



# Temporal variations of depressive symptoms in patients with bipolar, borderline personality, and major depressive disorder: an ecological momentary assessment study

Annasofia Martikkala<sup>a</sup>, Ilya Baryshnikov<sup>a</sup>, Hanna Granroth-Wilding<sup>c</sup>, Roope Heikkilä<sup>i</sup>,  
Kirsi Riihimäki<sup>d,e</sup>, Outi Saleva<sup>a</sup>, Joel Holmen<sup>f</sup>, Richard Darst<sup>g</sup>, Tom Rosenström<sup>h</sup>,  
Talayah Aledavood<sup>b</sup>, Erkki Isometsä<sup>a,\*</sup>

<sup>a</sup> Department of Psychiatry, University of Helsinki and Helsinki University Hospital, Helsinki, Finland

<sup>b</sup> Department of Computer Science, Aalto University, Espoo, Finland

<sup>c</sup> Biostatistics Unit, Faculty of Medicine, University of Helsinki, Helsinki, Finland

<sup>d</sup> Finnish Institute for Health and Welfare, Helsinki, Finland

<sup>e</sup> Department of Internal Medicine and Rehabilitation, Helsinki University Hospital, Helsinki, Finland

<sup>f</sup> Department of Psychiatry, University of Turku, Turku, Finland

<sup>g</sup> School of Science, Aalto University, Espoo, Finland

<sup>h</sup> Department of Psychology, Faculty of Medicine, University of Helsinki, Helsinki, Finland

<sup>i</sup> Mental Health Services, City of Helsinki, Helsinki, Finland

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## ABSTRACT

**Background:** Identifying the principal and comorbid diagnoses of a patient suffering from a major depressive episode (MDE) is crucial. Ecological momentary assessment (EMA) may help identify patterns of symptom fluctuations characteristic of a specific disorder and thus potentially improve the differential diagnostics.

**Methods:** This EMA study aimed to investigate the real-time group differences in temporal variations of depressive symptoms in patients with an ongoing MDE and a diagnosis of bipolar (BD;  $n = 17$ ), borderline personality (BPD;  $n = 15$ ), or major depressive disorder (MDD;  $n = 45$ ) and healthy controls (HC;  $n = 23$ ). Multilevel modeling analyses were performed to assess the mean level, inertia, and variability of five symptom dimensions, all ranging from positive to negative: mood, anger, anhedonia, energy, and hopelessness.

**Results:** All patient groups showed significantly different mean levels of all symptoms compared with HC as well as significantly greater inertia of anger and anhedonia. Furthermore, BPD patients exhibited significantly greater inertia of mood, anhedonia, and hopelessness than BD and MDD groups. By modeling different variance structures, variability of all five symptoms was found to be lowest among HC and highest among BD and/or BPD groups. Energy was the only symptom dimension where the difference in variability could also be found in the BD-BPD group comparison.

**Limitations:** While the overall number of participants included ( $n = 100$ ) was moderate for an EMA study, numbers of patients in the BD and BPD subgroups were small.

**Conclusions:** These findings suggest partially different temporal variations of depressive symptoms among depressed patients with BD, BPD, or MDD and HC.

## 1. Introduction

Depression, one of the leading contributors to the overall global burden of disease (Vos et al., 2020), is highly heterogeneous (Goldberg, 2011; Zimmermann et al., 2009). DSM-5 defines major depressive

episodes (MDEs) similarly for major depressive disorder (MDD) and bipolar disorder (BD) (American Psychiatric Association, 2013). While hypomanic or manic episodes characterize BD, its course is predominantly depressive (Judd et al., 2002, 2003) and more frequently begins with depression than hypomania or mania (Perugi et al., 2000). Thus,

\* Corresponding author.

E-mail address: [erkki.isometsa@hus.fi](mailto:erkki.isometsa@hus.fi) (E. Isometsä).

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depressed bipolar patients risk being misdiagnosed with MDD (Angst, 2011; Bowden, 2001; Hirschfeld et al., 2003). Borderline personality disorder (BPD) also often co-occurs with mood disorders (Friborg et al., 2014). Shared features, like affective instability (Antoniadis et al., 2012; Baryshnikov et al., 2015; Socada et al., 2021), make distinguishing BPD and BD especially challenging, particularly when BPD co-occurs with MDD (Gunderson et al., 2018).

Given distinct treatment strategies for MDD, BD, and BPD (Gunderson et al., 2018; Kupfer et al., 2012; Yatham et al., 2018) and the excess psychosocial morbidity of depression with co-occurring BPD (Söderholm et al., 2023; Soloff et al., 2000), accurate identification of both primary and comorbid diagnoses in MDE is essential. Current diagnostics rely on clinical observations and interviews, depending heavily on subjective information and patients' ability to recall symptoms retrospectively (Ben-Zeev et al., 2009; Ebner-Priemer and Trull, 2009). Ecological Momentary Assessment (EMA), an intensive longitudinal research methodology, includes asking patients to record their symptoms repeatedly over time, enabling investigation of symptoms in real time and natural settings (Shiffman et al., 2008). EMA aims to both reduce the risk of recall bias and capture the dynamic fluctuations of symptoms over time (Ebner-Priemer and Trull, 2009). Ultimately, identifying patterns of symptom fluctuations characteristic of a specific disorder could possibly improve the differential diagnostics. However, despite EMA's potential (Colombo et al., 2019), more clinical studies are needed to determine how well EMA could complement diagnostic interviews.

