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BRIEF REPORT

Negativity is Key for Understanding the Interplay Between Rumination's Features, Attention Control, and Their Dynamic Nature: A Temporal Network Approach

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Abstract

Background Rumination is a transdiagnostic correlate and risk factor for mental disorders. However, few studies have explored rumination and its components in everyday life, or their associations with other transdiagnostic processes, such as deficits in attention control, which may be an explanatory mechanism or consequence of rumination. Inspired by the Nolen-Hoeksema's operationalization of rumination, we investigated the associations between five features of rumination and attention control.

Method We conducted a study relying upon experience sampling methodology: forty participants answered six items four times per day over a two-week period. Using a multilevel vector autoregressive approach, we computed three networks representing temporal, contemporaneous, and between-subjects associations.

Results The results showed that negativity of thoughts temporally drives all other features of rumination and was the only feature impoverishing attention control over time. Negativity was also the only feature negatively associated with attention control within the same time frame. In contrast, brooding was the only rumination feature to be associated with attention control in the between-subject network (i.e., similar to cross-sectional approach).

Conclusion These results highlight negativity as a driving force of rumination and as a potent pathway in the interplay between rumination's features and attention control. Although these results appear inconsistent with the hypothesis that impoverished attention control drives rumination, they fully align with the resource allocation hypothesis that engaging in negative thoughts depletes attentional resources.

Keywords Rumination · Attention control · Temporal network analysis · Network approach · Experience sampling methodology

Everyone has experienced repetitive, negative, and self-focused thoughts like "*Why am I so sad?*" or "*Why can't I handle things better?*" Such a phenomenon illustrates rumination. It consists of repetitive, passive, self-focused thoughts about the content, causes, and consequences of one's affective state without taking any problem-solving action (Nolen-Hoeksema & Morrow, 1991). Though initially linked to depression, rumination appears best conceptualized as a transdiagnostic vulnerability and maintenance factor for affective dysregulation and related emotional disorders (McLaughlin & Nolen-Hoeksema, 2011; Wolkenstein et al., 2014). Research has identified rumination as a viable and plausible target for transdiagnostic clinical interventions (e.g., Watkins, 2015). Yet uncertainties remain regarding the very mechanisms of rumination, thus limiting the specificity of potential interventions.

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According to prominent cognitive approaches (e.g., De Raedt et al., 2015; Koster et al., 2011), rumination may arise from impairments in attention control (i.e., the ability to voluntarily regulate the allocation of attentional resources). Clinical and laboratory studies dovetail with this perspective. First, empirical research has extensively documented strong associations between rumination and reduced attention control (e.g., Zetsche et al., 2018). Moreover, mounting evidence indicates that attention control can be viewed as a key transdiagnostic process of anxiety- and mood-related disorders (e.g., Coussement et al., 2022; Eysenck & Derakshan, 2011), whose improvement via clinical interventions can mitigate rumination and, in turn, alleviate depression and anxiety (e.g., Heeren & Philippot, 2011; Hoebeke et al., 2021; Hoorelbeke et al., 2015).

Yet critical gaps remain in the literature. And one of the key issues is the conceptualization of rumination as a cohesive and unitary phenomenon, even though its definition denotes a complex and multifaceted system. For instance, the classic definition from Nolen-Hoeksema and Morrow (1991) involves perseveration, brooding, replaying, negativity, and self-critical focus. However, in empirical research, rumination has mostly been reduced to a single sum-score from a self-report measure. This approach treats each feature of rumination as interchangeable, thereby enabling researchers to tally responses to items when examining treatment effects or group differences. However, this sum-score strategy oversimplifies the story and it is easy to generate examples of how these hallmark features may interact (e.g., the more one criticizes oneself for failures, the more likely one is to brood about how sad one feels), meaning they are not interchangeable. One may also wonder how these different features differentially interact with attention control.

