Automaticity as a Vulnerability to Depression: Daily Mood-Reactive Rumination and Early-Life Stress in People With- and Without Depression History

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Abstract

Depressive rumination has been conceptualized as a mental habit that is initiated automatically without conscious awareness, intent or control in response to negative mood. However, it is unknown whether depression vulnerability is characterized by elevated levels of mood-reactive rumination at the level of short-term dynamics. Using mobile ecological momentary assessment, formerly depressed individuals with a recurrent history of depression ($n = 94$) and non-clinical controls ($n = 55$) recorded *in-the-moment* affect and rumination ten times daily over six days, after completing measures of trait ruminative brooding, early-life stress, and habitual characteristics of negative thinking (e.g., automaticity, lack of conscious awareness, intent, and control). Momentary fluctuations in negative affect were prospectively associated with greater rumination at the next sampling occasion in formerly depressed participants whereas this pattern was not observed in non-clinical controls. In formerly depressed participants, the degree of mood-reactivity was moderated by habitual characteristics of negative thinking, which interacted with a history of early-life stress in predicting greater mood-reactive rumination. It was not, however, associated with depression course nor with the frequency of trait ruminative brooding. Mood-reactive rumination may be a vulnerability marker for depression, triggered in response to negative affect with a high degree of automaticity, making it difficult to control. It might constitute a risk independent of the depressive course and originate in early-life stress. Future studies may need to go beyond frequency and target the mood-reactivity and automaticity of ruminative thinking to reduce depression vulnerability.

Keywords: Depression; Rumination; Early-life stress; Habit; Ecological Momentary Assessment.

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Efforts to identify indicators of depression risk have strongly implicated depressive rumination, a negative thinking style characterized by repetitive and passive thoughts about the causes, meanings, and consequences of one's feelings and distress (Nolen-Hoeksema et al., 1991). The Response Styles Theory, the principal theory of depressive rumination, defines rumination as an enduring and stable *habitual-like* cognitive response to changes in mood (Nolen-Hoeksema, 1991). This suggests that mental habits may underpin a persistent disposition to ruminate following increase in negative mood. Rumination has indeed been described as a mental habit in the depression literature (e.g., Hertel, 2004) and more recent theoretical frameworks of depression vulnerability continue to emphasize the role of habit in depressive rumination (see e.g., Shaw et al., 2019). Although the role of trait rumination in depression onset and maintenance has been extensively studied (Nolen-Hoeksema et al., 2008) it is still unclear if depression vulnerability is characterised by elevated mood-reactive rumination at the level of short-term dynamics. Only few studies have addressed the temporal interplay between negative affect (NA) and rumination on shorter time scales, from moment to moment, as described by the Response Styles Theory and more recent theoretical accounts of habitual rumination (e.g., Watkins & Nolen-Hoeksema, 2014). The current study aims to address this gap in the current knowledge on depression vulnerability by utilizing Ecological Momentary Assessment to better understand the dynamic interplay between NA and rumination in daily life in individuals vulnerable to depression.

Rumination as a Mood-Reactive Mental Habit

An increasingly popular theoretical perspective posits that depressive rumination is a mental habit that is initiated automatically without conscious awareness or intent in response to downward shifts in mood, making it persistent and difficult to control (Farb et al., 2015; Nolen-Hoeksema & Watkins, 2014; Shaw et al., 2019; Watkins & Roberts, 2020). Habits are

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behaviours that occur frequently and unintentionally (Orbell & Verplanken, 2010). They are formed by learned associations between behavioural responses and their performance contexts. Once formed, context cues become automatic triggers for the behaviour, such that it is controlled solely by the presence of the context cue (Wood & Neel, 2007). Thus, habits are characterized by a degree of automaticity (e.g, lack of conscious awareness and deliberate intent, mental efficiency, and lack of control (Verplanken et al., 2007).

According to habitual accounts of rumination, transient episodes of ruminative thinking are thought to arise in response to perceived discrepancies between desired states and present reality. This process is considered adaptive when rumination facilitates progress towards desired states, however, when goals are repeatedly not reached, rumination persists and mood deteriorates (Watkins, 2008). The consistent use of passive and abstract ruminative thoughts to cope with such persisting discrepancies cause NA and ruminative thinking to be paired over time, turning rumination into a habit triggered by context (i.e., NA) rather than intentions (Watkins & Nolen-Hoeksema, 2014). Person-specific factors that contribute to a lack of flexible responding and situational factors that systematically thwart important goals may serve as potential risk factors for transient episodes of rumination to consolidate into a habitual style of thinking (Shaw et al., 2019; Watkins & Robert, 2020). Consistent with this, meta-analyses have identified early-life stress not only as a risk factor for depression but also for an earlier age of onset and more chronic course of illness (Nelson et al., 2017). Notably, stressful early-life events, particularly a history of physical, sexual, and emotional abuse, predict elevated levels of rumination in adulthood (LeMoult et al., 2019) and rumination, in turn, has been found to mediate the relationship between childhood abuse and depression severity later in life (McLaughlin & Hatzenbuehler, 2009). Such stressful and abusive environments may constrain peoples' emotional coping repertoire, leading to greater

passivity, and consolidating rumination as a mental habit when paired with negative mood over time (Watkins & Roberts, 2020).

Empirical Support for Habitual Accounts

The brooding subscale of the Response Style Questionnaire (RRS; Nolen-Hoeksema, 1991; Treynor et al., 2003) has often been considered a measure of habitual rumination, and numerous studies have found elevated levels of brooding in currently and remitted depressed individuals compared to non-clinical controls (reviewed in Aldao et al., 2010). However, the RRS only assesses the frequency of rumination in response to low mood (rated on a scale of repetition from “almost never” to “almost always; Treynor et al., 2003) and does not assess other key characteristics of habits (e.g., are initiated without awareness, unintended, and difficult to control; Watkins & Robert, 2020).