EMA studies have introduced various dynamic symptom measures to reflect different aspects of the ebb and flow of symptoms (Dejonckheere et al., 2019; Trull et al., 2015). For example, many have investigated the range or amplitude of affect (here used interchangeably with the term emotion)—i.e. the variability of affect, often measured as standard deviation or within-person variance (Dejonckheere et al., 2019; Jahng et al., 2008). Furthermore, several studies have assessed the temporal dependency of affect by measuring the autocorrelation of affect over time (Jahng et al., 2008; Trull et al., 2015). This feature, often labeled as inertia, describes how consistently affect persists over successive moments, or its resistance to change (Koval et al., 2013; Trull et al., 2015). A meta-analysis found both greater variability and inertia of emotions, especially negative emotions, to be associated with depression and BPD (Houben et al., 2015). More recent studies had similar results regarding the variability of negative affect in both depression (Crowe et al., 2019; Nelson et al., 2020; Panaite et al., 2020) and BPD (Ringwald et al., 2022), but findings regarding emotional inertia remain inconsistent (Nelson et al., 2020; Panaite et al., 2020). Some evidence also links greater affect variability to BD (Knowles et al., 2007) and bipolar spectrum psychopathology (Sperry and Kwapil, 2019), which may also be associated with lower inertia of negative affect (Sperry and Kwapil, 2019).

Despite growing research, literature on dynamic patterns of emotions among psychiatric patients remains limited and at times inconclusive (Koval et al., 2013). Furthermore, many EMA studies have featured small sample sizes and exhibited heterogeneity in research design, methodology, and reporting (Stone et al., 2023; Wrzus and Neubauer, 2023). Concerns also exist about inconsistent definitions (Marwaha et al., 2014) and unclear predictive value (Dejonckheere et al., 2019) of some symptom dynamics. Reliable disorder comparisons require consistent methodology within the same study—otherwise, differences may reflect data or methodological variation rather than distinctions between diagnostic groups. Moreover, it remains unclear to what extent EMA can capture other illness-specific behaviors, such as intense anger or difficulty controlling anger among patients with BPD or persistently increased goal-directed activity or energy among BD patients with hypomania, mania, and mixed episode symptoms (American Psychiatric Association, 2013). In the end, the clinical utility of EMA and its ability to help distinguish these disorders are yet to be firmly established, emphasizing the need for further clinical studies.

In this EMA study, we aimed to examine the mean level, inertia, and variability of five symptom dimensions (mood, anger, anhedonia, energy, and hopelessness) in psychiatric patients with BD, BPD, or MDD during a depression episode and healthy controls (HC). We expected that, compared with HC, patients would exhibit 1) significantly different mean levels of all five symptoms, indicating a higher presence of depressive symptoms, 2) greater inertia, and 3) greater variability of all five symptoms. Furthermore, we expected that 4) the variability of all five symptoms would be greater among BD and BPD groups than in the MDD group, 5) the variability of energy would be greatest in the BD group, and 6) the differences in the mean level of anger would illustrate intense anger as a characteristic of BPD.

## 2. Methods

### 2.1. MoMo-mood project

This study was conducted as part of the Mobile Monitoring of Mood (MoMo-Mood) study. MoMo-Mood is a collaborative project between the Department of Psychiatry, University of Helsinki; the Department of Psychiatry, Helsinki University Hospital (HUUH); the Department of Psychiatry, University of Turku; the Department of Psychiatry, Turku University Hospital; the City of Espoo Mental Health Services; and the Department of Computer Science, Aalto University. The methodology of the project is described also elsewhere (Baryshnikov et al., 2023).

### 2.2. Participants

The patients included were outpatients suffering from an MDE. In total, 84 currently depressed patients with DSM-5 (American Psychiatric Association, 2013) diagnoses of BD ( $n = 17$ ), BPD ( $n = 17$ ), or MDD ( $n = 50$ ) and HC ( $n = 23$ ) were recruited. Inclusion criteria for patients were 1) either MDD, BD type I or II, or BPD with an ongoing MDE; 2) Patient Health Questionnaire (PHQ-9) (Kroenke et al., 2001) score  $\geq 10$ ; and 3) ownership of a smartphone with an Android operating system. MDD and BD were verified with the Mini International Neuropsychiatric Interview (Sheehan et al., 1998) and BPD with Structured Clinical Interview-II (First and Gibbon, 2004). Exclusion criteria were a) psychotic features; b) concurrent substance use disorder; and c) imminent risk of suicide. The healthy controls were interviewed with the Mini International Neuropsychiatric Interview (Sheehan et al., 1998) to rule out DSM-5 (American Psychiatric Association, 2013) depressive or bipolar disorders, and screened with the PHQ-9, the Mood Disorder Questionnaire (Hirschfeld et al., 2000), and the McLean Screening Instrument for Borderline Personality Disorder (Zanarini et al., 2003) to exclude MDD, BD, and BPD.

### 2.3. Data collection

EMA data were collected using AWARE, a smartphone application developed as a research tool at the University of Oulu (Ferreira et al., 2015). Data collected by AWARE were directly sent to Aalto University's Niima Data Collection Platform (Aledavood et al., 2017). The platform can be used to collect and link data from a variety of systems, including mobile phone applications, sensors, and web surveys. The platform is privacy-first; particularly, it does not use other cloud services as data intermediaries. Niima is an open-source project that allows use of other open-source applications for these studies as necessary. The EMA data collected by Niima were processed by Niimpy (Ikäheimonen et al., 2023), an open-source behavioral data analysis Python library, and put into an adequate format for further statistical analysis.

### 2.4. Procedures

Patients were recruited from the mood disorder outpatient treatment facilities of the Departments of Psychiatry of the Helsinki and Turku

University Hospitals and the City of Espoo services. Healthy controls were recruited through emailing lists of students of the University of Helsinki, students of Aalto University, users of student health services from these institutions, and voluntary healthcare personnel from HUH.

