

Subgrouping suicidal ideations: An ecological momentary assessment study in psychiatric inpatients

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This file contains

- Figures 1-10
- Tables 1-10

Simulation

To illustrate the effect of subgrouping based on averaged intensive longitudinal data, we simulated data for cases of high-risk psychiatric patients (patient 1 & patient 2) with suicidal ideations ($M = -0.23$, $\sigma = 2.9$, root mean square of successive differences, $RSSD = 2.6$; Figure 1A). Suicidal ideations were assessed with EMA that was simulated for five prompts a day for 20 days resulting in 100 prompts in total (response rate 100%). The summaries are identical (Figure 1B) and a cross-sectional statistical approach such as latent profile analysis would classify these cases as having the same profile. However, considering their time course with a dynamically different unfolding over time (Figure 1A) they should be grouped in different groups as the clinically different profiles of SI represent in one case a chronic, in the other an episodic case of SI. While prior research based on such an approach (Kleiman et al., 2018; Spangenberg et al., 2023) advances our understanding, conclusions may be limited as longitudinal EMA data were summarized into person-level means and variances for the cross-sectional analysis. Summary estimates of temporal data remove valuable information, and a resulting model can estimate classes that improperly discriminate cases based on a mean and variance. For example, an individual reporting a stable level of SI followed by a period of high variability would be classified the same as an individual who has a similar mean but a lower variance that is consistent across time (Figure 1). The distinction between such two cases could be critical for predicting future suicidal ideation and for the selection of the best treatment option (Rudd, 2006). Here, we suggest an alternative approach that considers raw temporal trajectories and discriminates between these example cases.

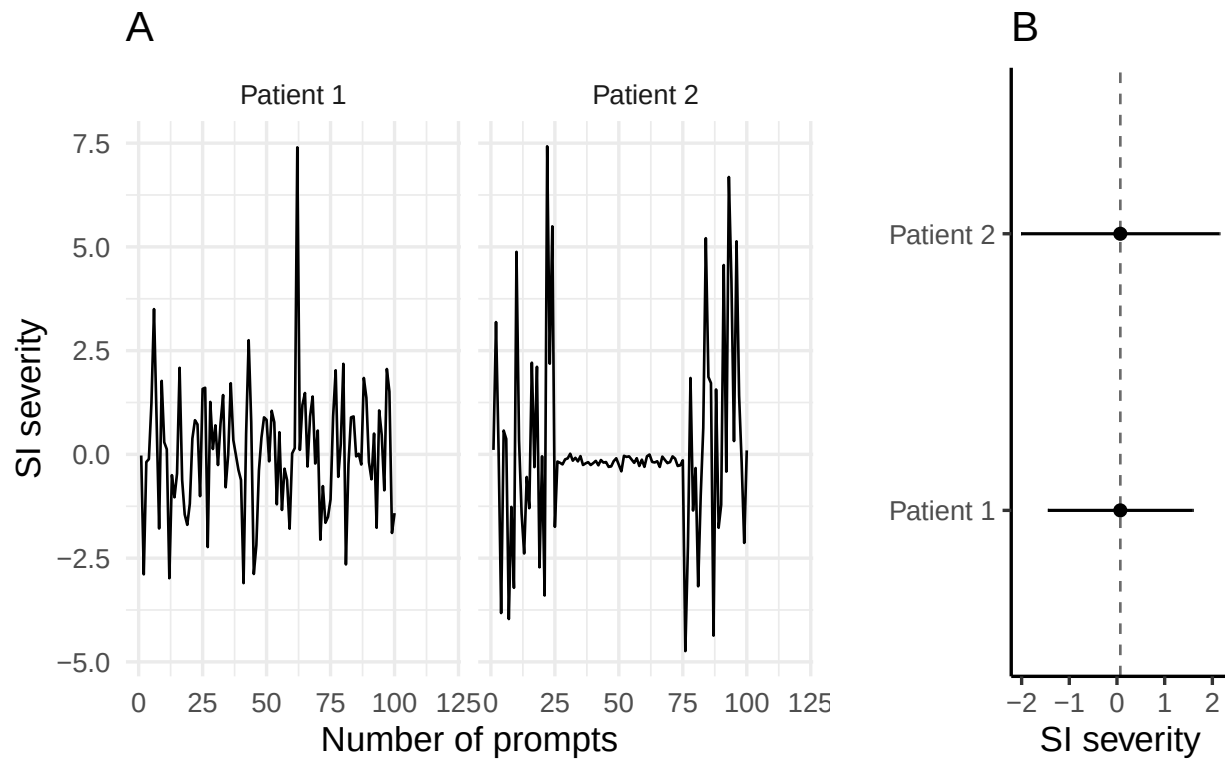


Figure 1. Simulation of trajectories with identical summary statistics. (A) We simulated two example trajectories of suicidal ideations (SI) over time with identical means ($M = -0.23$), variances (variance = 2.9), percent responded (100%), and root mean square of successive differences (RMSSD = 2.6). (B) The summaries are identical and a cross-sectional statistical approach such as latent profile analysis would classify these cases as having the same profile.

