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Slow and Powerless Thought Dynamic Relates to Brooding in Unipolar and Bipolar Depression

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Thought dynamics · Major depressive disorder · Bipolar disorder · Mind wandering · Brooding rumination

Abstract
Introduction: Depression can be characterized by rumination that is featured by spontaneity and perseveration of internally oriented thoughts. At the same time, depressed subjects complain about abnormal slowness and lack of power/energy in their thoughts, suggesting abnormal "thought dynamics." The relationship between rumination and thought dynamics in depression remains unclear, though. ***Method:*** We investigated thought dynamics and rumination in healthy control, major depressive disorder (MDD), and depressed bipolar disorder (BD) subjects. The dynamics in the spontaneous shift between internally and externally oriented thoughts were measured by a novel method of continuous experience sampling whose time series was subjected to power and frequency analyses. Subjects filled out the Beck Depression Inventory-II and Ruminative Response Scale questionnaires to evaluate current depressive symptoms and ruminative responses to negative affect. The methods used to analyze data included χ^2, Pearson correlation, ANOVA, and partial correlation. ***Results:*** Our main findings are: (i) increased number and longer duration of internally oriented thought contents in MDD and BD; (ii) reduced thought dynamics with slower frequency (calculated in Hz) and decreased power (power spectral density) in shifting between internally and externally oriented thoughts, especially in MDD and, less strongly, in BD subjects; and (iii) power spectral density as a dimension of thought dynamics is related to brooding rumination with depression severity explaining high degrees of their variance. ***Conclusion:*** Our results show slow frequency and low power in the internal-external thought dynamic of acute MDD and depressed BD. Together with its close relation to depression severity and rumination, our findings highlight the key importance of abnormal dynamics on the cognitive level of depression.

Introduction

Rumination is a hallmark feature of depression occurring in both major depressive disorder (MDD) and bipolar disorder (BD) [1–3]. The hallmark feature of rumination is the "compulsively focused attention on the symp-

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toms of one's distress and its possible causes and consequences, as opposed to its solutions" [4]. This results in thought preservation where subjects think increasingly about themselves in their internally oriented thoughts (increased self-focus) [5–7].

Rumination has been identified as a critical transdiagnostic predictor of symptom severity in mood disorders, i.e., MDD and BD [8, 9]. This is in line with the observation that ruminative thoughts are typically associated with negative valence [3], enhance negative affect [10, 11], and negative thinking [12] while impairing problem-solving [8]. However, rumination is a heterogenous phenomenon as it includes different thought styles like brooding and reflection [1].

Reflection is conceived as the more adaptive form of rumination, as it involves actively seeking an understanding of and a solution to one's problems [13]. In contrast, brooding is considered the more dysfunctional, maladaptive form of rumination, as it represents passively focusing on one's problems and their consequences [14, 15]. The mechanisms of the predominantly passive thought perseveration in brooding remain unclear. Specifically, one would want to know why and how thoughts passively persevere in brooding rumination in an automatic way and beyond the individual's active and voluntary control. Taken in this way, brooding reflects a particular style of thought where the mind's thoughts wander freely without deliberative control by the subject [16]. This raises the question of the relation of brooding rumination to mind-wandering (MW) in depression.

MW in Depression: Abnormal Thought Dynamics

MW is a key feature of our mental life. Individuals spend between 15 and 46 percent of their awake time in MW, which includes daydreaming, thinking about memories, and planning for the future [17–19]. Several studies have shown a positive correlation between MW and depressive mood [20–22]. The experience sampling method (ESM) is widely used in the MW field [e.g., 7, 14, 17]. The standard method for measuring MW is ESM, which depends on one's capacity for introspection of their own experiences [21]. ESM in examining MW can be divided into two categories: using a probe, which is recording the content of thoughts or direction of awareness after hearing a sound or seeing a picture during MW, and without a probe, which the individual records without any probe during MW. A large-scale, experience-sampling study showed that MW is the cause of negative mood [17], not its consequence [23]. That makes it even more critical to investigate how mind wandering relates to brooding rumination and depressive symptoms.

MW describes the capacity to yield spontaneous thoughts, including both internally and externally oriented thought contents [16, 24–26]. Internally oriented thoughts concern events and objects related to the self, including memories, while externally oriented thoughts are about external events, including their sensory constellation [27]. Depressed subjects suffering from MDD and BD show typically increased frequency of internally oriented thoughts which are abnormally negative, past-oriented, highly self-related, and less social [22, 28–30]. Such shift towards internally oriented thoughts during MW is manifest in brooding rumination in depression.