To fill this gap, Bernstein et al., (2017, 2019, 2020) proposed a radically different conceptualization of rumination: a network approach. Inspired by the network approach to psychopathology that posits that mental disorders can be viewed as causal systems of mutually reinforcing symptoms (Borsboom, 2017; McNally, 2016), they relied upon network analysis to examine the relationships among the five key features of the classic Nolen-Hoeksema and Morrow's (1991) theory—i.e., perseveration (i.e., the repetitiveness of one's thoughts); negativity (i.e., to what extent one's thoughts are negative); self-criticism (i.e., having self-critical thoughts); brooding (i.e., thinking of the causes and consequences of emotional experiences); and replaying (i.e., mentally reviewing parts of emotional experiences). In two studies (Bernstein et al., 2017, 2020), they found that these features were unsurprisingly strongly interrelated but not interchangeable. When each component of rumination was treated as its own entity, it appeared to relate to, influence, and be influenced by the others in different ways and to different degrees. Notably, across distinct computational network models, self-criticism consistently stood out as the most influential node within the entire network system (Bernstein et al., 2017, 2020). Moreover, in one study (Bernstein et al., 2017), they also examined the relationships among these features and tasks tapping into top-down executive control. They found that, of the five features, self-criticism seemingly drove brooding, which in turn, predicted poor executive control (Bernstein et al., 2017). However, despite their merits, these studies both relied upon cross-sectional data, thus precluding any strong inference regarding the temporal dynamics between these variables (Bringmann et al., 2022).

In addition to the conceptualization of rumination, the failure to account for rumination as a process unfolding over time is another limitation in rumination research. Most studies have relied on a cross-sectional approach, which is unfortunate given the inherently ever-changing nature of emotion regulation processes such as rumination (McRae & Gross, 2020). There is, however, a small but growing literature on the temporal dynamics of rumination (e.g., Hjartarson et al., 2021). Researchers used experience sampling methodology (ESM), which assesses pertinent variables multiple times a day over several days or weeks (Myin-Germeys et al., 2018). And the conclusions from these studies were unequivocal: rumination fluctuates over time, self-predicts itself over time (that is, from one time-point to the next), and can temporally predict variables such as mood and negative affect. Yet, this research did not investigate the distinct evolution of the different features of rumination, nor how they can activate or perpetuate one another over time. Moreover, despite the assumed key role of top-down attention control in rumination research, no study has unraveled the potential interactions between attention control and the key features of rumination.

In this project, we seek to map the dynamic interplay between the hallmark features of rumination with one of its theory-driven key mechanisms: top-down attention control. To best capture the ever-changing nature of these processes, we instructed participants to report their experiences four times a day for 14 days. To characterize the dynamic associations between variables, we used a multilevel vector autoregressive model which is especially suited to visualizing temporal multivariate relationships (for a review, see Blanchard et al., 2023). Specifically, we estimated three types of networks from this high-intensive time-series dataset: (1) a temporal network to examine how variables are associated from one time-point to the next; (2) a contemporaneous network to inspect how variables interrelate within the same timeframe (potentially reflecting fast-moving temporal processes occurring at a time interval quicker than the sampling interval); and (3) a between-subjects network to observe the mean-level relationships between variables collapsed across

time. This threefold framework is typical practice in temporal network analysis (Blanchard et al., 2023). It can offer radically new data-driven insights into rumination.

Method

Data Availability and Openness

De-identified data, R script, and other supplemental materials have been made publicly available via the Open Science Framework at https://osf.io/k5dyf/. All participants provided written informed consent. The project received the approval of the UCLouvain biomedical review board (REF# 2020/057). All participants provided written informed consent. Participants received 50€ for participating in the entire study.

Participants

We recruited 40 French-speaking Belgian participants (aged 18–26 years, $M = 21.2$, $SD = 2.03$, 77.5% female) from the general community via social media and listserv advertisements (see Supplemental Materials for how we determined our sample size and inclusion criteria). Participants had, on average, 9.18 ($SD = 1.72$) years of education (after elementary school).

Measures and Procedure

We used a time-contingent sampling scheme with fixed intervals: participants received text messages four times a day at 09:00, 13:00, 17:00, and 21:00 with a link to the survey, over 14 consecutive days. It resulted in 56 assessment per participant, consistent with recent guidelines regarding the requisite number of timepoints for temporal network research (Blanchard et al., 2023).

The ESM survey consisted of 6 items, with five focusing on key features of rumination (i.e., perseveration, negativity, self-criticism, brooding, replaying) and one on attention control (i.e., ability to control attention when dealing with distractors). All items appear in the legend of Fig. 1, and the ESM survey instructions appear in the supplementary material section (Table S2 and Table S3). Items were assessed with a slider scale from 0 (not at all) to 100 (absolutely), delivered using *formr* (Arslan et al., 2019) that allows creating complex longitudinal surveys with R. Table 1 contains the descriptive statistics of all the ESM items. Of note, further information about the psychometric development of the items depicting the five key features of state rumination is available elsewhere (i.e., Hoebeke et al., 2022).