STROBE flow chart

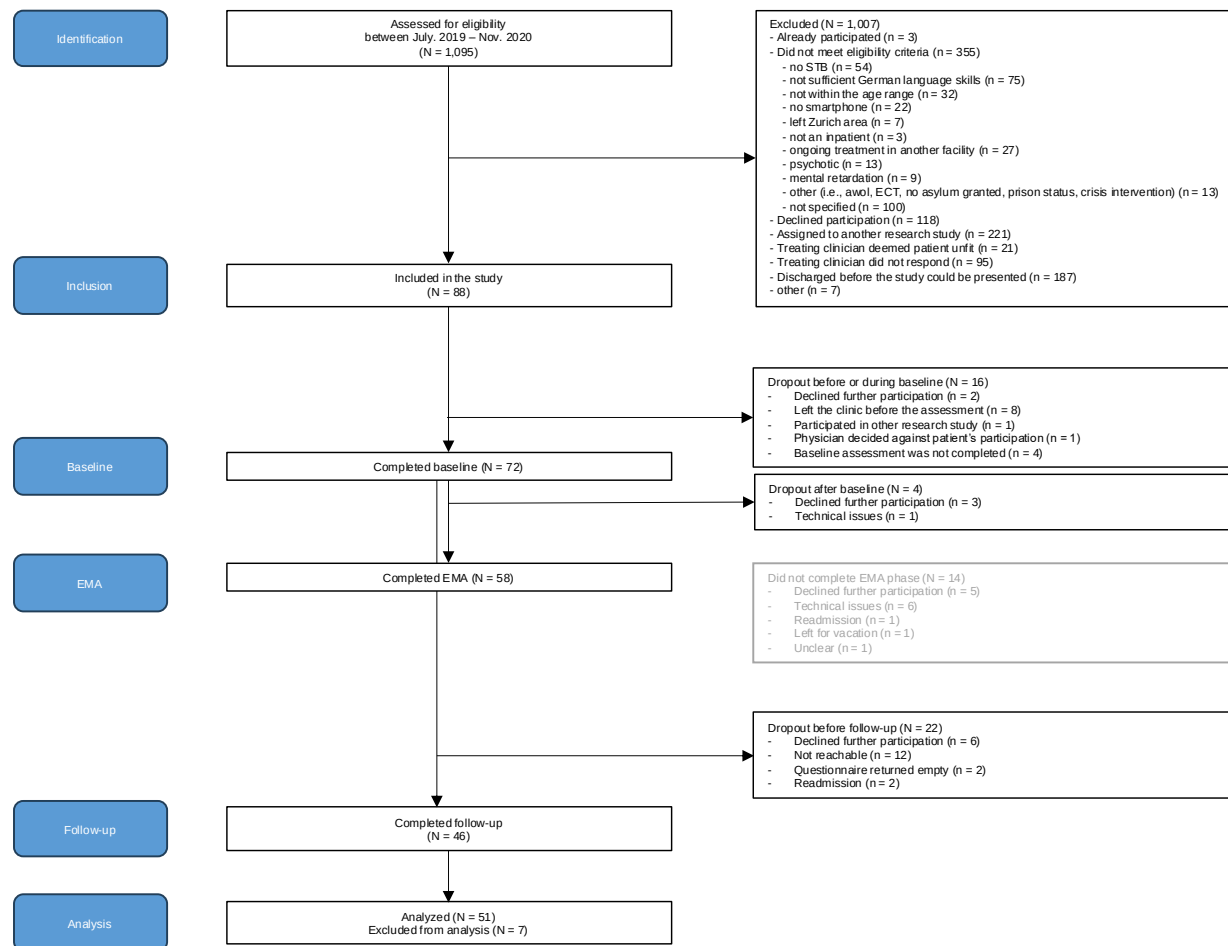


Figure 2. Recruitment flow chart. We screened 1,095 patients, of whom 88 were deemed eligible and thus gave written informed consent. Recruitment concluded before reaching the target sample size of 100 participants due to the termination of funding. Of the total 88 who consented, 16 had to be excluded or dropped out already before the baseline assessment and another four after the baseline assessment for various reasons including declining to participate in the study and leaving the hospital before the baseline assessment could be done. For a comprehensive overview, we also present the number of participants who completed the EMA phase (n = 58) along with the reasons for non-completion. There were 22 participants that were lost to follow-up, leaving 46 participants who completed the follow-up assessment.

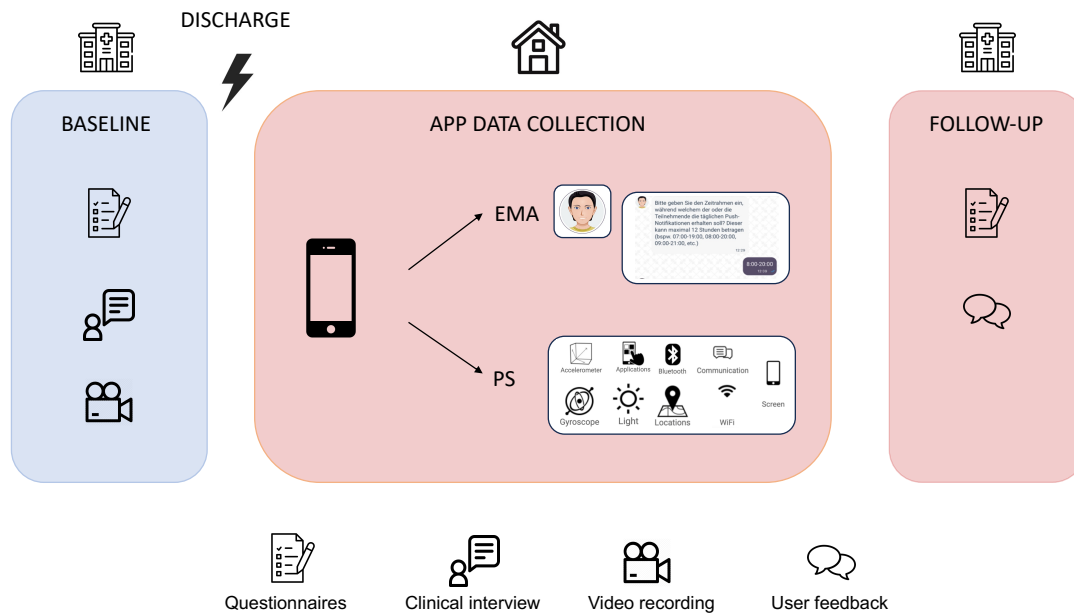


Figure 3. SIMON study design. The study consisted of three different parts: (1) the baseline assessment, (2) 4 weeks of ecological momentary assessment and passive sensing data collection via smartphone, and (3) a one-month follow-up. (1) The baseline assessment entailed an assessment with the Mini International Neuropsychiatric Interview, a short videotaped semi-structured qualitative interview, self-rating questionnaires that evaluated relevant psychological variables, and the installation of the smartphone applications on the participant's phone. (2) After hospital discharge, the in-house developed app was used for collecting self-report data according to a pre-defined ecological momentary assessment protocol, while the AWARE app was used to collect smartphone sensor data. (3) The one-month follow-up assessment entailed self-rating questionnaires that evaluated relevant psychological variables and questionnaires about the user experience with the app. Study participation was reimbursed with up to CHF 120.