Some preliminary evidence for rumination as-a-habit comes from a study by Verplanken et al. (2007) who found that in a sample of university students rumination was strongly correlated with the Habit Index of Negative Thinking (HINT) - a self-report measure of the habitual characteristics of negative thoughts (i.e., repetition, lack of conscious awareness and deliberate intent, mental efficiency, lack of control and self-descriptiveness). In a novel simulation study, Van Vugt et al. (2018) showed that modelling rumination as-a-habit best predicted the impairments of depressed participants on a sustained attention task. More recently, a study by Hjartarson et al. (2020) found that higher scores on HINT were associated with a stronger response to experimental rumination-induction in a student sample. Furthermore, Ólafsson et al. (2020) found that in remitted formerly depressed individuals, ruminative brooding was associated with increased habitual characteristics, whereas this relationship was not evident for ruminative reflection, often considered a more adaptive form of rumination.

Although promising, these findings are limited in several ways. First, because rumination is measured at the trait level, at a single time-point and averaged across time, they may not apply to state fluctuations in affect and rumination. Second, rumination is measured with self-report, by asking respondents to think back to a time when they felt sad, increasing the probability of retrospective bias. Additionally, inducing rumination by asking participants to focus on a standardized battery of rumination-like questions may not generalize to habitual rumination automatically cued in daily life. Finally, they do not address the hypothesized temporal context-response association between affect and rumination, rendering causal inference impossible.

One way to address these shortcomings is to use more ecologically valid assessment procedures, such as Ecological Momentary Assessment (EMA), to capture the interplay between affect and rumination in the flow of daily life experiences. The longitudinal nature of EMA makes it ideally suited to examine temporal relationships between context and behaviour on the microlevel (Myin-Germeys, 2018) and provides the basis for testing dynamic models empirically that has been missing so far. Studies using EMA in student samples have revealed a reciprocal relationship between affect and rumination at the level of short-term dynamics, with rumination predicting subsequent changes in NA, and NA predicting changes in rumination to the same effect (Blanke et al., 2021; Hoorelbeke et al., 2016; Moberly & Watkins, 2008). In a recent EMA study among university students (Hjartarson et al., 2021), the mood-reactivity of rumination was moderated by habitual characteristics (HINT), such that momentary increased NA predicted greater subsequent rumination when associated with greater levels of habitual characteristics. This relationship was not fully explained by trait levels of ruminative brooding (RRS) but overlapped with current depression symptoms, suggesting that, when habitual, mood-reactive rumination is associated with increased depression vulnerability.

We are not aware, however, of any EMA study that directly tests the assumption that individuals vulnerable to depression demonstrate elevated mood-reactive rumination in daily life. Also, existing research has yet to determine if individuals vulnerable to depression demonstrate such mood-reactive rumination as a function of habit. Prior findings are limited to student samples and may therefore not generalize to vulnerable individuals with a history of depression. Furthermore, the findings are limited to measures of current depression severity and are therefore unable to distinguish between vulnerability factors that precede depression and concomitants of a current depressive episode (Ingram et al., 2011).

Aims of the Current Study

The current study aimed to provide a test of the presumed mood-reactive nature of rumination as a vulnerability marker for depression that has yet to be examined empirically. We investigated the dynamic interplay between NA and rumination in the flow of daily life experiences among individuals vulnerable to depression. In line with the theoretical framework of rumination as a persistent habit that confers risk for depression (Watkins & Roberts, 2020) and prior research design recommendations to limit confounds with current depressive status (Ingram et al., 2011), the current study was conducted in a sample of euthymic participants with a history of recurrent depression. A group of non-clinical controls was also recruited to serve as a comparison. We made two predictions derived from the theoretical framework of habitual rumination (Nolen-Hoeksema & Watkins, 2014; Shaw et al., 2019; Watkins & Roberts, 2020) and prior findings (Blanke et al., 2021; Hjartarson et al., 2021; Moberly & Watkins, 2008).

- H1. We expected recurrent formerly depressed individuals to demonstrate considerable mood-reactive rumination in daily life, such that momentary increased NA should prospectively predict greater rumination-levels at the next

sampling occasion. However, mood-reactive rumination should not be apparent in healthy non-clinical controls that should be more resilient to depression.

H2. It is when rumination turns habitual that it is thought to give rise to depression vulnerability, we therefore expected the degree of mood-reactive rumination in daily life of depression vulnerable participants to be moderated by habit, with heightened habitual characteristics of negative thinking predicting greater rumination in response to momentary fluctuations in NA.

To our knowledge, this is the first direct empirical test of the proposed mood-reactivity of rumination in the daily life of depression vulnerable individuals. We followed these hypotheses with a number of exploratory analyses. As mentioned previously, early-life stress might serve as a catalyst for habitual rumination (Shaw et al., 2019). Furthermore, it is reasonable to expect rumination, that has consolidated as a persistent habit, to be associated with a more severe course of depression. We therefore explored if early-life stress, particularly a history of physical, sexual, or emotional abuse, and depression course (number of episodes, age of onset and stability of remission) was associated with greater mood-reactive rumination.