Data Analysis

We used a multilevel vector autoregressive model (mlVAR). Data were analyzed using R via the *mlVAR* (Epskamp et al.,

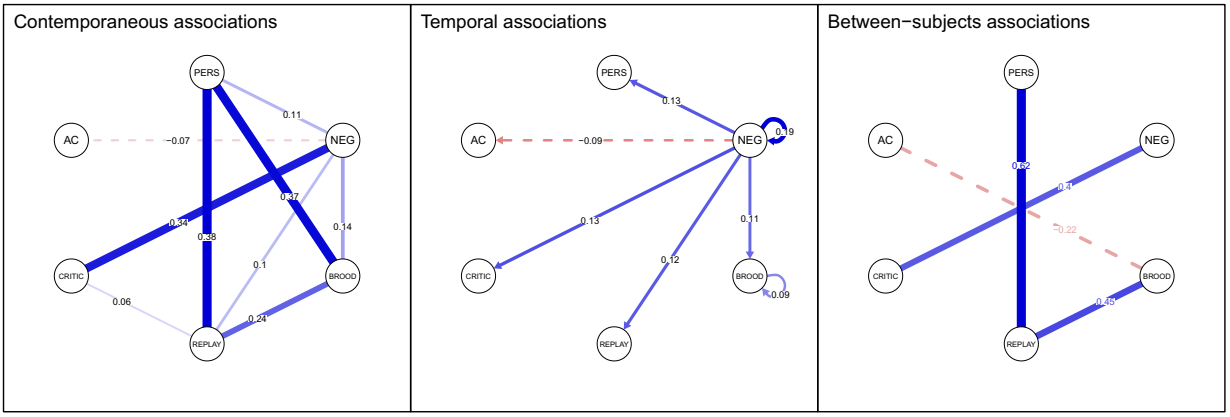

Fig. 1 The contemporaneous, temporal, and between-subject networks. *AC* attention control (i.e., "When I wanted to deliberately concentrate on something, I was capable of ignoring environmental distractions (noise, notifications, visual distractors, …)"), *PERS* perseveration (i.e., "How much time did you spend thinking of one or more emotional experiences?"), *NEG* negativity (i.e., "To what extent were your thoughts negative?"), *CRITIC* criticism (i.e., "To what extent were your thoughts self-critical?"), *REPLAY* replaying (i.e., "To what extend have you mentally replayed emotional experiences that you've had?"), *BROOD* brooding (i.e., "How much did you think about the causes and consequences of emotional experiences?"). Solid blue lines represent positive associations; striped red lines represent negative associations. The contemporaneous network depicts the associations between variables within the same time frame after controlling for all other temporal and contemporaneous associations. The temporal network represents the extent to which nodes predict themselves (i.e., autoregression) and each other from one time-point (t) to the next time-point (t + 1). The arrow depicts the direction of prediction. The between-subject network shows the correlations between the person-level means of each variable for each participant (i.e., the average response of each participant for each variable over the course of the fourteen days)

Table 1 Descriptive statistics of the ESM items

ESM item	Within-person mean	Within-person SD	ICC
Perseveration	37.38	14.01	0.24
Negativity	28.45	13.02	0.24
Brooding	33.91	14.33	0.25
Replaying	34.93	13.82	0.23
Self-criticism	30.00	15.12	0.33
Attention control	58.74	12.23	0.17

ICC Intra-class correlation

2017) and *qgraph* (Epskamp et al., 2012) packages. We estimated the multilevel VAR model (generating contemporaneous, temporal, between-subject networks) through sequential estimation of univariate multilevel regression models, and we allowed the random effects to be correlated (Bringmann et al., 2013). For the contemporaneous and between-subject networks, we used the "and" rule: for an edge to be kept in the final network, both coefficients (from node A to node B and vice-versa) had to be significant (see Supplemental Material for further analyses). Based on Shapiro–Wilk tests, all within-person means were normally distributed ($p > 0.05$), but the residuals of the mlVAR model were not ($p < 0.05$). We also confirmed the stationarity of our data by using the Kwiatkowski–Phillips–Schmidt–Shin test (KPSS; $p > 0.05$ using a Bonferroni correction). We also computed the within-person mean, the standard deviation, and the intraclass correlation (ICC) of each item (see Table 1). The ICC represents the proportion of the total variance due to between-person variance (Snijders & Bosker, 1999).