After providing informed consent, the AWARE application (Ferreira et al., 2015) was installed on participants' smartphones. During 14 days of active monitoring, participants received notifications on their smartphones five times per day (once in the morning, once in the evening, and three times between the morning and evening at random timepoints). Participants were asked to answer questions regarding five different symptom dimensions: mood, anger, anhedonia, energy, and hopelessness. Answers were given on a Likert scale ranging from 1 to 7, with lower scores corresponding to more severe depressive symptoms. The mood item of the scale varied from 1 - "I am very depressed" to 7 - "I am very happy"; the anger item from 1 - "I am very angry" to 7 - "I am not at all angry"; the anhedonia item "I am enthusiastic and feel pleasure" (1 - "not at all", 7 - "very much"); the energy level item from 1 - "I am totally exhausted" to 7 - "I am very energetic"; the hopelessness item from 1 - "I am totally hopeless" to 7 - "I am very hopeful".

## 2.5. Statistical analysis

Statistical analysis was carried out in R (R Core Team, 2025). All steps of the analysis were repeated separately for each of the five symptoms.

### 2.5.1. Sample size

Because the first and last day of the 14-day monitoring period did not always yield complete data, we removed these so that the analysis covered only 12 days, with full monitoring data, per participant. From the initial number of patients ( $n = 84$ ), seven patients (two patients from the BPD group and five patients from the MDD group) had participated in the study for less than half of the monitoring period (i.e. less than six days) and were therefore not included in the analyses. The amount of EMA data lost through exclusion was 0.44 %. This led to a total of 100 participants (BD:  $n = 17$ ; BPD:  $n = 15$ ; MDD:  $n = 45$ ; HC:  $n = 23$ ) and 30 000 prompted EMA questions, approximately 16 % of which went unanswered. Consequently, a total of 25 244 data points were included in the analyses.

### 2.5.2. Mean level of symptom dimensions

To examine mean symptom levels across the different groups, a linear mixed effects model was fitted with group, age, sex, and education as fixed effects; subject as a random intercept; and time as a random slope. Backward model selection was conducted, and non-significant predictors were removed. Demographic predictors (i.e. age, sex, and education) were found to be insignificant for all symptoms except anger, for which age was identified as a significant predictor and therefore included in the models. Group means for anger were estimated with age set to the overall mean age by using the emmeans package (Lenth, 2025). All models were fitted using the function lme from the nlme package (Pinheiro et al., 2021). To compare the group differences in mean levels of symptoms between the three patient groups, we used Wald Chi-square tests for fixed effects ("linearHypothesis" function from the car package [Fox and Weisberg, 2019]). Diagnostic plots were used to evaluate the model assumptions. For anger, the residuals were positively skewed, and the response was therefore log<sub>10</sub>-transformed to meet the assumptions of linear modeling.

### 2.5.3. Inertia of symptom dimensions

To investigate the inertia of symptoms, we examined the autocorrelation between successive answers by modeling the relationship between the previous and the current answer. We used a linear mixed effects model as described above, also including a variance function to allow heteroscedasticity between groups. To identify the best-fitting model, we used backward model selection starting with the model

with the following variables: (group)\*(previous answer) + (group)\*(time since previous answer) + (time since previous answer)\*(previous answer). To focus on patterns within individuals, current answer and previous answer were mean centered within each individual.

### 2.5.4. Variance of symptom dimensions

To examine whether variability in symptoms arose primarily within or between individuals across the different groups, we fitted four linear mixed effects models with different variance and covariance structures to allow group differences in symptom variability between and/or within subjects (Hedeker et al., 2009). The models contained the same fixed and random effects—specifically, group as a fixed effect and subject as a random intercept. The variance homogeneity model assumed both within- and between-person variance across the groups. The heterogeneous between-person variance model allowed only between-person variance to differ between the groups, whereas the heterogeneous within-person variance model allowed only within-person variance to differ between the groups. Finally, the heterogeneous between- and within-person variance model allowed both between- and within-person variance to differ between the groups. The best-fitting variance/covariance structure was identified by selecting the best-fitting model for each symptom based on the Akaike information criterion (AIC). In brief, if the heterogeneous within-person variance model and/or the heterogeneous between- and within-person variance model emerged as the most suitable, it signified meaningful differences in within-person variance among the groups. To quantify within-person variability of the patient groups, the standard deviation for each group was extracted from the best fitting model. All four patient groups were initially included in the analysis. To examine more closely which patient groups differed most from each other, we repeated the analysis process including only two groups at a time. The anger responses were log<sub>10</sub>-transformed to meet model assumptions, as the residuals were positively skewed.

## 3. Results

### 3.1. Sample characteristics

A total of 100 participants were included in analyses (BD,  $n = 17$ ; BPD,  $n = 15$ ; MDD,  $n = 45$ ; HC,  $n = 23$ ). The mean age of participants was 36.35 ( $SD 12.54$ ) years, ranging from 18 to 64 years. Of the participants, 77 % ( $n = 77$ ) were female. Mean PHQ-9 score at inclusion for patients was 16.62 ( $SD 5.38$ ). Further sociodemographic and clinical characteristics are presented in Table 1.

### 3.2. Mean level of symptom dimensions

All patient groups had significantly lower mean levels of symptom scores than the HC group ( $p \leq 0.001$  Table 2, Fig. 1).

Among the three patient groups, we found no significant differences in mean symptom levels between any combination of two groups ( $p \geq 0.1246$ ).

### 3.3. Inertia of symptom dimensions

#### 3.3.1. Difference between healthy controls and patient groups

Current individual mean-centered answers were significantly predicted by previous answers in all symptoms, indicating inertia, but the strength of the relationship differed between the groups (Table 3).