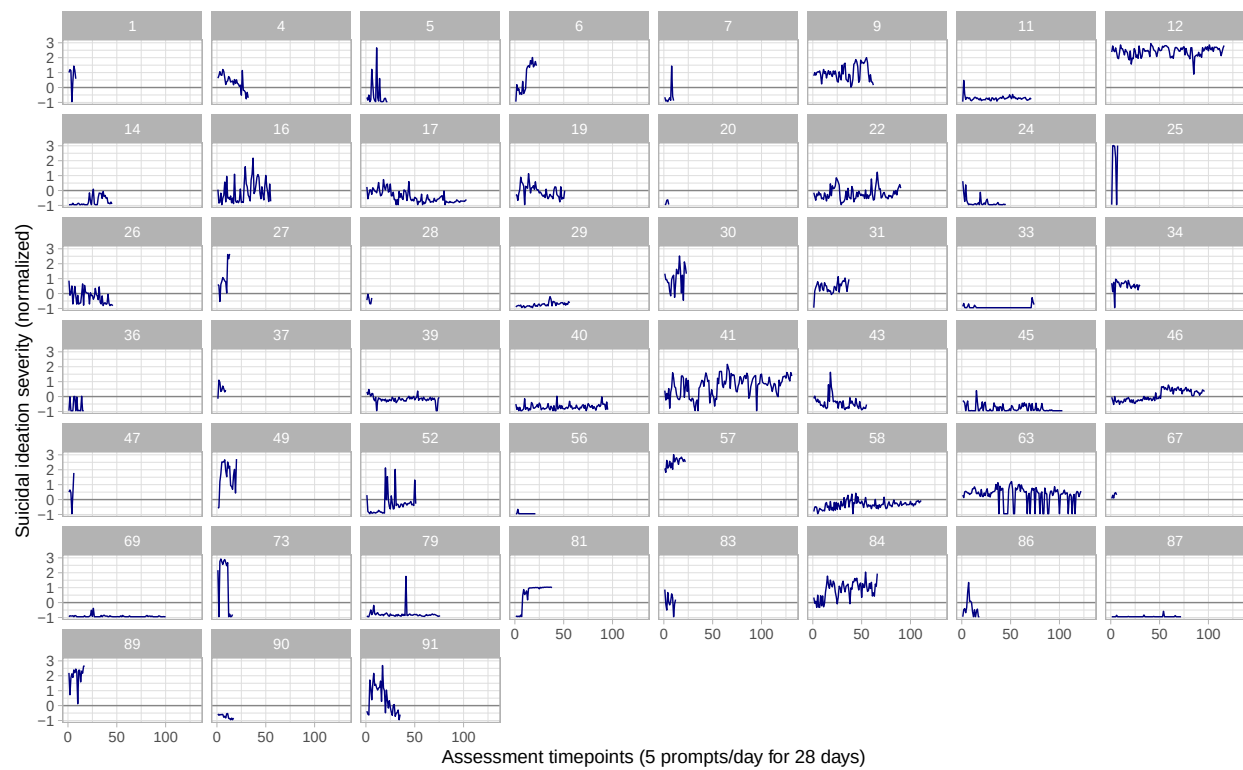


Figure 4. Suicidal ideation trajectories. The line plots show the development of suicidal ideation (SI) over time with time on the x-axis and the severity of SI on the y-axis. The time series is depicted for each of the 51 subjects individually.

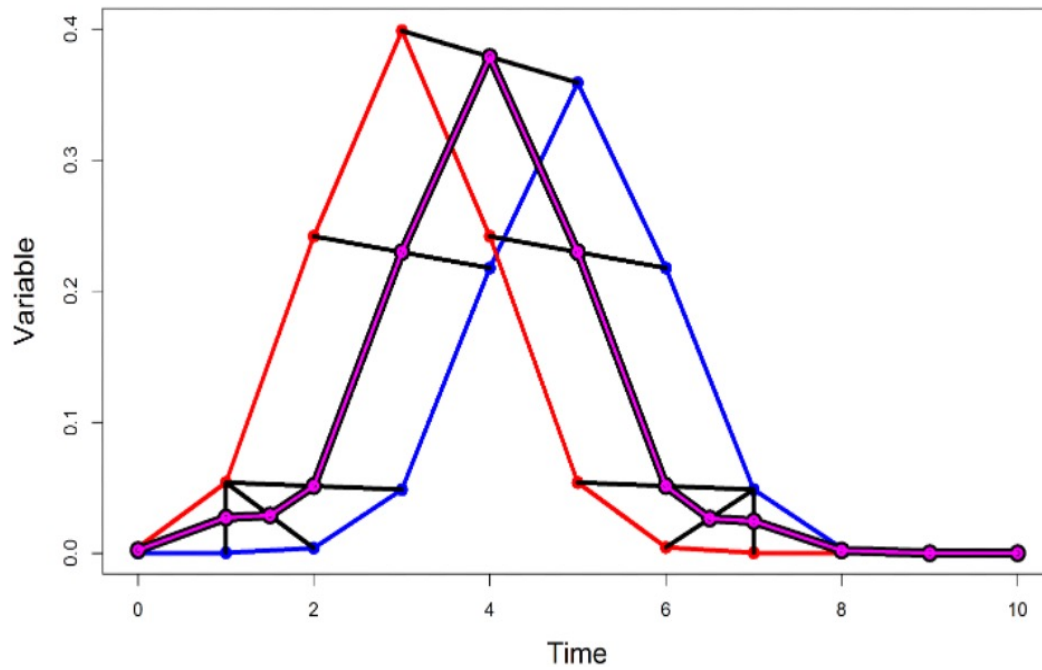


Figure 5. Longitudinal clustering: Grouping cases. Graphical depiction of Fréchet distances and means between two temporal trajectories P and Q (red and blue) with a different number of measurement occasions, where black lines indicate distance after reparameterization while the violet function provides the Fréchet means (adapted from (Genolini et al., 2016)). Longitudinal clustering makes use of Fréchet distances (Frechet, 1906; Eiter and Mannila, 1994) by computing discrete Fréchet distances between the cases' nearest measurement occasions to assess the similarity of the time series.

Analyses

Replication of prior work

First, we used latent profile analysis (LPA) with the same indices as Kleiman and colleagues (2018) to quantify patterns of within-subjects SI: (1) Mean scores across the SI items (i.e., average severity of SI), (2) within-subject *SDs* of SI score (i.e., average within-subject variability of SI), (3) the maximum SI score (i.e., the greatest SI severity during assessment), (4) the percent of nonzero SI prompts (i.e., the relative frequency of SI), and (5) the root mean square of successive differences (i.e., the average magnitude of change from one measurement occasion to the next). To identify the best profile solution, we used the following model fit indices: Bayesian information criterion (BIC), which takes into account the number of model parameters, entropy, a measure of classification uncertainty (Celeux & Soromenho, 1996), and the bootstrapped $k-1$ likelihood ratio test (bLRT) that compares a model with the current number (k) of profiles to one with one fewer ($k-1$) to decide whether precision is improved by the addition of a profile. The best profile solution is indicated by the lowest BIC, largest entropy, and a significant $k-1$ test.