Method

Participants

Data were consecutively collected as a part of a randomized controlled trial (for preregistration see [isrctn.com: No. 92714827](https://isrctn.com/No.92714827)). The current study is based on data collected at baseline prior to treatment. Ethics approval was attained from the National Bioethics

Committee, the Bioethics Committee of the Primary Health Care, and reviewed by the Icelandic Data Protection Authority. Recurrent formerly depressed participants (RFDs) were recruited via referrals from general practitioners and mental health specialists in primary care centres, as well as through public advertisements. Inclusion criteria included an age between 18 and 65 years and a history of 3 or more major depressive episodes but currently in remission. Exclusion criteria included a current major depressive episode and moderate or severe depression symptoms (a score >19 on the BDI-II; Beck et al., 1996). Non-clinical controls (NCs) were simultaneously recruited through public advertisements. Inclusion criteria included an age between 18 and 65 years and a score of 19 or lower on the BDI-II. Exclusion criteria included a presence or history of mental disorders. Detailed description of participant recruitment and inclusion criteria is provided in the online supplementary materials (Supplementary A).

Procedure

Baseline assessment. Participants partook in a 2-hour in-laboratory session. Participants completed self-report questionnaires and were briefed one-on-one on the EMA procedure by a research assistant following a standardized research protocol. The EMA items were explained by a research assistant, exemplifying the meaning of each item and answering any questions. Participants then reviewed a sample EMA alert with the researcher to ensure proper understanding of the smartphone app and the sampling procedure.

EMA assessment. Beginning the following day after the in-lab assessment, participants were prompted by the smartphone app to answer 10 alerts per day for six consecutive days during a 12-h period (between 10 a.m. and 10 p.m.). Alerts were programmed according to a stratified semi-random interval scheme. Each day was divided into ten 72-minute intervals, with a signal occurring randomly within each interval, with an

average of 92-minutes between alerts. Each time, participants gave their momentary rating of NA and rumination. Participants were instructed to answer given how they felt and thought “in-the-moment” just before the alert and to complete the measures immediately upon receiving an alert. After receiving an alert, participants had 25 minutes to respond before it expired. Alerts were presented and responses collected using The Experience Sampler App (Thai & Page-Gould, 2017) an open-source app for EMA research (www.experiencesampler.com).

Debriefing. Upon completing the EMA period, participants returned to the laboratory where they were debriefed and received compensation for their participation (Approx. €30).

Measures

Lifetime history of depressive episodes and psychiatric diagnoses. The MINI-International Neuropsychiatric Interview (MINI; Sheehan et al., 1998) was used to obtain psychiatric diagnoses. MINI is a semi-structured interview for the most common Axis I disorder of the DSM-IV. The Icelandic version was administered for which adequate validity has been demonstrated (Kristjánsdóttir et al., 2015; Sigurðsson, 2008). The present study utilized a composite version of MINI with the depression module from MINI-Plus but with other modules from the standard MINI. Based on Ólafsson et al. (2020) questions were added to assess the number of past depressive episodes, age of onset, and the stability of remission. After confirming the presence of a past major depressive episode, participants were asked how often they had experienced such an episode and to indicate when each episode had started and when it ended. Only episodes of adequate duration (2 weeks or more) that caused significant functional impairment and were separated by periods of remission (at least 2 months) were included. Participants also indicated if they had experienced one or both core symptoms (depressed mood/anhedonia) in the past 8 weeks, but with a shorter duration of at

least one week. If endorsed, they were inquired about other potential symptoms using the same criteria. Stability of remission was defined as the total number of subclinical symptoms. We recorded audio from all MINI interviews. A sample of 22 recordings (approx. 20%) was randomly selected for reassessment by an independent researcher. Interrater reliability between the original evaluation and reassessment was .92, 95% CI = [0.96, 0.99] for number of previous episodes and .91, 95% CI = [0.78, 0.96] for age of onset. All participants sampled were found to have a history of at least 3 previous episodes but currently in remission with perfect agreement between raters.

Beck Depression Inventory (BDI-II). The BDI-II is a 21 item self-report questionnaire that measures the severity of depression symptoms during the past two weeks (Beck et al., 1996). The Icelandic versions (Arnarson et al., 2008) has shown good psychometric properties. The BDI-II had an $\alpha = 0.87$ in the current study.

The Ruminative Responses Scale (RRS). The RRS is a self-report measure of ruminative disposition which contains 22 items that assess a person's tendency to think about the symptoms, causes, and consequences of their depressed mood (Nolen-Hoeksema & Morrow, 1991). The current study utilized the 5-item brooding subscale (RRS-B), which measures more passive, analytical and repetitive forms of thinking, and is thought to represent the maladaptive component of rumination (Treynor et al., 2003). The Icelandic version has shown good psychometric properties (Pálsdóttir & Pálsdóttir, 2008). In the current study RRS-B had an $\alpha = 0.81$.

Habit Index of Negative Thinking (HINT). The habitual quality of negative thinking was measured with the HINT (Verplanken et al., 2007), a 12 item self-report scale that measures the degree to which self-focused negative thoughts occur frequently, are initiated without awareness, are unintended, are difficult to control, and are self-descriptive.

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Each item is rated on a 7-point scale in response to the general prompt; “Thinking negatively about myself is something...”. and included items such as “I do unintentionally” and “I start doing before I realize I’m doing it”. The Icelandic version has shown high internal consistency and good discriminant validity (Ólafsson et al., 2019). In the current study HINT had an $\alpha = 0.96$.

Early-life stress. The Childhood Traumatic Events Scale (CTES; Pennebaker & Susman, 1988) was used to assess participants’ history of early-life stress before the age of 17. Participants were asked whether they had experienced certain stressful events, the age at which they experienced them (not reported here), how traumatic the event had been on a 7-point scale (1 = not at all traumatic, 7 = extremely traumatic). Events included: Physical abuse, mugging or assault; sexual abuse or molestation; major parental conflicts; death of a family member or person very close to the child; severe illness or injury; and other traumatic events which were perceived to impact the individual’s personality or life trajectory. An additional item to assess history of emotional abuse was added in the present study; “Prior to the age of 17, did a parent or other household member frequently swear at you, degrade or humiliate you?” based on questions in other well-established measures of adverse childhood experiences (e.g., the ACE scale; Felitti et al., 1998). The CTES yielded a cumulative score, by summing the number of stressful early-life events, and a total severity score, calculated by summing the severity of each reported event. The CTES demonstrates good reliability and validity (Pennebaker & Susman, 1988) and sensitivity to clinical symptoms following early life stress, including PTSD and depression (Scheller-Gilkey et al., 2004).