Taken together, MW and brooding rumination in depression can be characterized by an increased frequency of highly perseverative internally oriented thoughts while externally oriented thoughts decrease, i.e., decreased environment-focus [31]. This raises the question of whether the frequency of shifting between internally and externally oriented thoughts, which occurs around every 20 s (0.05 ± 0.03 Hz) in healthy subjects [26], is decreased and more tilted towards internally oriented thoughts in depression. To that end, one would want to investigate what we describe as "thought dynamics". The concept of thought dynamics refers to the pattern of change in our thought contents over time: the dynamics of thought are, for instance, manifest in the frequency and the power that drive the shifts between internally and externally oriented thoughts.

Goal, Aims, and Hypotheses

The goal of our study was to investigate the thought dynamics, that is, the pattern of change of internally and externally oriented thoughts in healthy subjects and depressed MDD and BD, and how that relates to rumination. We hypothesized increases in both the number of occurrences and duration of internally oriented thoughts as well as decreased power/energy with a slower frequency of internal-external thoughts shift in MDD and depressed BD. Moreover, we assumed that such abnormal thought dynamics are closely related to specifically brooding rumination.

Our first aim was to investigate the number and duration of internally and externally oriented thoughts. Given the previous findings, we hypothesized that both MDD and BD depressed subjects would show an increased number and longer duration of internally oriented thoughts at the expense of externally oriented thoughts. Albeit tentatively, due to our low case number and lack of