Regarding mood and hopelessness, the current answer increased by 0.30 and 0.26 units, respectively, for each unit increase in the previous answer for HC. MDD patients showed similar patterns (mood: slope difference = 0.045 [SE 0.034],  $p = 0.1831$ ; hopelessness: 0.051 [SE 0.034],  $p = 0.1359$ ). However, BD and BPD patients had significantly steeper slopes than HC, i.e., closer to a 1:1 relationship between current and previous answer, indicating greater inertia (slope difference between HC and BD — mood: 0.12 [SE 0.042],  $p = 0.0038$ ; hopelessness:

**Table 1**  
Sociodemographic and clinical characteristics of participants (n = 100).

	BD	BPD	MDD	HC
Participants (n)	17	15	45	23
Age, mean (SD)	36.94 (10.52)	28.73 (6.57)	36.80 (13.35)	40.00 (13.76)
Female sex % (n)	88.24 (15)	93.33 (14)	68.89 (31)	73.91 (17)
Education				
Comprehensive school, % (n)	5.88 (1)	20.00 (3)	11.11 (5)	4.35 (1)
Vocational upper secondary school, % (n)	47.06 (8)	40.00 (6)	20.00 (9)	4.35 (1)
Upper secondary school, % (n)		26.67 (4)	24.44 (11)	4.35 (1)
University of applied sciences, % (n)	29.41 (5)	6.67 (1)	22.22 (10)	34.78 (8)
University, % (n)	17.65 (3)	6.67 (1)	22.22 (10)	53.17 (12)
Civil status				
Single, % (n)	41.18 (7)	80 (12)	44.44 (20)	26.09 (6)
Unmarried cohabitation, % (n)	11.76 (2)	20 (3)	13.33 (6)	26.09 (6)
Married, % (n)	23.53 (4)		31.11 (14)	30.43 (7)
Divorced or judicial separation, % (n)	23.53 (4)		11.11 (5)	17.39 (4)
Widow, % (n)				
Type of BD				
BD I, % (n)	23.53 (4)			
BD II, % (n)	70.59 (12)			
BD NOS, % (n)	5.88 (1)			
PHQ-9 at inclusion, mean (SD) <sup>a</sup>	16.38 (6.24)	17.73 (6.92)	16.33 (4.50)	
MDQ at inclusion, mean (SD) <sup>b</sup>	11.50 (1.67)	6.14 (4.74)	3.37 (3.37)	
MSI-BPD at inclusion, mean (SD) <sup>c</sup>	6.94 (2.08)	7.29 (2.33)	4.27(2.64)	

HC = healthy controls, BD = bipolar disorder, BPD = borderline personality disorder, MDD = major depressive disorder, NOS = not otherwise specified, PHQ-9 = Patient Health Questionnaire, MDQ = Mood Disorder Questionnaire, MSI-BPD = McLean Screening Instrument for BPD, SD = standard deviation.

<sup>a</sup> Data missing for 1/77.

<sup>b</sup> Data missing for 4/77.

<sup>c</sup> Data missing for 2/77.

0.12 [SE 0.042],  $p = 0.0041$ ; slope difference between HC and BPD — mood: 0.21 [SE 0.041],  $p < 0.0000$ ; hopelessness: 0.26 [SE 0.041],  $p < 0.0000$ .

Regarding energy, the current answer increased by 0.28 units for each unit increase in the previous answer for HC. BD and MDD patients did not differ significantly from HC (slope difference for BD: 0.072 [SE 0.042],  $p = 0.0879$ ; MDD: 0.054 [SE 0.034],  $p = 0.1122$ ), whereas the

**Table 2**  
Means and 95 % confidence intervals from a mixed model with group as the fixed effect, of the ecological momentary assessment (EMA) questions during a 12-day monitoring period of healthy controls (n = 23) and psychiatric patients with an ongoing major depressive episode (n = 77).

	HC		BD		BPD		MDD	
EMA items <sup>a</sup>	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
Mood	5.67	5.32; 6.03	4.07	3.65; 4.48	4.00	3.56; 4.44	4.06	3.80; 4.31
Anger	6.75	6.15; 7.38	5.31	4.79; 5.90	4.91	4.38; 5.51	5.43	5.09; 5.79
Anhedonia	5.56	5.18; 5.95	3.85	3.40; 4.31	3.88	3.40; 4.36	3.65	3.37; 3.93
Energy	5.24	4.90; 5.58	3.73	3.34; 4.13	3.39	2.97; 3.81	3.37	3.13; 3.62
Hopelessness	5.73	5.34; 6.11	4.14	3.69; 4.59	3.94	3.47; 4.42	3.84	3.57; 4.12

HC = healthy controls, BD = bipolar disorder, BPD = borderline personality disorder, MDD = major depressive disorder, 95 % CI = 95 % confidence interval.

Difference between means of HC and patient groups achieved statistical significance for each item ( $p < 0.01$ ).

<sup>a</sup> Ecological momentary assessment items. Answers were given on a Likert scale ranging from 1 to 7, with lower scores corresponding to more severe depressive symptoms. The mood item of the scale varied from 1 - "I am very depressed" to 7 - "I am very happy"; the anger item from 1 - "I am very angry" to 7 - "I am not at all angry"; the anhedonia item "I am enthusiastic and feel pleasure" (1 - "not at all", 7 - "very much"); the energy level item from 1 - "I am totally exhausted" to 7 - "I am very energetic"; the hopelessness item from 1 - "I am totally hopeless" to 7 - "I am very hopeful".

BPD group showed greater inertia (slope difference 0.12 [SE 0.042],  $p = 0.0063$ ).