Momentary mood ratings. Participants rated their current mood at each alert during the EMA period. The choice of items was based on the widely used Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) and previous EMA studies (revealing items

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with high loadings on NA; e.g., Wichers et al., 2012). NA consisted of the following items:

1) *I feel sad right now*, 2) *I feel irritable right now*, and 3) *I feel guilty right now*. Participants responded using a five-point scale from 1 (Not at all) to 5 (Very much). NA had an $\alpha = 0.69$ and was strongly correlated with BDI-II ($r = 0.53$)¹.

Momentary rumination. An abbreviated form of the Momentary Ruminative Self-Focus Inventory (MRSI-A; Connolly & Alloy, 2017; Hjartarson et al., 2021) was chosen for use during the EMA period which contained three items: 1) *Right now, I am thinking about how happy or sad I feel*, 2) *Right now, I wonder why I react the way I do*, and 3) *Right now, I am thinking about the possible meaning of the way I feel*. Participants indicated their degree of rumination at the time of the alert using a 7-point scale, from 1 (Strongly disagree) to 7 (Strongly agree). The MSRI-A has shown excellent internal consistency and is correlated with alternative measures of rumination (Connolly & Alloy, 2017). The MSRI-A had an $\alpha = 0.92$ and was moderately correlated with RRS-B ($r = 0.33$)¹.

Statistical Analyses

Analyses were conducted in Mplus version 8.5 (Muthén & Muthén, 2017) and in R version 4.0.3 (R Core Team, 2020) using the package *ggplot2* for data visualization (Wickham, 2009). Previous research has shown that EMA assessment with less than 30% completed alerts may be unreliable (Delespaul, 1995). Participants with fewer than 12 out of 60 completed alerts were therefore excluded from the analyses. Given the nested structure of the data (repeated assessments within individuals) we utilized Dynamic Structural Equation Modelling (DSEM) in Mplus, a multilevel approach to analysing EMA data (Hamaker et al., 2018). Using DSEM we fitted cross-lagged models to investigate the dynamic relationship between momentary affect and rumination. The models were run using Bayesian estimation

¹ Correlations are based on within-person averages of NA and MSRI-A

with non-informative priors. We used 50.000 iterations on two independent Monte Carlo Markov Chains, of which every 10th was recorded for estimation purposes. A Bayesian approach is used in DSEM because it allows for the simultaneous estimation of multiple outcome variables and their covariances and the accurate modelling of time-series data with unequal intervals between measurement occasions (Schuurman et al., 2016). We provide standardized results for within-person and between-person effects. All continuous between-level variables were grand-mean centered. Statistical significance is based on the credible interval not containing zero (the default in DSEM). The corresponding Mplus code is included in the supplementary materials (Supplementary B).

Hypothesis 1: Group differences in mood-reactive rumination in the daily life of RFDs and NCs. To test our hypothesis that momentary fluctuations in NA predict subsequent rumination in RFDs but not NCs, three successive models were computed. A visual representation of the models is shown in Figure 1.

[Figure 1 about here]

We first modelled the within-person relationships between momentary NA and rumination for each group separately to estimate significant paths within each group (Figure 1a). NA and rumination at any given time-point (t) were predicted by NA and rumination at the previous time-point ($t-1$). We were interested in the effect of the variables on themselves (autoregressive paths) and on each other (cross-lagged paths). These associations were allowed to differ between individuals (i.e., random means and slopes). We follow Hamaker and colleagues (2018) in presenting our models. The models decompose affect and rumination into latent within- and between-person components. The within-person components describe affect and rumination of individual i at time t :

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$$\begin{aligned} Affect_{it} &= \mu_{NA, i} + \varphi_{1i} NA_{it-1}^{(w)} + \varphi_{3i} Rumination_{it-1}^{(w)} + \zeta_{1it} \\ Rumination_{it} &= \mu_{Rumination, i} + \varphi_{2i} Rumination_{it-1}^{(w)} + \varphi_{4i} NA_{it-1}^{(w)} + \zeta_{2it} \end{aligned} \quad (\text{eq. 1})$$

where $\mu_{Affect, i}$ and $\mu_{Rumination, i}$ are the time-invariant (between-person) means of affect and rumination for individual i . The autoregressive parameters φ_{1i} and φ_{2i} represent the effect of the variables at $t-1$ on themselves at time t . The cross-lagged parameters φ_{3i} and φ_{4i} are the effects of the variables at $t-1$ on each other at time t . The parameters ζ_{1it} and ζ_{2it} represent the residual variation at time-point t not explained by rumination and affect at the previous time-point $t-1$. Both the means μ_i and the lagged parameters φ_i are allowed to vary across individuals (hence the subscript i). Scores were latent person-mean centered to better capture fluctuations in NA and rumination relative to individuals' mean levels during the assessment period (the default in DSEM; Asparouhov et al., 2018)