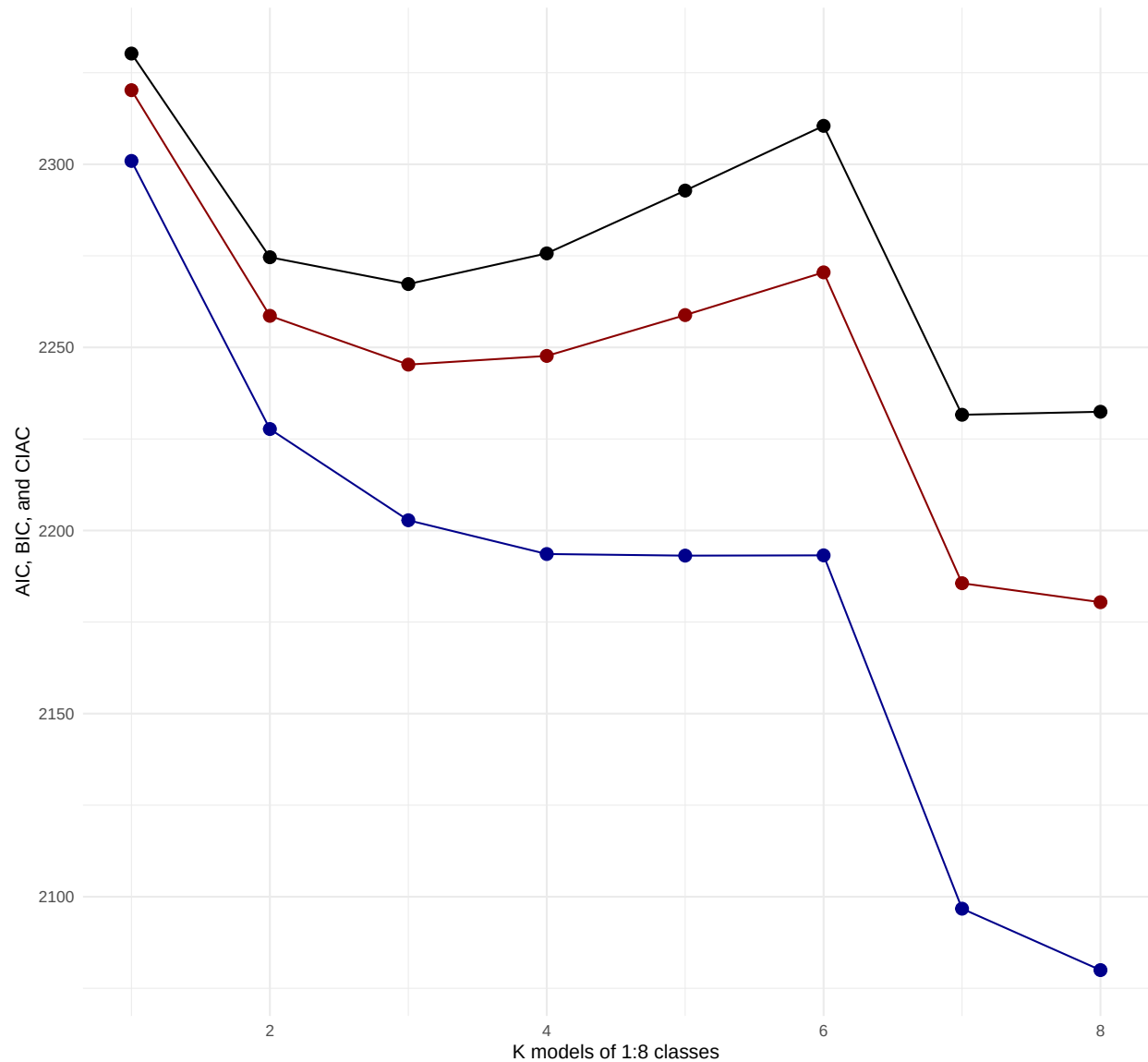


Figure 6. Latent profile analysis model fit. Using the same latent profile analysis approach as Kleiman and colleagues (Kleiman et al., 2018), we found that the best class solution consisted of four groups indicated by the sudden drop in three model fit indices: Aikake information criterion (AIC), Bayesian information criterion (BIC), and Consistent Aikake information criterion (CAIC).

The best fit to the data was a four-class solution in our LPA (BIC = 2,101.62, entropy = 0.98, bLRT = 33.76, $P < .01$; Supplementary Figure 5, Supplementary Table 1). The four subgroups were characterized based on mean SI severity and variability (Supplementary figure 6): (1) high mean, high volatility, and high maximum (23.53%, “high SI, high volatility” group), (2) low mean, low volatility, and high maximum (35.29%, “Low SI, low variability” group), (3) lowest mean, lowest volatility, and lowest maximum (11.76%, “lowest SI, lowest volatility” group), and (4) highest mean, highest volatility, and highest maximum (11.76%, “highest SI, highest volatility” group).



Figure 7. Latent profile analysis results. The line plot shows the development of suicidal ideation (SI) over time with time on the x-axis and the severity of SI on the y-axis. The time series is depicted for each of the 51 subjects individually. Colors indicate class membership and are chosen to show which subgroups match the ones identified by Kleiman and colleagues (2018) while different shades of color represent that subgroups shared only similar properties. We found four SI subgroups using the same latent profile analysis approach as a previous study (Kleiman et al., 2018). These subgroups overlapped with previously identified subgroups such that LPA Group 1 was similar to Kleiman and colleagues' subgroup 3 (characterized by moderate mean and high variability), LPA Group 2 overlapped with subgroup 3 (characterized by moderate mean and high variability), LPA Group 3 overlapped with subgroup 1 (characterized by low mean and low variability), and LPA Group 4 overlapped with subgroup 4 (characterized by high mean and low variability).

Supplementary Table 1*Summary of analysis results for latent profile analysis*

Table 1

	Estimated class	N	SI mean	SI SD	SI RMSSD	Maximum SI	Response %
5	LPA Group 1	12.00	146.56	78.57	84.64	316.67	29.40
6	LPA Group 2	18.00	95.15	44.85	47.98	204.44	35.95
7	LPA Group 3	15.00	20.89	19.85	24.12	87.47	39.86
8	LPA Group 4	6.00	290.89	100.28	114.86	386.33	23.57

Note. LPAC, latent profile analysis; N, number of subjects; Response %, percent of prompts for which a nonzero score on SI was reported; RMSSD, root mean square of successive differences; SD, standard deviation; SI, suicidal ideation.