Regarding anger and anhedonia, the current answer increased by 0.15 and 0.24 units, respectively, for each unit increase in the previous answer for HC. All patient groups had significantly steeper slopes than the HC group, indicating greater inertia (slope differences regarding anger — BD: 0.14 [SE 0.045],  $p = 0.0014$ ; BPD: 0.18 [SE 0.045],  $p = 0.0001$ ; MDD: 0.15 [SE 0.036],  $p < 0.0000$ ; anhedonia — BD: 0.15 [SE 0.043],  $p = 0.0006$ ; BPD: 0.32 [SE 0.041],  $p < 0.0000$ ; MDD: 0.073 [SE 0.035],  $p = 0.0364$ ).

### 3.3.2. Difference between patient groups

All group slopes and p-values are presented in Table 3. Focusing only on the patient groups, we found a significant difference in inertia of mood between all three groups ( $p \leq 0.0439$ ). The BPD group showed the highest inertia, followed by the BD group and then the MDD group. Energy and anger, in contrast, showed no significant differences in inertia between the patient groups ( $p \geq 0.1057$  and  $p \geq 0.4849$ , respectively). Anhedonia and hopelessness showed the greatest inertia in BPD patients, who differed significantly from BD (anhedonia:  $p = 0.0002$ ; hopelessness:  $p = 0.0015$ ) and MDD groups (anhedonia:  $p < 0.0000$ ; hopelessness:  $p < 0.0000$ ), which in turn showed similar inertia (anhedonia:  $p = 0.0507$ ; hopelessness:  $p = 0.0647$ ).

### 3.4. Variance of symptom dimensions

#### 3.4.1. Variance across all groups

Four linear mixed effects models with different covariance and/or variance structures were fitted in order to assess the symptom variability within and across the four groups.

For all symptoms, allowing within-person variability to differ between the groups substantially improved the fit of the model ( $\Delta AIC$  varying from 3.61 to 404.12; Table 4), indicating that between-group differences in individuals' symptom variability is an important feature. For anger, additionally including between-person variability (the heterogeneous between- and within-person variance model) gave the best fit ( $\Delta AIC$  13.01; Table 4). Across all symptoms, BD and BPD patients tended to have similar, relatively high within-person variability, while MDD patients and HC generally had lower variability (Table 5, Fig. 1).

#### 3.4.2. Two-group comparisons of variance

When including only two groups at a time in analysis, group differences in within-person variance were observed for all symptoms between almost all group pairs. The exception was between the BD and BPD groups, where the variance homogeneity model gave a similar fit for all symptoms (i.e., mood, anger, anhedonia and hopelessness) except for energy, for which the heterogeneous within-person variance model and the heterogeneous between- and within-person variance model provided the best fit (Table 4). Furthermore, when comparing HC and MDD patients only,



Fig. 1. Mean symptom levels and within-person variance by group: visual representation of mean-level and variance modeling.

Mean symptom levels across the different groups (HC, BD, BPD, MDD) are extracted from a linear mixed effects model with homogeneous variance (Chapter 3.2). To examine how symptoms varied in the four groups, we fitted four linear mixed effects models with different variance and covariance structures, and within-person variability of the groups is shown here in terms of the standard deviation for each group, extracted from the best fitting model (Chapter 3.4).

HC = healthy controls, BD = bipolar disorder, BPD = borderline personality disorder, MDD = major depressive disorder, SD = standard deviation.

Table 3

Results from the inertia model, examining the association between the current and the previous answer. The table shows group means, estimated from a model including an interaction term between previous answer and group, and the significance of the interaction term, both in the overall model (“All groups” column) and in separate models comparing pairs of groups (subsequent columns) for each symptom dimension.

Symptom	Group slopes								Interaction term between group and previous answer						
	HC		BD		BPD		MDD		All groups	HC vs. BD	HC vs. BPD	HC vs. MDD	BD vs. BPD	BD vs. MDD	BPD vs. MDD
	B	95 % CI	B	95 % CI	B	95 % CI	B	95 % CI	p-value	p-value	p-value	p-value	p-value	p-value	
Mood	0.30	0.25; 0.36	0.42	0.36; 0.49	0.51	0.45; 0.57	0.35	0.31; 0.39	<0.0001	0.0038	<0.0000	0.1831	0.0421	0.0439	<0.0000
Anger	0.15	0.09; 0.21	0.29	0.22; 0.36	0.33	0.25; 0.40	0.30	0.25; 0.35	0.0001	0.0014	0.0001	<0.0000	0.4849	0.8145	0.5423
Anhedonia	0.24	0.18; 0.30	0.39	0.32; 0.46	0.56	0.49; 0.62	0.31	0.27; 0.36	<0.0001	0.0006	0.0000	0.0364	0.0002	0.0507	<0.0000
Energy	0.28	0.22; 0.33	0.35	0.28; 0.41	0.39	0.33; 0.46	0.33	0.29; 0.37	0.0485	0.0879	0.0063	0.1122	0.3460	0.6280	0.1057
Hopelessness	0.26	0.20; 0.31	0.38	0.31; 0.44	0.52	0.46; 0.58	0.31	0.27; 0.35	<0.0001	0.0041	<0.0000	0.1359	0.0015	0.0647	<0.0000

The interaction term allows the steepness of the relationship between current and previous answer to differ between groups. In the case of perfect inertia, i.e. previous answer strongly predicts current answer, this slope would be 1.

HC = healthy controls, BD = bipolar disorder, BPD = borderline personality disorder, MDD = major depressive disorder, B = parameter estimate for the slope of how current answer depends on previous answer, 95 % CI = 95 % confidence interval.

several symptoms (mood, anger, and anhedonia) showed further model improvement when between-person variability was also allowed to differ between the groups ( $\Delta AIC$  3.97, 15.35, and 3.86, respectively; Table 4). Similarly, in both HC vs. BD and HC vs. BPD group

comparisons, anger showed further model improvement when between-person variability was also allowed to differ between the groups ( $\Delta AIC$  for HC vs BD 4.81;  $\Delta AIC$  for HC vs BPD 10.75; Table 4).