Using the whole sample, we then estimated the effect of group membership on the between-level (see Figure 1b) on the autoregressive and cross-lagged parameters on the within-person level (dichotomous; 1 = RFDs, 0 = NCs):

$$\begin{aligned} \mu_{NA, i} &= \gamma_{00} + \gamma_{01} \text{Group}_i + u_{0i} \\ \mu_{Rumination, i} &= \gamma_{10} + \gamma_{11} \text{Group}_i + u_{1i} \\ \varphi_{1i} &= \gamma_{20} + \gamma_{21} \text{Group}_i + u_{2i} \\ \varphi_{2i} &= \gamma_{30} + \gamma_{31} \text{Group}_i + u_{3i} \\ \varphi_{3i} &= \gamma_{40} + \gamma_{41} \text{Group}_i + u_{4i} \\ \varphi_{4i} &= \gamma_{50} + \gamma_{51} \text{Group}_i + u_{5i} \end{aligned} \quad (\text{eq. 2})$$

where γ_{00-50} is the fixed average of the parameters and u_i is the individual deviations from these effects. On the between-level, group membership, denoted as γGroup , was included as a predictor of the person-specific means and person-specific autoregressive and cross-lagged associations. All parameters were allowed to covary.

Hypothesis 2: Habitual characteristics predict mood-reactive rumination in daily life of RFDs. To test whether habitual characteristics (HINT) was a predictor of mood-reactive rumination in RFDs, we computed the cross-lagged model (Figure 1) using HINT instead of group membership as our between-level predictor (eq. 2) of the autoregressive and cross-lagged associations between NA and rumination on the within-person level (eq. 1). If fluctuations in NA trigger subsequent ruminative thinking as a function of habit, stronger $\phi_{NA \rightarrow Rum}$ associations should be associated with greater habitual characteristics (HINT).

Exploratory analyses: The role of depression course and early-Life stress in mood-reactive rumination in daily life of RFDs. We also explored if mood-reactive rumination in RFDs was associated with the depression course (age of onset, number of episodes, stability of remission) and history of early-life stress (cumulative early-life stress, perceived stress severity, and history of abuse (physical, sexual, or emotional)). We first computed the cross-lagged model (Figure 1) in RFDs and entered each exploratory variable individually on the between-level (eq. 2), as predictors of the autoregressive and cross-lagged associations on the within-person level (eq. 1). We then explored whether the effect of each variable was moderated by habitual characteristics (HINT) by simultaneously entering each individual variable (γ_{VAR}) along with HINT on the between-level as well as adding an interaction term $HINT * \gamma_{VAR}$, created by multiplying each variable by scores on HINT (no correction for multiple testing). Due to the low number of RFDs reporting 4 or more stressful early-life events, they were collapsed into one category, resulting in cumulative stress scores between 0 and 4. When analysing the models for subgroups events were dummy coded (1 = history of abuse, 0 = no history of abuse).

Result

Sample Characteristics

A total of 102 RFDs were included in the trial, of which 94 (19 men, 75 women) provided sufficient EMA data (>20%) to be included in the analyses. In total 55 NCs (12 men, 43 women) were recruited, all of which provided adequate EMA responding. See Table 1 for details on the characteristics of both samples. RFDs had experienced an average of 7.1 ($SD = 3.6$) lifetime depressive episodes and mean age of first-episode onset was 18.1 ($SD = 6.9$) years. There were no significant differences between the groups concerning age (mean age of 36.8 vs 39.7), gender, relationship status, educational level, or current employment status. As might be expected, RFDs worked somewhat lower percentages compared to NCs. On average, RFDs reported a greater number of stressful early-life events and were more likely to have a history of abuse. RFDs also showed higher levels of depression (BDI-II), habitual-characteristics (HINT) and trait levels of brooding (RRS-brood). Non-completers (those who did not provide a sufficient number of responses) did not significantly differ from the sample with regards to age, gender ratio, relationship status, educational level, or employment status (See supplementary materials G).

Preliminary Analyses of EMA Data

Participants completed a total of 6008 EMA alerts (RFDs = 3733, NCs = 2275). RFDs completed on average 66% (range = 20%-93%) of the EMA alerts compared to 69% (range = 20% - 95%) in the NCs, with no-significant difference between the groups, $t(107.5) = 0.86$, $p = 0.394$. Across time, ratings of momentary NA were significantly higher in RFDs ($M = 4.27$, $SD = 0.98$) than in NCs ($M = 3.28$, $SD = 0.32$), $t(123.3) = 9.02$, $p < .001$. In addition, RFDs demonstrated more moment-to-moment fluctuations in NA ($MSSD = 2.67$, $SD = 2.76$)

compared to NCs ($MSSD = 0.87$, $SD = 1.14$), $t(135) = 5.58$, $p < .001$. The groups did not differ in their average level of momentary rumination ($M = 6.87$, $SD = 3.14$, in RFDs vs. $M = 6.10$, $SD = 3.57$, in NCs), $t(101.7) = 1.34$, $p = .185$. However, RFDs showed more pronounced moment-to-moment fluctuations in rumination ($MSSD = 16.61$, $SD = 12.21$) compared to NCs ($MSSD = 6.81$, $SD = 8.12$), $t(144.5) = 5.87$, $p < .001$. Mean levels of NA and rumination did not change as a function of time during the EMA assessment period².

[Table 1 about here]

Hypothesis 1: Group Differences in Mood-Reactive Rumination in the Daily Life of RFDs and NDs

The effect of group on the temporal associations between NA and rumination is presented in Figure 2 and their corresponding paths are visualized in Figure 1. Detailed model results are provided in supplementary materials C and D. Group was a significant predictor of mood-reactive rumination (Group on $\phi_{NA \rightarrow Rum}$) during the EMA assessment period ($B = 0.247$, $SD = 0.10$, 95% CI = [0.04, 0.45]). The cross-lagged association between NA and subsequent rumination was significant in RFDs ($\phi_{NA \rightarrow Rum}$; $B = 0.086$, $SD = 0.02$, 95% CI = [0.04, 0.13]) but not in NCs ($B = -0.005$, $SD = 0.05$, 95% CI = [-0.09, 0.09]), when controlling for both initial levels of rumination and the effect that rumination had on subsequent mood. Given the significant difference between groups in current depressive symptoms (see Table 1), we entered BDI-II and group membership simultaneously on the between-level, to control for possible confounds with current depressive status. Group membership still remained a

² The current results remained unchanged when time of measurement was inserted in the within-part of the models to control for trends or non-stationary of the data during the EMA assessment period.

significant predictor of greater mood-reactive rumination (Group on $\phi\text{NA} \rightarrow \text{Rum}$; $B = 0.260$, $SD = 0.12$, 95% $CI = [0.17, 0.51]$).