Results

We excluded one participant who had a variance and mean of zero on two items, and removed one outlier response with a response time of 289 min. In the end, 2013 observations were kept (average compliance rate = 92.17%; mean response time = 2.45 min; median response time of 0.82 min). The mean time between two measurement-completions within a day was 3 h and 55 min.

Network Analysis

Contemporaneous Network

The features of rumination are positively associated at the same time point (see Fig. 1): (1) perseveration was the most strongly associated with brooding and replaying, and (2) criticism and negativity were strongly associated as well, whereas they share small associations with replaying, brooding, and perseveration. There is no association between criticism and perseveration. Finally, attention control is negatively associated with negativity: more negative thoughts are associated with a lower ability to ignore distractions within the same time-point.

Temporal Network

As shown in Fig. 1, negativity appears as the most influential variable. Negativity is the only variable associated with other variables at the following time-point: more negative thoughts at one timepoint are associated with greater critical, replaying, and perseverative thoughts, as well as lower attention control, at the next time-point. Moreover, only negativity and brooding show positive autocorrelation over time (i.e., a variable self-predicting itself from one time-point to the next), with the autocorrelation of negativity emerging as the largest arrow in the entire network.

Between-Subjects Network

The between-subject network (Fig. 1) indicates that participants with higher average negativity also have higher average self-criticism, and that higher average perseveration is associated with higher replaying. Attention control is only associated with brooding: lower average attention control is associated with higher average levels of brooding.

Discussion

Rumination appears to be a key transdiagnostic risk factor for mental disorders. Yet, despite the clinical relevance of rumination, little is known about its temporal and multifaceted nature. In this study, we sought to fill this gap by examining the dynamic temporal interplay between attention control and five features of rumination, as suggested by the prominent Nolen-Hoeksema and Morrow (1991) approach. By generating networks from intensive ESM time-series data, we aimed to offer a novel perspective on the complex and dynamic interplay between rumination's features and attention control.

Overall, our results dovetail with prior literature on rumination. In line with the cross-sectional studies of Bernstein et al., (2017, 2020), we found that the five features of rumination emerge as a coherent network system (i.e., each variable was connected to at least one other variable), but, for the first time, extended this observation to the temporal realm. Our findings thus support a vision of rumination as a network system of interacting features that evolves dynamically over time. Yet not all nodes were equally important. Negativity in particular emerged as the strongest predictor

of other nodes and of itself in the temporal network. This suggests negativity might act to kickstart the key features of rumination.

Our observation that the negative valence of thoughts could be a key pathway in triggering the entire network system of rumination also fully aligns with the key role of negative affect posited by several prominent theories of rumination (e.g., Nolen-Hoeksema, 1991; Watkins & Nolen-Hoeksema, 2014). Likewise, prior research has emphasized the pivotal role of negativity content induction in the emergence of rumination, and particularly vis-à-vis brooding (e.g., Ciesla & Roberts, 2007). Moreover, our observation of negativity as the rumination feature exhibiting the strongest autoregression (i.e., self-predicting itself over time) echoes early ESM findings of negative affect as strongly self-predicting itself over time (e.g., Koval et al., 2013). From a clinical viewpoint, one may thus wonder whether an intervention that specifically targets negativity might lead to a beneficial cascade of downstream benefits, reducing rumination overall. Another key next step would be to examine whether negativity constitute a prodromal sign of maladaptive rumination and, in turn, of the instigation of mood and related disorders.

Because researchers have long postulated and studied associations between rumination and attention control, we also examined the relations between the features of rumination and attention control. One of the most striking findings was that negativity was the only feature that affected attention control over time; it was also the only feature associated with attention control in the contemporaneous network. In contrast, this association no longer appeared in the between-subjects network when the relationships between all variables are pooled across time (i.e., similar to cross-sectional approach), wherein attention control was negatively associated with the brooding feature. Of note, this observation replicates Bernstein et al. (2017) who reported a strong negative association between brooding and attention control in their cross-sectional, between-subject network study. Since this unique role of brooding only emerged in the between-subject network, it might also suggest a more trait-level relationship in the case of brooding (i.e., people more prone to brooding may also be more prone to struggling with attention control), whereas a more state-level relationship with attention control seems to occur in the case of negativity (i.e., the momentary experience of negative thoughts may concomitantly hamper attention control). Taken together, this set of observations suggests that the way rumination connects to attention control might vary across timescales— a phenomenon worthy of further elucidation (e.g., some statistical models are more precise in understanding how time intervals impact associations, such as continuous-time approach; Ryan et al., 2018).