**Table 4**  
Best-fitting models and the  $\Delta AIC$  (Akaike information criterion) values from variance modeling.

	Mood		Anger		Anhedonia		Energy		Hopelessness	
	Best fitting model(s)*	$\Delta AIC^{**}$	Best fitting model(s)*	$\Delta AIC^{**}$	Best fitting model(s)*	$\Delta AIC^{**}$	Best fitting model(s)*	$\Delta AIC^{**}$	Best fitting model(s)*	$\Delta AIC^{**}$
All groups	<b>between- and within-person;</b> within-person	404.12	<b>between- and within-</b> <b>person</b>	13.01	<b>between- and within-</b> <b>person;</b> within-person	168.21	<b>within-person</b>	3.61	<b>within-person</b>	4.43
HC vs. BD	<b>within-person;</b> between- and within-person	294.48	<b>between- and within-</b> <b>person</b>	4.81	<b>within-person;</b> between- and within-person	136.98	<b>within-person</b>	2.00	<b>within-person;</b> between- and within-person	294.27
HC vs. BPD	<b>within-person;</b> between- and within-person	288.46	<b>between- and within-</b> <b>person</b>	10.75	<b>within-person;</b> between- and within-person	91.28	<b>within-person</b>	2.00	<b>within-person;</b> between- and within-person	262.75
HC vs. MDD	<b>between- and within-person</b>	3.97	<b>between- and within-</b> <b>person</b>	15.35	<b>between- and within-person</b>	3.86	<b>within-person;</b> between- and within-person	2.76	<b>within-person;</b> between- and within-person	78.67
BD vs. MDD	<b>within-person;</b> between- and within-person	107.91	<b>between- and within-</b> <b>person;</b> within-person	104.17	<b>within-person;</b> between- and within-person	67.65	<b>between- and within-</b> <b>person;</b> within-person	99.08	<b>within-person;</b> between- and within-person	122.19
BD vs. BPD	<b>homogeneity;</b> within-person	2.00	<b>all models</b>	–	<b>within-person;</b> homogeneity	2.00	<b>within-person;</b> between- and within-person	6.80	<b>homogeneity;</b> within-person; between-person	3.45
BPD vs. MDD	<b>within-person;</b> between- and within-person	104.31	<b>within-person</b>	2.00	<b>within-person;</b> between- and within-person	33.27	<b>within-person;</b> between- and within-person	35.44	<b>within-person;</b> between- and within-person	99.33

To examine how symptoms varied in the four groups (HC, BD, BPD, MDD), we fitted four linear mixed effects models with different variance and covariance structures to allow group differences in symptom variability between and/or within subjects. In brief, if *the heterogeneous within-person variance model* and/or *the heterogeneous between- and within-person variance model* emerged as the most suitable, it signified differences in within-person variance among the groups.

*The variance homogeneity model* assumed both within- and between-person variance across the groups. *The heterogeneous between-person variance model* allowed only between-person variance to differ between the groups, whereas *the heterogeneous within-person variance model* allowed only within-person variance to differ between the groups. Finally, *the heterogeneous between- and within-person variance model* allowed both between- and within-person variance to differ between the groups. The best-fitting variance/covariance structure was identified by selecting the best-fitting model for each symptom based on *AIC*.

HC = healthy controls, BD = bipolar disorder, BPD = borderline personality disorder, MDD = major depressive disorder.

\*Model with the lowest *AIC*. If the difference between the lowest *AIC* and the second lowest *AICs* was less than 2, multiple models were identified as the best-fitting models. The model with the lowest *AIC* is indicated in boldface. In the table, the models were named as follows: homogeneity = *the variance homogeneity model*; between-person = *the heterogeneous between-person variance model*; within-person = *the heterogeneous within-person variance model*; between- and within-person = *the heterogeneous between- and within-person variance model*.

\*\* $\Delta AIC$  = the difference between the lowest *AIC* (i.e. the *AIC* of the best-fitting model) and the second lowest *AIC*. If multiple models were identified as the best-fitting models,  $\Delta AIC$  was calculated as follows: the lowest *AIC* of models not identified as best-fitting models - the lowest *AIC* of models identified as best-fitting models.

**Table 5**

Within-person variance (measured as standard deviation in each group) of symptom scores.

Symptom	BD	BPD	MDD	HC
Mood	1.23	1.23	0.92	0.71
Anger	1.36	1.29	1.06	0.87
Anhedonia	1.31	1.23	1.04	0.91
Energy	1.27	1.14	0.96	0.90
Hopelessness	1.17	1.14	0.86	0.68

Within-person variability of the groups was quantified in terms of the standard deviation for each group, extracted from the best fitting model.

HC = healthy controls, BD = bipolar disorder, BPD = borderline personality disorder, MDD = major depressive disorder.

## 4. Discussion

This study investigated temporal variations in five symptom dimensions in HC and in patients with an MDE and a primary diagnosis of BD, BPD, or MDD. Symptoms were measured using EMA, providing high-resolution insights into patients' emotional states, including anger and energy—symptom dimensions less studied with high-frequency monitoring techniques. Aligned with our first expectation, all patient groups showed significantly different mean levels of symptoms compared to HC, indicating more severe depressive symptoms. In contrast, our second expectation, that all three patient groups would have significantly greater inertia of symptoms than HC was only fully met for anger and anhedonia. Supporting our third and fourth expectations, all patient groups significantly differed from HC in symptom variability, with BD and/or BPD showing the highest variability, MDD the second lowest, and HC the lowest. Interestingly, and aligned with our fifth expectation, the variability of energy was greatest among BD patients. Finally, contrary to our sixth expectation, that the mean level of anger would be distinctive among BPD patients, we found no significant differences in mean anger levels between the three patient groups.