We identified two risk factors that were significantly related to the subgroups (Supplementary figure 7). LPA Group 1 (“high SI, high volatility”) comprised moderately hopeless individuals (beta = 0.14, 95% CI = 0.06, 0.22, $P = 0$, corrected $P = 0$) compared with the other groups, while LPA Group 2 (“Low SI, low variability”) comprised individuals who exhibited less hopelessness (beta = -0.15, 95% CI = -0.25, -0.05, $P = 0.004$, corrected $P = 0$) compared with the other groups. LPA Group 3 (“lowest SI, lowest volatility”) comprised individuals who were least hopelessness (beta = -0.55, 95% CI = -0.65, -0.45, $P < .001$, corrected $P < .001$), while LPA Group 4 (“highest SI, highest volatility”) comprised individuals who were most severely hopelessness (beta = 1.21, 95% CI = 1.06, 1.36, $P < .001$, corrected $P < .001$) and had prior suicidal ideation (BSS total score: beta = 1.37, 95% CI = 0.23, 2.51, $P = 0.021$, corrected $P = 0$).

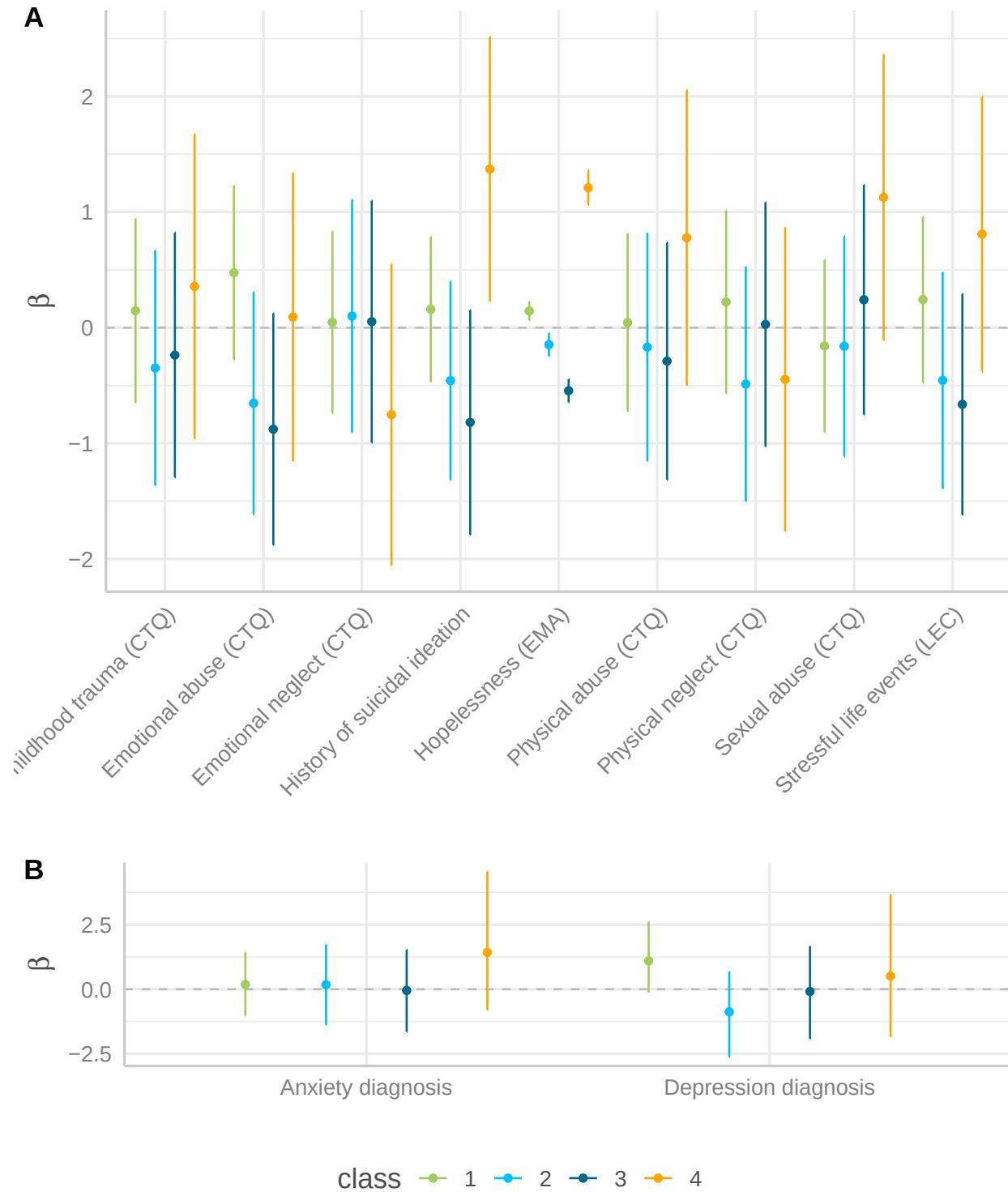


Figure 8. Latent profile analysis: Association of suicidal ideation (SI) subgroups with risk factors. The dot plots show the results of (A) the linear regressions of the continuous risk factors and (B) the logistic regressions of the categorical risk factors. The beta coefficients with their 95%-confidence interval resulted from the regression analyses that assessed the association between the SI subgroups retrieved from the latent profile analysis to common risk factors (Franklin et al., 2016).