[Figure 2 about here. In colour]

Hypothesis 2: Habitual Characteristics Predict Mood-Reactive Rumination in Daily Life of RFDs

To test whether mood-reactive rumination is associated with habitual characteristics of negative thinking (HINT), a cross-lagged model using HINT as a between-level predictor was tested in RFDs where NA was shown to be a significant predictor of rumination across time. HINT was significantly associated with larger cross-lagged parameters between NA and subsequent rumination in RFDs (HINT on $\phi\text{NA} \rightarrow \text{Rum}$; $B = 0.253$, $SD = 0.12$, 95% $CI = [0.02, 0.49]$). Detailed full model results for HINT are provided in supplementary materials E. This relationship is depicted in Figure 3 which shows that when associated with greater trait habitual characteristics, a momentary increase in NA evoked heightened rumination on the next measurement occasion.

[Figure 3 about here. In colour]

Additional analyses were carried out to test the robustness of this findings. When controlling for RRS-brooding, entered simultaneously with HINT on the between-level, HINT still remained a significant predictor of cross-lagged path between NA and subsequent rumination (HINT on $\varphi\text{NA} \rightarrow \text{Rum}$; $B = 0.282$, $SD = 0.12$, 95% CI = [0.04, 0.51]) whereas RRS-brooding did not demonstrate a significant effect (RRS-brooding on $\varphi\text{NA} \rightarrow \text{Rum}$; $B = -0.15$, $SD = 0.12$, 95% CI = [-0.39, 0.09]). Furthermore, when entering depressive symptoms simultaneously with HINT on the between-level, HINT still emerged as a significant predictor of greater mood-reactive rumination (HINT on $\varphi\text{NA} \rightarrow \text{Rum}$; $B = 0.260$, $SD = 0.12$, 95% CI = [0.17, 0.50]) whilst depressive symptoms did not (BDI-II on $\varphi\text{NA} \rightarrow \text{Rum}$; $B = -0.01$, $SD = 0.12$, 95% CI = [-0.23, 0.24]).

Exploratory Analyses: The Role of Depression Course and Early-Life Stress in Mood-Reactive Rumination in Daily Life of RFDs

We also explored if mood-reactive rumination in daily life of RFDs was associated with early-life stress and depression course. Results of the main analyses are presented in Figure 4. Detailed results are provided in supplementary materials F. As can be seen in Figure 4, depression course (number of depressive episodes, age of onset, stability of remission) did not emerge as significant predictors of mood-reactive rumination nor did habitual characteristics (HINT) moderate their effect to any significant degree.

[Figure 4 about here. In colour]

Self-reported severity of early-life stress did not emerge as a significant predictor of mood-reactive rumination. Cumulative early-life stress before the age of 17 (see Table 1) was, however, a significant predictor of larger cross-lagged associations between NA and

subsequent rumination in RFDs (Cumulative stress on $\varphi\text{NA} \rightarrow \text{Rum}$; $B = 0.270$; see Figure 4). Additional analyses were carried out to assess if this finding was specific to the type of early-life stress in question. RFDs with a history of abuse (dummy coded as 1 or 0), demonstrated significantly greater mood-linked rumination compared to RFDs that did not report an early-life experience of abuse (Abuse on $\varphi\text{NA} \rightarrow \text{Rum}$; $B = 0.261$). Although cumulative early-life stress did not interact with self-reported habitual characteristics (HINT) in predicting mood-reactivity of daily ruminative thoughts (HINT x Cumulative stress on $\varphi\text{NA} \rightarrow \text{Rum}$; $B = 0.01$, $SD = 0.13$, 95% CI = [-1.5, 0.35]), a history of abuse did (HINT x Abuse on $\varphi\text{NA} \rightarrow \text{Rum}$; $B = 0.332$, $SD = 0.15$, 95% CI = [0.02, 0.60]). This relationship is depicted in Figure 5.

Habitual characteristics of self-focused negative thinking (HINT) significantly predicted stronger temporal pairing between NA and subsequent rumination in participants reporting physical, sexual, or emotional abuse before age of 17, but not in RFDs reporting no such history of abuse.

[Figure 5 about here. In colour]

Discussion

Measures of the dynamic interplay between NA and rumination in daily life revealed significant mood-related reactivity of state ruminate thoughts in recurrent formerly depressed participants, but not healthy controls. To our knowledge, this is the first explicit test of the mood-reactivity of depressive rumination using mobile EMA assessment in a clinical sample. These key findings extend previous results (Blanke et al., 2021; Hjartarson et al., 2021; Hoorelbeke et al., 2016; Moberly & Watkins, 2008) by showing that fluctuations in everyday

NA may act as a trigger of subsequent ruminative thinking in euthymic individuals vulnerable to depression. This is in line with the Response Styles Theory (Nolen-Hoeksema, 1991) and more recent theoretical accounts that define depressive rumination as a stable and enduring cognitive process that has become conditioned on negative mood (Nolen-Hoeksema & Watkins, 2014; Shaw et al., 2019). Importantly, these findings held when controlling for current depressive symptoms, in line with theoretical accounts of mood-reactive ruminative thinking as a vulnerability marker (Watkins & Nolen-Hoeksema, 2014) and not just a concomitant of current depressive episodes (e.g., Ingram et al., 2011).

