provided final approval of the version to be published.

Data availability statement

To safeguard the traceability of the participant in this study, data from the Mirror study is available upon reasonable request, in adherence to the code of conduct of the University Medical Center Groningen, where the data is securely stored. In our analysis, we employed the multilevelTools package in R (Wiley, 2024) and the publicly available R-code developed by Schat et al. (2021) to calculate within and between persons omega and generate the EWMA charts, respectively.

Appendix 1 – Dimensions, subdimensions and items of psychopathology

Dimension	Subdimension	Item
Depressive symptoms	Energy levels	I felt energetic today (reverse coded*)
	Enthusiasm	I felt enthusiastic today (reverse coded*)
	Cheerfulness	I felt cheerful today (reverse coded*)
	Apathy	I felt apathetic today
	Tiredness	I felt tired today
	Feeling down	I felt down today
Anxiety symptoms	Anxiousness	I felt anxious today
	Restlessness	I felt restless today
	Worriedness	I felt worried today
Psychotic experiences	Suspiciousness	I felt suspicious today
	Persecution	I had the feeling that others disliked me today
	Thought broadcasting	I felt that other could read my thoughts today
	Dissociation	I felt unreal today
	External locus of control	I felt that others could control me today

(continued on next page)

(*continued*)

Dimension	Subdimension	Item
	Auditory hallucinations	I heard voices that others couldn't hear today
	Visual hallucinations	I saw things that others couldn't see today
Thought	Impulsive thoughts	I had the tendency to do something unrestrained/wild today
disturbances	Persistent thoughts	My thoughts wouldn't leave me alone today
	Running thoughts	My thoughts were racing today
	Thought expression	My thoughts were difficult to express today
Life worthiness	Passive suicide ideation	I found my life was worthwhile today

*100-score

Appendix 2 – Additional Interview

1. Explanation of background

As you know, today we agreed to talk together about a period in your life when you had a very difficult time and when you tried to end your life. I can imagine that it can be quite difficult to talk about this; Therefore, please let us know if it is too much for you, if it does not feel good or if you want to stop for a while. We can take all the time we need.

2. Practical questions

 i. Would you mind if Esdras joins our conversation? He is the researcher who will write up the study; He is from Brazil but understands Dutch quite well and he would like to be here, if that's okay with you. He will only listen, I will ask you questions.
 ii. Do you mind if I record our conversation? This is mainly for myself, so that I can use all the details later to create a report. Then I can now focus on our conversation and I don't have to take notes. I will destroy the recording as soon as I finish transcribing our conversation.

3. Purpose

The additional questions we discuss today are intended to map out the background of your attempt. If we better understand how your situation arose, it will help us to better understand your experiences. This can also help in trying to prevent people from taking such a step in the future.

I have no judgment about your situation or what you tell me; I hope you feel free to tell your story openly and honestly. There are no right or wrong answers, we want to hear your story. Your answers will be treated confidentially and with respect.

Are you ready to get started?

4. Questions

 i. First, let's look back at the period before you made your attempt. Although it's been a while, let's see what you remember from this time. Can you remember how you were doing in general during this period?
 ii. Do you remember specific details from the days before the attempt?
    a. Do you remember how you were doing these days? What did you think, how did you feel?
    b. Were you alone a lot during this period, did you see other people, what did you do?
    c. Was there something specific that triggered you?
 iii. Now let's zoom in on the day of the attempt itself, if that feels OK to you. Do you remember specific details of the day itself?
    a. Do you remember how you were doing on this day? What did you think, how did you feel?
    b. Were you alone a lot during that day, did you see other people, what did you do?
    c. Was there something specific that triggered you?
 iv. Was your decision planned, or spontaneous, or perhaps a little of both?
 v. Had you made any preparations?
 vi. Did you intend to hurt yourself or end your life?
 vii. How did you do after your attempt?
 viii. How are you doing now?

These were all my questions. Thank you very much for talking so openly with me here, we really appreciate it. I can imagine that it was quite difficult at times. How do you feel now that we've talked about this?

If you have any questions or would like to talk, please feel free to contact us! Thank you again for your time, your openness and your trust.

Appendix 3 – Omega reliability: within- and between-level ω

Dimension	OW (95 %CI)	OB (95 %CI)
Depression	0.840 (0.835–0.846)	0.904 (0.873–0.936)
Anxiety	0.756 (0.747–0.765)	0.963 (0.950–0.976)
Psychotic experiences	0.602 (0.588–0.616)	0.897 (0.863–0.931)
Thought disturbances	0.624 (0.609–0.639)	0.857 (0.806–0.908)

OW: Within-level omega, OB: between-level omega, CI: Confidence interval

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