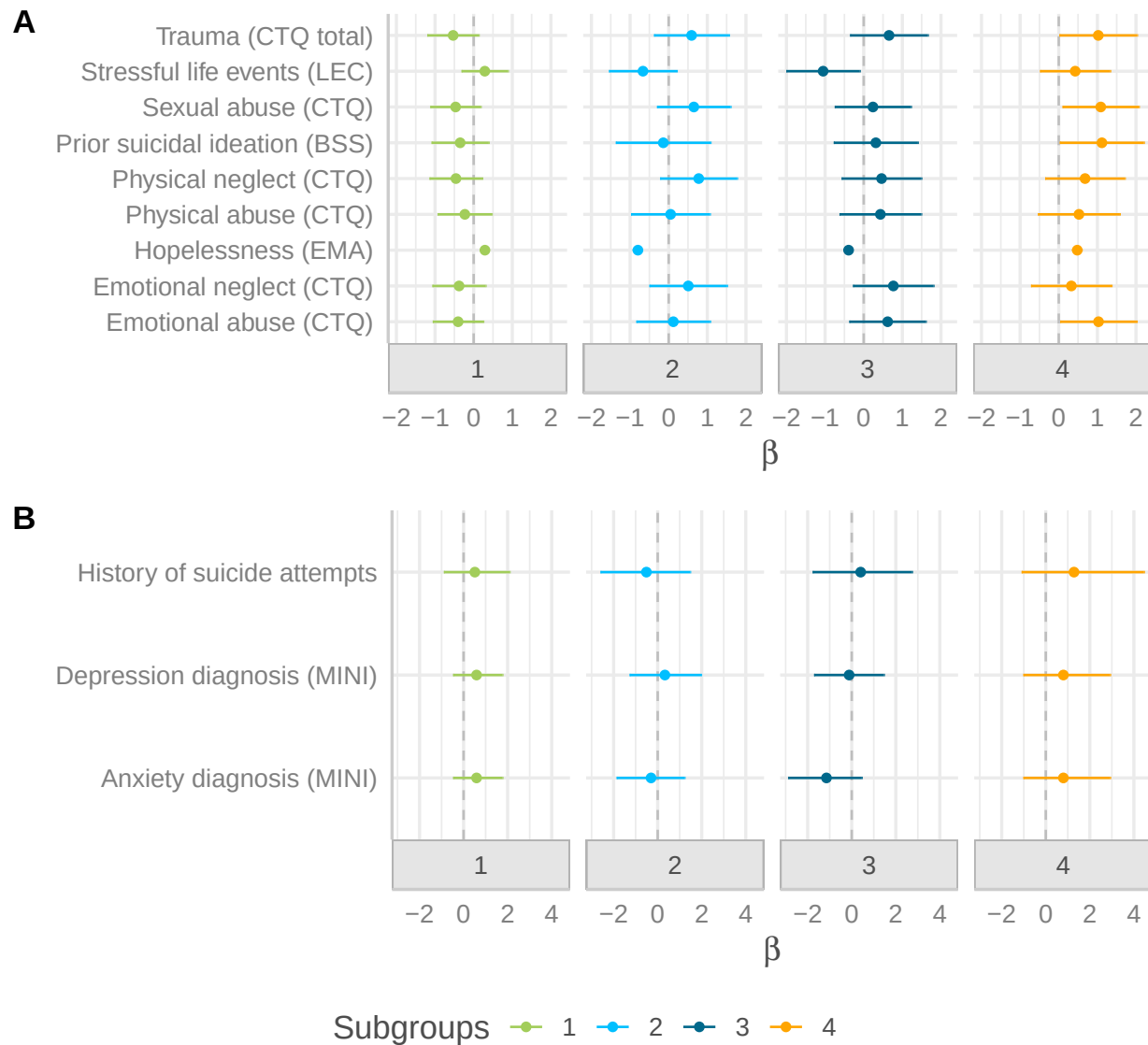


Figure 9. Longitudinal clustering results: Association of suicidal ideation subgroups with common correlates. The dot plots show the results of (A) the linear regressions of the continuous risk factors and (B) the logistic regressions of the categorical risk factors. The beta coefficients with their 95%-confidence interval resulted from the regression analyses that assessed the association between the suicidal ideation subgroups retrieved from the longitudinal clustering to common correlates (Franklin et al., 2016).

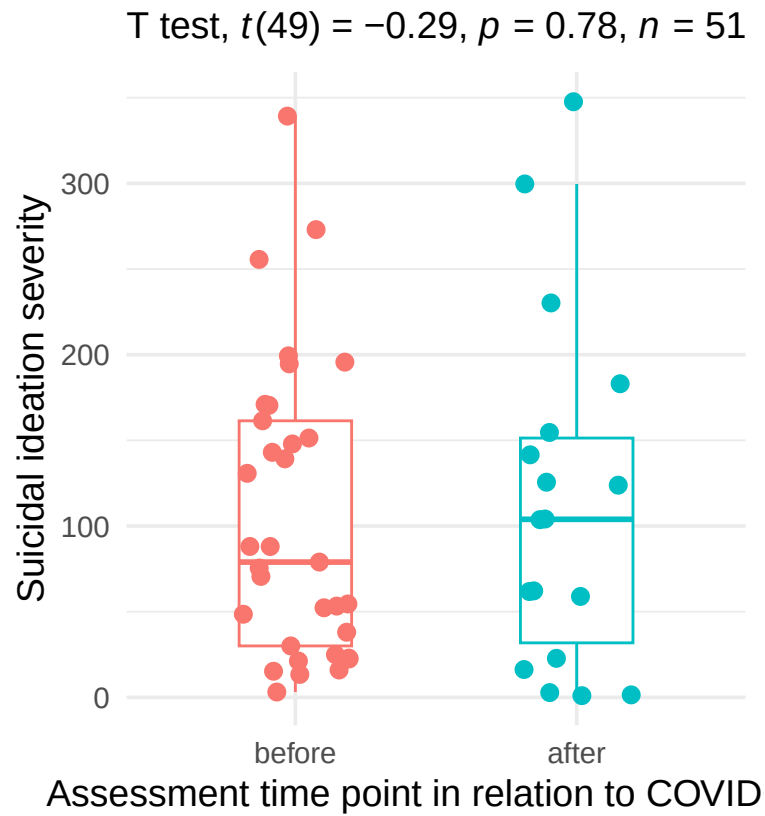


Figure 10. Comparison between participants recruited before and during the COVID-19 pandemic. The boxplot shows the distribution of suicidal ideation (SI) severity in individuals recruited and measured before the COVID-19 pandemic (red) and during (green). There was no statistically significant difference between at-risk individuals in terms of severity of SI.

Supplementary table 2

SIMon study questionnaires.

Table 2

Questionnaires and assessments	Reference	Abbreviation	Administration	Baseline	Follow-up
Demographic and personal information	NA	NA	Self-report	x	NA
Acquired Capability for Suicide Scale	Ribeiro et al., 2014; German validated revised version: Spangenberg et al., 2016	ACSS-FAD	Self-report	x	NA
Suicide Attempts	Chu et al., 2018	NA	Self-report	x	NA
Positive and Negative Affect Scale	Watson, Clark, & Tellegen, 1988	PANAS	Self-report	x	x
Non-suicidal self-injury single item	Chu et al., 2018	NSSI	Self-report	x	NA
Childhood Trauma Questionnaire	Bernstein et al., 1998; German version: Klinitzke et al., 2012	CTQ	Self-report	x	NA
Life Events Checklist for DSM-5	Weathers et al., 2013; German version: Krüger-Gottschalk et al., 2017	LEC-5	Self-report	x	NA
Beck Inventory-II	Beck et al., 1996; German version: Kliem et al., 2017	BDI-II	Self-report	x	x
Patient Questionnaire-9	Kroenke et al., 2001; German version: Loewe et al., 2004	PHQ-9	Self-report	x	x
Pittsburgh Sleep Inventory	Buysse et al., 1989	PSQI	Self-report	x	NA
Interpersonal Needs Questionnaire	Van Orden et al., 2012; German version: Hallensleben et al., 2016	INQ	Self-report	x	x
Beck Scale for Suicide Ideation	German-validated version: Kliem et al., 2017	BSS	Self-report	x	x