We also found that increased micro-level shifts in mood-dependent ruminative thinking were associated with the perceptions of one's negative self-focused thoughts being automatically triggered without intention and control. This reaffirms previous findings of Hjartarson et al. (2021) and is consistent with recent conceptualisations of depressive rumination as a response triggered by context (i.e., downward shifts in mood) rather than goals or intentions (Farb et al, 2015; Nolen-Hoeksema & Watkins, 2014; Shaw et al., 2019; Watkins & Roberts, 2020). Since mood-reactive rumination was only evident in individuals vulnerable to depression, and habitual characteristics specifically predicted the strength of the reactivity, this suggests that depression vulnerability may be in the form of rumination being triggered with a high degree of automaticity in response to daily fluctuations in negative affect, making it difficult to control.

The emphasis that habitual accounts place on the automaticity of ruminative thinking is novel given that traditional measures of rumination only measure the frequency of ruminative thinking in response to negative mood (Treyner et al., 2003; Watkins & Roberts, 2020). HINT (but not brooding) was as a significant predictor of the temporal pairing of NA and subsequent rumination whereas it did not predict the dynamic pairing between rumination and subsequent NA. Thus, the impact of rumination on affect was not associated

with habitual characteristics, further highlighting the specificity of the current findings. Importantly, HINT remained a unique predictor of mood-reactive rumination when controlling for trait levels of brooding and current depressive symptoms, suggesting that HINT assesses aspects of mood-reactive rumination not fully captured by traditional trait measures of rumination and which cannot be explained by confounds with current depression status or overlap in negative content of the self-report measures. Thus, we may need to go beyond frequency to tap vulnerability and concentrate on reactivity and automaticity, in addition to trait or mean levels of rumination.

Depression course (number of episodes, age of onset, and stability of remission) was not associated with mood-reactive rumination in daily life. This could reflect the homogeneity of the current clinical sample, consisting of high-risk individuals with at least three-lifetime depressive episodes, restricting the lower end of vulnerability and potentially inhibiting the ability to detect these effects (cf. Buckman et al., 2018), but may also indicate a mechanism independent of the depression course that constitutes a risk or vulnerability on its own (Shaw et al., 2019). Consistent with this view, we found that RFDs with a history of physical, sexual, or emotional abuse before the age of 17, demonstrated greater levels of mood-reactive rumination. Furthermore, habitual characteristics (HINT) predicted stronger mood-reactive rumination in RFDs reporting physical, sexual, or emotional abuse but not in RFDs without such a history. Prior findings show that rumination is associated with a history of early-life stress and abuse (LeMoult et al., 2019) and recent habitual accounts of rumination suggest that stressful and abusive environments may constrain peoples' emotional coping repertoire, consolidating rumination as a mental habit when paired with negative mood over time (Shaw et al., 2019; Watkins & Roberts, 2020). Evidence suggests that stressful early-life events play a role in internalizing psychopathology through sensitization

processes (McLaughlin et al., 2019) and reduced cognitive control (Jenness et al., 2020) that may pave the way for habit formation (e.g., Gordon et al., 2020).

Our results should also be interpreted in light of some limitations. Although the intensive longitudinal EMA methodology of the current study provided an inference of temporal causality, effects were generally small to moderate in size. Other contributing factors might also cause NA to evoke a subsequent ruminative response. Furthermore, although the current investigation identified the automaticity of mood-reactive rumination at the level of short-term dynamics as a potential vulnerability marker, it remains to be tested whether it *predicts* depression onset and relapse using prospective designs and *under what conditions* it results in such emotional cascades (e.g., at times of heightened and persistent NA).

There exist yet no reliable behavioural proxies to measure rumination as-a-habit. In the current study, habitual characteristics were inferred from self-report, highlighting the need for the development of more specific behavioural measures of habitual rumination to clarify the unique role of habit in depressive rumination. Similarly, even though mood-reactive rumination was associated with a history of early-life stress, the study does not address how rumination develops as-a-habit in the first place. Other potential catalysts for rumination to consolidate as a mood-reactive habit have been suggested, such as cognitive inflexibility (Watkins & Nolen-Hoeksema, 2014), difficulties with attentional disengagement (Koster et al, 2011), and an imbalance in habit vs goal-directed behaviour control (Ólafsson et al., 2020). Future research should strive to assess if the strength of the habitual association between NA and rumination changes longitudinally as a function of these potential moderators. The EMA assessment methodology utilized in the current study is ideally suited to test these novel predictions.

The findings of the study could have significant clinical implications. They provide a direct test of the habitual model of rumination that has not been tested empirically so far and reveal a potential vulnerability marker that could constitute an important mechanism of change during therapy. Rumination that is triggered with a high degree of automaticity might make it difficult for some people to fully recover from depression. Elevated rumination has been found to predict poorer outcomes following standard cognitive-behavioural therapy (Kertz et al., 2015). Preventive and acute therapy of depression may need to target the *context-response association* between negative mood and rumination and not just the *content* of the ruminative thoughts. This is in line with the recent development of interventions specifically designed to target the habitual qualities of rumination, such as rumination-focused CBT (Watkins, 2018) and mindfulness-based cognitive therapy (MBCT; Segal et al., 2018) where the ruminative response is specifically replaced with more helpful ways of responding (e.g., concrete thinking, compassion, mindfulness). Although rumination-focused interventions have found outcome effects that compare favourable to standard CBT (Teismann et al., 2014) it remains to be seen whether they lead to greater reductions in rumination compared to other established treatments (Spinhoven et al., 2018).