### 4.1. Strengths and limitations

This study has multiple strengths. First and foremost, it included depressed patients from three different diagnostic groups, all subjected to identical methodology within the same study. This uniform approach increases the reliability of the study, ensuring that the findings are genuinely attributed to the differences among the three diagnostic groups. Second, these patients were diagnosed by experienced psychiatrists through semistructured clinical interviews. Third, utilizing EMA allowed us to monitor participants in real time and in real-life situations, which increases the accuracy and generalizability of these findings (Ebner-Priemer and Trull, 2009). Fourth, as the EMA compliance (i.e. the proportion of answered questions from the total number of prompted questions) in previous studies typically ranges between 70 % and 85 % (Stone et al., 2023), we reached an acceptable level of compliance at 84 %. Fifth, the duration of the study (12 days) was comparable to the average duration of EMA studies (12.4 days [Wrzus and Neubauer, 2023]).

This study also has some limitations. First and crucially, while the overall number of participants included in this study ( $n = 100$ ) was reasonable compared with the average number of 136.6 participants in EMA studies (Wrzus and Neubauer, 2023), the number of both BD and BPD patients remained low (Table 1). This increases risk of type II errors and may limit generalizability of findings. Second, since HC were either voluntary care personnel or university students, university education was overrepresented in the HC group compared with the patient groups. In addition, the HC group exhibited a higher average age than the patient groups, and disparities in relationship status were also observed between the HC group and patient groups (Table 1). Consequently, it is possible that these details might explain some of our findings. Third, the majority of patients in the BD and BPD groups were recruited from

hospitals, whereas patients in the MDD group were recruited mainly from primary healthcare. Nevertheless, the PHQ-9 scores (Table 1) were in fairly close proximity across all patient groups. Fourth, as illustrated by PHQ-9 scores at inclusion (Table 1), overall depression severity was relatively moderate, which may have limited our ability to detect group differences between patient groups. Fifth, EMA questions did not include all depressive symptoms. However, the EMA item selection was curated to capture the distinctions among the three diagnostic groups. For instance, alongside the core criteria of an MDE, the EMA survey also incorporated anger, a significant symptom in BPD (American Psychiatric Association, 2013). Finally, we acknowledge that the methodological and conceptual challenges regarding EMA studies in general (Dejonckheere et al., 2019; Marwaha et al., 2014; Stone et al., 2023; Wrzus and Neubauer, 2023) also apply to the current study and caution that results should be interpreted accordingly.

### 4.2. Mean level of symptom dimensions

As reflected in the mean levels of symptoms, depressed patients experienced more severe depressive symptoms than HC, whereas no significant differences between the patient groups were found. It is notable that differences between HC and patients were observed, despite individuals evaluating their own experiences on the Likert scale from their own subjective perspective. As all patients were suffering from a current MDE, similarities in the mean level of symptoms between different patient groups were understandable. However, as intense anger or difficulty controlling anger is one of the DSM-5 diagnostic criteria for BPD (American Psychiatric Association, 2013), it is notable that the mean level of anger in the BPD group was not significantly different compared to other patient groups. That being said, prior research supports the association between pathological anger and depression (Cassidello-Robbins and Barlow, 2016). Anger can also be situational and therefore may not be readily assessed by EMA (patients may not report when in the situation). Furthermore, BPD patients may experience strong shame related to outbursts of anger, which may reduce the ability to recognize anger (Linehan, 1993). It should also be noted that the current study did not examine impulsivity or aggressive behavior. Future research could benefit from including these aspects, or from using a multi-item anger scale or event-based sampling. Nevertheless, the findings contribute to an existing body of research (e.g. [Baryshnikov et al., 2023; Colombo et al., 2019]) suggesting that EMA may be a valid tool to recognize and follow up various depressive symptoms.

### 4.3. Inertia of symptom dimensions

Relative to HC, inertia was greater in the BD group regarding all symptom dimensions other than energy, in the BPD group regarding all five symptom dimensions, and in the MDD group regarding only anger and anhedonia. Furthermore, BPD patients exhibited greater inertia—at any point along the negative-to-positive Likert scale—of mood, anhedonia, and hopelessness than BD and MDD patients. Prior research has suggested that increased emotional inertia might be related to a reduced ability to adequately react to internal or external events (Kuppens et al., 2010) and a tendency to get stuck in emotional states—i.e. the absence of psychological flexibility (Koval et al., 2012). However, despite the possible link between lower psychological well-being and increased emotional inertia (Houben et al., 2015), findings on the association between inertia of emotions and depression have been inconclusive (see [Houben et al., 2015; Kuppens et al., 2010; Nelson et al., 2020] but also [Panaite et al., 2020; Thompson et al., 2012]). The findings of the current study suggest that depressed patients, regardless of their primary diagnosis, tend to become fixed in their current level of experienced enthusiasm and pleasure (measured with the anhedonia item; scale varying from negative to positive experience). The average symptom scores (Table 2) also suggest that patients experience more lack of

enthusiasm and pleasure (i.e. anhedonia) than HC. Thus, these results may indicate that highly inert or lingering anhedonia could be an important transdiagnostic characteristic for depressed patients. As depressive mood is a core symptom (American Psychiatric Association, 2013), it is interesting that mood inertia was significantly increased only in BD and BPD groups compared with HC. It is possible that this might relate to anhedonia being much more specific for depression's psychopathology than depressed mood (Rosenström and Jokela, 2017). Moreover, our results suggest that heightened inertia of anger might also be another transdiagnostic characteristic of depressed patients, possibly indicating that when depressed patients experience anger they might also have difficulties in transitioning out of that state.