The present study has theoretical implications. Because our results suggest that negativity is a potential trigger for attention control impairments, our findings are at odds with the well-known hypothesis that rumination may arise from impaired attention control (e.g., De Raedt et al., 2015; Joormann, 2010; Koster et al., 2011). In contrast, our results are consistent with the limited but consistent literature on the resource allocation hypothesis, which posits that engaging in negative thoughts depletes limited attentional resources that accordingly become unavailable for concurrent tasks (e.g., Connolly et al., 2014; Curci et al., 2013; Levens et al., 2009; Philippot & Brutoux, 2008). For example, our results dovetail with experiments showing that inducing negative thinking almost immediately depletes general attentional resources (Philippot & Brutoux, 2008). When carefully inspecting this literature, we realized that perhaps one of the most striking key differences between these two competing approaches might be the type of information to which top-down attention control is directed. Whereas most studies supporting the hypothesis that rumination arises from impaired attention control have focused on attention control during processing self-referential information (e.g., Joormann, 2010; Koster et al., 2011), those of the resource allocation hypothesis have not. Instead, these studies, like ours, assessed general attention control irrespective of the content of the information processed. A crucial step would therefore be to clarify whether the directions of temporal associations between rumination and poor attention control differ according to the self-referential versus general nature of the processed information.

Several other issues require further research. First, our sample was unselected and included mainly women aged 18 to 26 years. A key step would therefore be to investigate whether the present results can be generalized to more diverse samples in terms of age, gender, and clinical status. In particular, one might wonder how variables such as age groups or psychiatric diagnoses (e.g., depression) might impact the associations between attention control and rumination features. Second, we used a single item per node, which may raise concerns about the reliability and validity of our measures. For instance, the "attention control" item could be controversial as previous research has cast doubts on self-report measures of attention control (e.g., Quigley et al., 2017). On the other hand, self-report measures of attention control sometimes yield more comprehensible findings than lab-based measures (e.g., McNally et al., 2013). Moreover, research has shown that single-item measures can have good predictive validity and reduce participant burden by keeping surveys brief (Song et al., 2022), and the excellent psychometric qualities of the ESM items used in this study were reported elsewhere (Hoebeke et al., 2022). Future studies could also include brief computerized tasks measuring attention control, though administrating reliable computerized tasks assessing attention control four times a day may discourage participants. Moreover, our item measuring

attention control does not cover all the facets of attention control. For instance, we did not distinguish between situations wherein attention is distracted by internal thoughts (e.g., intrusive thoughts, memories, somatic experiences) versus external stimuli (e.g., phone notifications).

Finally, although most prominent cognitive models of rumination consider it a regulatory emotional stress response, we unfortunately did not assess stress. The only prior cross-sectional network study on the interplay between the five features of rumination and attention control (i.e., Bernstein et al., 2017) did include a single social stressor. Instead, in our study, participants' rumination episodes were likely triggered by naturally occurring events from their daily life, and perhaps by an accumulation of diverse stressors. Since Bernstein et al. (2017) identified self-criticism as a central pathway in the network and that we did not, one may wonder whether this discrepancy might not result from the different types of stressors used in these studies.

In summary, our findings provide data-driven clues to the temporal and dynamic underpinnings of the interplay between key features of rumination and attention control. Although the current findings need to be replicated and further investigated, the present study underscores the importance of rethinking the associations between rumination features and attention control through a temporal network approach. Moreover, our results highlight the critical role of negativity as a trigger for rumination and its detrimental effects on attention control over time.

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Author Contributions YH: Conceptualization, software, formal analysis, investigation, writing—original draft; MAB: software, formal analysis, investigation, writing—review and editing. EEB: Validation; writing—review and editing. RJM: Validation; writing—review and editing. AH: Conceptualization, methodology, funding acquisition, writing—original draft.

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Data Availability We share the study materials, R code, and de-identified data on the Open Science Framework at https://osf.io/k5dyf/.

Declarations

Conflict of interest Dr. Alexandre Heeren receives honoraria for his editorial work from Elsevier. This financial support had no influence on the study design, data collection, analysis, decision to publish, or writing of the article. Yorgo Hoebeke, M. Annelise Blanchard, Emily E. Bernstein, Richard J. McNally declare that they have no conflict of interest.

Informed Consent The project received the approval of the biomedical review board of UCLouvain (REF# 2020/057). All participants provided written informed consent. Participants received 50€ for participating in the entire study.

Animal Rights No animals were involved in the study.

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