The EMA measurement strategy used in the current study is also ideally suited to test whether interventions are successful in reducing the mood-reactive automaticity of ruminative thinking and to study mechanisms of change during therapy. Furthermore, the current findings suggest that rumination-focused interventions may be highly prescriptive for those with a history of childhood abuse. This is consistent with previous findings that MBCT provides additional protection over treatment-as-usual or placebo but only for those with a history of childhood abuse or adversity (Williams et al., 2014).

To sum up, the present results indicate that mood-reactive rumination may be a vulnerability marker for depression with rumination being habitually triggered in response to

momentary fluctuations in negative mood with a high degree of automaticity. As a vulnerability, habitual rumination may constitute a risk independent of the depressive course and originate in early-life stress and abuse. Our findings begin to outline how depression vulnerability may emerge as a dynamic relationship between NA and rumination across time, not captured by traditional trait measures of rumination frequency. Future studies could expand on these findings by exploring whether targeting the mood-reactive automaticity of rumination as a mechanism of change during therapy can inform more personalized treatment selection and thereby reducing suffering and burden of depression.

Declaration of competing interest

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Table 1
Demographic and clinical characteristics of formerly depressed and healthy non-clinical controls.

Characteristic	Formerly depressed (n=94)		Non-clinical controls (n=55)		Statistic	
	<i>M (SD)</i>	%	<i>M (SD)</i>	%	<i>t</i>	χ^2
Age (years)	36.8 (10.9)		39.7 (11.9)		$t(147)=-1.492, p=0.138$	
Gender (males)	19	20.2	12	22		$\chi^2(1, N=149)=0.001, p=0.981$
Relationship status						$\chi^2(4, N=149)=3.634, p=0.458$
Married	34	36.2	23	42		
Single	30	32	10	18		
Relationship	8	9	5	9		
Cohabitation	20	21	16	29		
Other	2	2	1	2		
Education (final level)						$\chi^2(3, N=149)=0.848, p=0.838$
High school	7	7	6	11		
Gymnasium	34	36	17	31		
College, undergraduate level	33	35	19	35		
College, graduate level	20	21	13	24		
Employment status						$\chi^2(1, N=149)=0.181, p=0.671$
Employed	71	76	44	80		
Unemployed	23	24	11	20		
Employment percentage	79.6 (29)		87.2 (24.2)		$t(105.09)=-1.692, p=0.094$	
Student	36	38	18	33		$\chi^2(1, N=149)=0.307, p=0.580$
Age at depression onset (<i>M, SD</i>)	18.1 (6.88)					
Number of MDD episodes (<i>M, SD</i>)	7.14 (3.64)					
Stability of remission (<i>M, SD</i>)	0.957 (1.91)					
Cormorbid diagnosis						
Yes (at least one)	25					
No	69					
Total of comorbid diagnoses	24					
Anxiety disorders	27					
Eating disorders	1					
CTES						
Number of stressful events	2.43 (1.75)		1.55 (1.136)		$t(147)=-3.205, p=0.002$	
Severity	12.2 (10.1)		6.61 (7.23)		$t(140.9)=-3.951, p<0.001$	
History of physical, sexual, or emotional abuse	47	50	14	25.5		$\chi^2(1, N=149)=7.661, p=0.006$
HINT	62.2 (13)		32.2 (16.2)		$t(147)=-12.389, p<0.001$	
RRS-brood	11.6 (3.01)		6.85 (1.59)		$t(145.81)=-12.463, p<0.001$	
BDI	8.57 (5.97)		2.18 (2.82)		$t(141.92)=-8.827, p<0.001$	

Note. CTES=Childhood Traumatic Events Scale; HINT=Habit-Index of Negative Thinking; RRS-brood=Ruminative Response Scale - brooding; BDI-II=Beck Depression inventory

Figure 1. Multilevel cross-lagged model estimating the effect of group membership on the temporal associations between momentary negative affect (NA) and rumination (RUM). Black dots indicate random effects. ^(w) represent within-person estimates.

Figure 2. Temporal relationships between negative affect (NA) and momentary rumination (MRSI-A) in daily life (EMA assessment) in recurrent formerly depressed individuals compared to non-clinical controls. Point estimates (posterior means) of cross-lagged ($\phi NA \rightarrow Rum / \phi Rum \rightarrow NA$) and autoregressive ($\phi NA \rightarrow NA / \phi Rum \rightarrow Rum$) paths are shown. Error bars indicate the standard deviation of the posterior distributions. *Statistical significance is based on the 95% credible interval not containing zero.

Figure 3. Negative affect (NA) predicting subsequent rumination (MSRI-A) in daily life (EMA assessment) in formerly depressed individuals as a function of habitual characteristics (HINT). Raw estimates of cross-lagged parameters $\phi_{NA \rightarrow Rum}$ are shown. Each dot corresponds to one participant with a history of depression. Marginal plots show density distributions for HINT and the cross-lagged parameters.

Figure 4. Early-life stress (CTES) and depression course (MINI depression module) predicting mood-linked rumination ($\phi_{NA \rightarrow Rum}$) in daily life (EMA assessment) in formerly depressed individuals (standardized effects). Dashed lines signify effects moderated by habitual characteristics (HINT). *Statistical significance is based on the 95% credible interval not containing zero.

Figure 5. Habitual characteristics (HINT) moderating the effect of early-life stress (physical, sexual, or emotional abuse) on mood-linked rumination in the daily life (EMA assessment) of formerly depressed individuals. Raw estimates of cross-lagged parameters $\phi_{NA \rightarrow Rum}$ are shown. Each dot corresponds to one participant with a history of depression.