Table 2 continued

Questionnaires and assessments	Reference	Abbreviation	Administration	Baseline	Follow-up
Beck Hopelessness Scale	German-validated version: Kliem et al., 2017	BHS	Self-report	x	x
Generalized Self-Efficacy Scale	Schwarzer, & Jerusalem, 1999; German version: Schwarzer, & Jerusalem, 2003	GSE	Self-report	x	x
Emotion regulation questionnaire	Gross & John, 2003	ERQ	Self-report	x	NA
The Trait Hope Scale	Snyder et al., 1996	THS	Self-report	x	x
Suicidal crisis information	NA	NA	Self-report	NA	x
Kansas Marital satisfaction scale	Nichols et al., 1983	NA	Self-report	x	X
Dyadic Coping Inventory	Bodenmann et al., 2019	DCI	Self-report	x	NA
Experiences in Close Relationships-Revised	Friley et al., 2000	ECR-R	Self-report	x	NA
Adult Attachment Questionnaire					
Research experience questionnaire, User experience	NA	NA	Self-report	NA	X
Mobile Application Rating Scale: user version	Stoyanov et al., 2016	uMARS	Self-report	NA	X

Note. This table summarizes all questionnaires that were administered in the main study, the SIMon study, at baseline and follow-up. In this subproject, only a selected few questionnaires were investigated.

Note. References for Supplementary Table 2 (Beck et al., 1996; Bernstein, 1998; Bodenmann et al., 2019; Buysse et al., 1989; Chu et al., 2018; Fraley et al., 2000; Gross & John, 2003; Hallensleben et al., 2016; Kliem et al., 2017; Klinitzke et al., 2011; Kroenke et al., 2001; Krüger-Gottschalk et al., 2017; Löwe et al., 2004; Nichols et al., 1983; Ribeiro et al., 2014; Schwarzer, 1999; Schwarzer & Jerusalem, 2003; Snyder et al., 1996; Spangenberg et al., 2016; Stoyanov et al., 2016; Van Orden et al., 2012; Watson et al., 1988; Weathers et al., 2013)

Supplementary table 3

SIMon study EMA items.

Table 3

Construct	Timepoint	Code	EMA item	Scale	Reference
Sleep Condition Indicator	only included in the first EMA of the day	EMAsleeplatency	How long did it take for you to fall asleep yesterday?	Min.	Espie et al, 2014
Sleep Condition Indicator	only included in the first EMA of the day	EMAAwakefulness	If you woke up during the night: how long were you awake in total? (Please add up all waking states)	Slider scale: 0 min. to >= 61 min.	Espie et al, 2014
Sleep Condition Indicator	only included in the first EMA of the day	EMAsleepquality	How would you rate your sleep quality?	(4) Very good, (3) good, (2) average, (bad), (0) very bad	Espie et al, 2014
Nightmares	only included in the first EMA of the day	EMANightmare	Did you have nightmares?	Yes/No	NA
Nightmares	only included in the first EMA of the day	EMAstressnightmare	Depending on EMANightmare: How stressful were they?	Not at all à extrem	NA
PHQ-2: two-item depression screener	included in each EMA	EMAInterest	Currently, I feel little interest to do things.	(0) «Not at all», (1) «several days», (2) «more than half the days», (3) «nearly every day»	Kroenke et al., 2003
PHQ-2: two-item depression screener	included in each EMA	EMAdepressed	Currently, I feel down and depressed.	(0) «Not at all», (1) «several days», (2) «more than half the days», (3) «nearly every day»	Kroenke et al., 2003
Perceived burdensomeness	included in each EMA	EMAUseless	Currently, I feel useless.	Slider Scale: (0) not at all to (4) extremely	Hallensleben et al, 2018; Forkmann et al, 2018
Perceived burdensomeness	included in each EMA	EMAburdenothers	Currently, I feel as a burden for others.	Slider Scale: (0) not at all to (4) extremely	Hallensleben et al, 2018; Forkmann et al, 2018
Thwarted belongingness	included in each EMA	EMAlonely	Currently, I feel lonely.	Slider Scale: (0) not at all to (4) extremely	Hallensleben et al, 2018; Forkmann et al, 2018
Thwarted belongingness	included in each EMA	EMAbelonging	Currently, I feel as if I didn't belong.	Slider Scale: (0) not at all to (4) extremely	Hallensleben et al, 2018; Forkmann et al, 2018
Hopelessness	included in each EMA	EMAhopeless	Currently, I feel hopeless.	0 (not at all) to 4 (very much)	Kleiman et al. 2017

Table 3 continued

Construct	Timepoint	Code	EMA item	Scale	Reference
Passive suicidal ideation	included in each EMA	EMAworthliving	Currently, I feel life is not worth living.	Slider Scale: (0) not at all to (4) extremely	Hallensleben et al, 2018; Forkmann et al, 2018
Passive suicidal ideation	included in each EMA	EMAmorereasonstodie	Currently, I feel there are more reasons to die than to live for.	Slider Scale: (0) not at all to (4) extremely	Hallensleben et al, 2018; Forkmann et al, 2018
Active suicidal ideation	included in each EMA	EMAwantsuicide	Currently, I want to die.	Slider Scale: (0) not at all to (4) extremely	Hallensleben et al, 2018; Forkmann et al, 2018
Active suicidal ideation	included in each EMA	EMAthoughtsuicide	Currently, I think about taking my own life.	Slider Scale: (0) not at all to (4) extremely	Hallensleben et al, 2018; Forkmann et al, 2018
Locus of control	included in each EMA	EMA control	I feel that I have control over the things that happen to me.	5-point Likert scale from 0 (not at all true) to 4 (very true)	Ryon & Gleason, 2013
Affect Slider	only included in the last EMA of the day	EMAcurentjoy	Please move the slider to indicate the current level of your pleasure.	Slider Scale with emoticons	Betella & Verschure, 2016
Affect Slider	only included in the last EMA of the day	EMAcurentarousal	Please move the slider to indicate your current level of arousal.	Slider Scale with emoticons	Betella & Verschure, 2016
Mood	only included in the last EMA of the day	EMAawakeaffect	At this moment I feel tired/awake.	Their endpoints 0 and 6 were associated with the label "very."	Wilhelm & Schoebi, 2007
Mood	only included in the last EMA of the day	EMAcontentaffect	At this moment I feel content/discontent.	Their endpoints 0 and 6 were associated with the label "very."	Wilhelm & Schoebi, 2007
Mood	only included in the last EMA of the day	EMAagitatedaffect	At this moment I feel agitated/calm.	Their endpoints 0 and 6 were associated with the label "very."	Wilhelm & Schoebi, 2007
Mood	only included in the last EMA of the day	EMAenergyaffect	At this moment I feel full of energy/without energy.	Their endpoints 0 and 6 were associated with the label "very."	Wilhelm & Schoebi, 2007
Mood	only included in the last EMA of the day	EMAunwellaffect	At this moment I feel unwell/well.	Their endpoints 0 and 6 were associated with the label "very."	Wilhelm & Schoebi, 2007