As affective instability is one of the core features in BPD (American Psychiatric Association, 2013), the findings regarding more persisting and self-predictable mood, anhedonia, and hopelessness in BPD than in other patient groups may first seem counterintuitive. However, some researchers (Gunderson et al., 2018) suggest that emotional instability in BPD patients means primarily the (reactive) fluctuation of intense negative emotions (dysphoric emotions such as depression, anxiety, and irritability), not the occurrence of positive emotions. In the current study, any negative emotional state is located at the negative end of the Likert scale. Thus, although emotional states change over time, they possibly move at one end of the scale, which could be one of the explanatory factors for greater inertia. Moreover, our findings are in line with earlier research suggesting that BPD patients might experience difficulty transitioning out of emotional states (Reisch et al., 2008). As argued in a previous meta-analysis (Houben et al., 2015), the association between increased emotional inertia and BPD also aligns with Linehan's concept of emotional dysregulation (Linehan, 1993), in which a delayed return to the emotional baseline in BPD is proposed. Finally, depressed BPD patients might have a tendency towards chronic depression and poor response to treatment (Ceresa et al., 2021; Söderholm et al., 2022), which may also explain the findings of this study. Overall, heightened inertia of various depressive symptom dimensions, possibly indicating increased psychological inflexibility, might be an important characteristic of depressed patients. This characteristic may be particularly present in depressed patients with a primary diagnosis of BPD.

#### 4.4. Within-person variability of symptom dimensions

All three patient groups had greater within-person variance of all symptom dimensions than HC. In addition, the within-person variance of all symptom dimensions was greater in the BD and BPD groups than in the MDD group, and the within-person variance of energy was greater in the BD group than in the BPD group. Our findings indicate that heightened variability in depressive symptom dimensions could be a noteworthy trait in individuals with depression, irrespective of primary diagnosis. As several previous studies have suggested that depression may have an association with increased variability of negative affect (Houben et al., 2015; Koval et al., 2013; Nelson et al., 2020), our study, together with other recent studies (e.g. [Stapp et al., 2023]), sheds light on the nuanced variability of distinct symptom dimensions. Our findings suggest that, on the scale varying from negative experiences to positive ones, not only mood but also levels of experienced anger, anhedonia, energy, and hopelessness exhibit greater variability among all depressed patients than among HC.

The terms instability and variability have occasionally been used synonymously (Ebner-Priemer et al., 2009), while others have suggested variability to be a component of instability (Jahng et al., 2008; Koval et al., 2013; Trull et al., 2008). Thus, given the importance of emotional instability in BPD and in BD (Antoniadis et al., 2012; Baryshnikov et al., 2015; Henry et al., 2001), it is unsurprising that participants in the BD and BPD groups demonstrated a tendency towards similar, relatively high within-person variability, while those with MDD generally exhibited lower variability of symptoms. This finding is mostly consistent with previous studies (BD: [Knowles et al., 2007; Stapp et al., 2023]

and BPD: [Jahng et al., 2008; Trull et al., 2008]). Furthermore, as irregularities in psychomotor activity and energy play a pivotal role in the psychopathology of BD (American Psychiatric Association, 2013; Sobin and Sackeim, 1997), it is interesting that energy was the only symptom dimension in which the difference in variability also emerged in the BD-BPD group comparison. The importance of activity/energy instability in BD has also been recognized in other recent reports (Faurholt-Jepsen et al., 2023; Stapp et al., 2023). Our findings further emphasize the significance of energy fluctuation in BD, prompting speculation about whether increased variability of energy might assist clinicians in distinguishing depressed BD patients not only from MDD patients but also from depressed BPD patients. In summary, increased variability of depressive symptom dimensions may be a notable trait among all depressed patients but especially if their primary diagnosis is BD or BPD, warranting further research.

In conclusion, although all patients entered the study as depressed, and thus with similar types of depressive symptoms, distinctive and interesting group differences in the temporal variations of depressive symptoms between patient groups could still be captured by using EMA methods. However, implementing EMA in clinical practice requires further studies with larger sample sizes. Nevertheless, current analyses showed that, compared to HC, depressed patients—whether diagnosed with BD, BPD, or MDD—not only tend to experience more severe depressive symptoms, as reflected in mean levels, but might also exhibit greater variability in depressive symptom dimensions. Depressed patients might also have a tendency to become stuck at their current level, be it at any point along the negative-to-positive scale, of anger and anhedonia. Taken together, the findings highlight the importance of further investigations into the temporal variations of depressive symptoms in depressed patients.

#### CRedit authorship contribution statement

**Annasofia Martikkala:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Ilya Baryshnikov:** Writing – review & editing, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Hanna Granroth-Wilding:** Writing – review & editing, Visualization, Formal analysis. **Roope Heikkilä:** Methodology, Investigation. **Kirsi Riihimäki:** Writing – review & editing, Investigation. **Outi Saleva:** Writing – review & editing, Investigation. **Joel Holmen:** Methodology, Investigation. **Richard Darst:** Software, Data curation. **Tom Rosenström:** Writing – review & editing, Formal analysis. **Talayeh Aledavood:** Writing – review & editing, Supervision, Project administration, Methodology, Data curation, Conceptualization. **Erkki Isometsä:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

#### Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, A. Martikkala used AI-powered language models ChatGPT-3.5 and ChatGPT-4 (<https://chat.openai.com/>) to correct grammar errors and improve readability of the text. After using this service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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## Declaration of competing interest

No conflict of interest.

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