Table 3 continued

Construct	Timepoint	Code	EMA item	Scale	Reference
Mood	only included in the last EMA of the day	EMArelaxed affect	At this moment I feel relaxed/tense.	Their endpoints 0 and 6 were associated with the label "very."	Wilhelm & Schoebi, 2007
NA	only included in the last EMA of the day	InteractionCO	Please indicate who you spent time with today (do not indicate anyone, or as many as apply).	e.g., partner, parents (part), siblings, friend(s), roommate (if not friend or family), coworkers or classmates, others	NA
NA	only included in the last EMA of the day	InteractionCO1	If selected, select the person you have interacted with the most today (enter only one person).	e.g., partner, parents (part), siblings, friend(s), roommate (if not friend or family), coworkers or classmates, others	NA
Perceived partner responsiveness	only appear if EMA 'InteractionCO' were answered	selfdisclosure	To what extent did you disclose your feelings to this person during the day?	Slider scale: 'not at all' to 'completely'	Laurenceau et al., 1998
Perceived partner responsiveness	only appear if EMA 'InteractionCO' were answered	suppression	To what extent did you suppress your feelings with this person during the day?	Slider scale: 'not at all' to 'completely'	NA
Perceived partner responsiveness	only appear if EMA 'InteractionCO' were answered	understandingppr	To what extent did you feel understood by this person?	7-point Likert scale ranging from 1 (not at all) to 7 (very much)	Gadassi et al., 2016
Perceived partner responsiveness	only appear if EMA 'InteractionCO' were answered	caringppr	To what extent do you feel liked and supported by this person?	7-point Likert scale ranging from 1 (not at all) to 7 (very much)	Gadassi et al., 2016
Perceived partner responsiveness	only appear if EMA 'InteractionCO' were answered	validationppr	To what degree do you believe this person values your skills and opinions?	7-point Likert scale ranging from 1 (not at all) to 7 (very much)	Gadassi et al., 2016

Table 3 continued

Construct	Timepoint	Code	EMA item	Scale	Reference
NA	only appear if EMA 'Interac- tionCO' were answered	conflict	Have you experienced a con- flict with this person during the day?	Yes/No	NA

Note. This table summarizes all EMA items that were administered in the main study, the SIMon study, during the app assessment phase. In this subproject, only a selected few items were investigated.

Note. References for Supplementary Table 3 (Betella & Verschure, 2016; Espie et al., 2014; Forkmann et al., 2018; Gadassi et al., 2016; Hallensleben et al., 2019; Kleiman et al., 2017; Kroenke et al., 2003; Laurenceau et al., 1998; Ryon & Gleason, 2014; Wilhelm & Schoebi, 2007)

Supplementary table 4*Regression results for 'suicidal ideation'*

Parameter	Coefficient	SE	95% CI	t(19)	p
(Intercept)	-0.35	0.35	(-1.09, 0.39)	-0.99	0.336
longClass (2)	-0.14	0.59	(-1.37, 1.09)	-0.24	0.813
longClass (3)	0.31	0.52	(-0.78, 1.40)	0.60	0.553
longClass (4)	1.12	0.52	(0.03, 2.21)	2.15	0.045

Supplementary table 5*Regression results for 'hopelessness'*

Parameter	Coefficient	SE	95% CI	t(2365)	p
(Intercept)	0.29	0.04	(0.21, 0.37)	7.19	< .001
longClass (2)	-0.80	0.05	(-0.90, -0.70)	-15.42	< .001
longClass (3)	-0.39	0.05	(-0.50, -0.29)	-7.43	< .001
longClass (4)	0.48	0.06	(0.36, 0.60)	8.04	< .001

Supplementary table 6*Regression results for 'history of trauma'*

Parameter	Coefficient	SE	95% CI	t(27)	p
(Intercept)	-0.53	0.32	(-1.20, 0.13)	-1.64	0.113
longClass (2)	0.59	0.47	(-0.38, 1.56)	1.25	0.222
longClass (3)	0.66	0.49	(-0.35, 1.66)	1.34	0.193
longClass (4)	1.02	0.49	(0.02, 2.03)	2.09	0.047

Supplementary table 7*Regression results for 'stressful life events'*

Parameter	Coefficient	SE	95% CI	t(26)	p
(Intercept)	0.29	0.29	(-0.31, 0.89)	0.99	0.334
longClass (2)	-0.67	0.43	(-1.54, 0.21)	-1.56	0.131
longClass (3)	-1.05	0.46	(-2.00, -0.10)	-2.27	0.032
longClass (4)	0.43	0.44	(-0.48, 1.34)	0.96	0.345

Supplementary table 8*Regression results for 'history of suicide attempts'*

Parameter	Log-Odds	SE	95% CI	z	p
(Intercept)	0.51	0.73	(-0.89, 2.10)	0.70	0.484
longClass (2)	-0.51	1.02	(-2.59, 1.48)	-0.50	0.615
longClass (3)	0.41	1.11	(-1.77, 2.74)	0.37	0.715
longClass (4)	1.28	1.30	(-1.10, 4.46)	0.98	0.326

Supplementary table 9*Regression results for 'diagnosis of depression'*

Parameter	Log-Odds	SE	95% CI	z	p
(Intercept)	0.59	0.56	(-0.48, 1.77)	1.05	0.292
longClass (2)	0.33	0.81	(-1.27, 1.98)	0.40	0.686
longClass (3)	-0.12	0.80	(-1.71, 1.47)	-0.15	0.883
longClass (4)	0.80	0.97	(-1.02, 2.93)	0.83	0.409

Supplementary table 10

Regression results for ‘diagnosis of anxiety disorder’

Parameter	Log-Odds	SE	95% CI	z	p
(Intercept)	0.59	0.56	(-0.48, 1.77)	1.05	0.292
longClass (2)	-0.30	0.78	(-1.86, 1.23)	-0.39	0.699
longClass (3)	-1.15	0.84	(-2.88, 0.46)	-1.37	0.171
longClass (4)	0.80	0.97	(-1.02, 2.93)	0.83	0.409

References

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