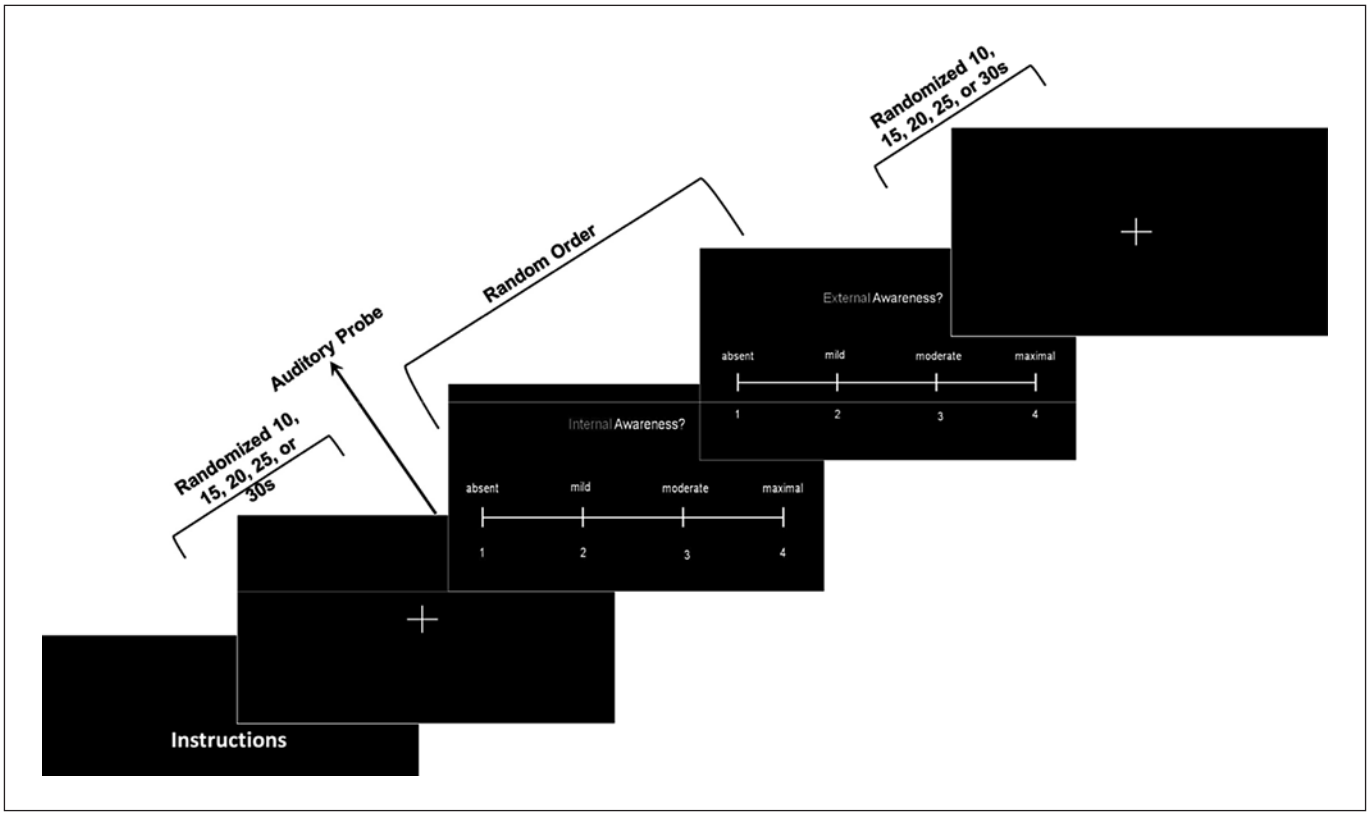


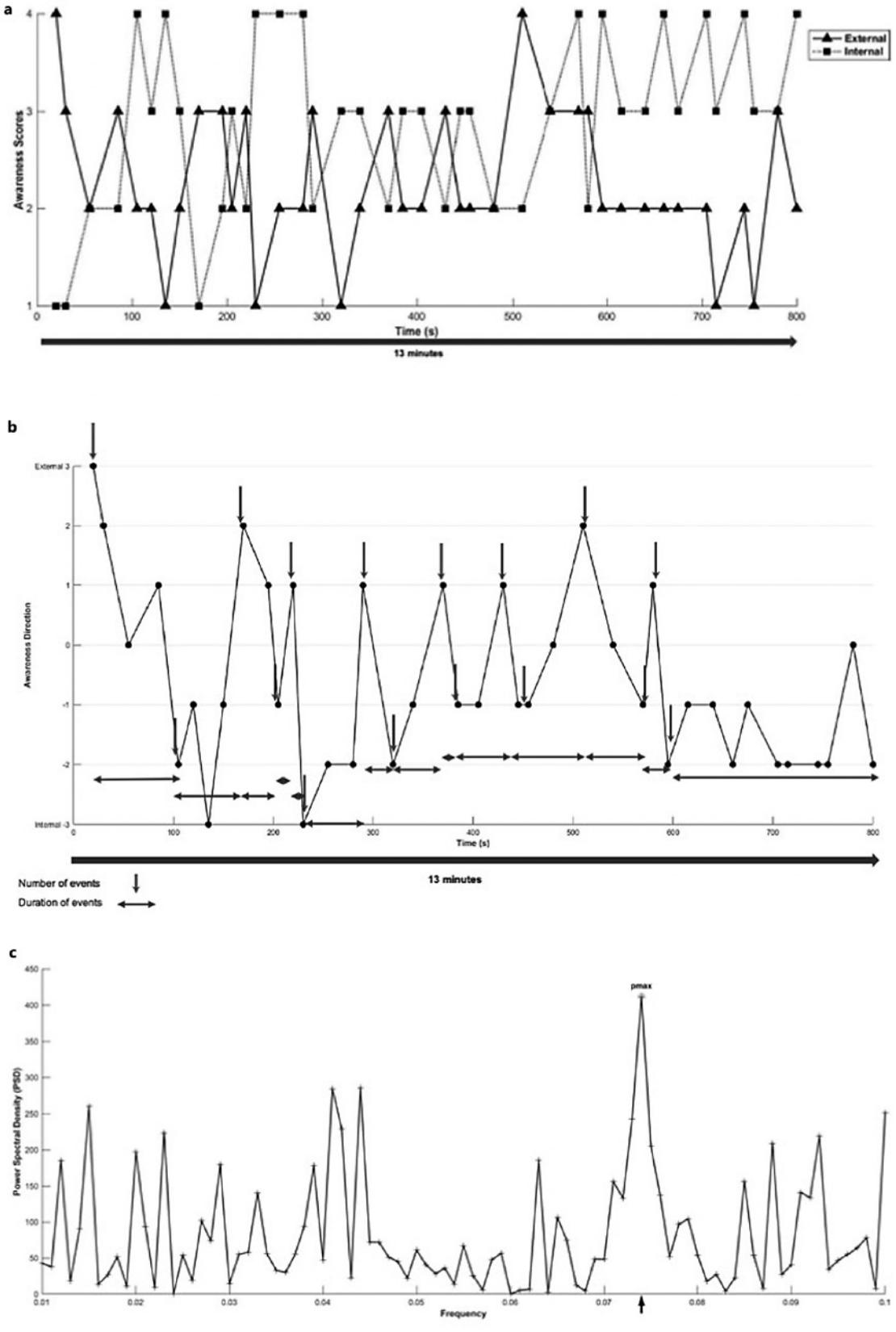
Fig. 1. Schema of probe-caught experience sampling paradigm during mind wandering. Experiment instruction: "During the following time period, we ask you to keep the eyes open and to avoid prolonged structured thinking, such as counting or singing. When you hear a beep, please use the keyboard to communicate the intensity of 'external awareness' and 'internal awareness' ongoing before the beep. 'External' is here defined as a perception of environmental sensory stimuli (e.g., auditory, visual, olfactory, or somesthetic). 'Internal' here refers to all environmental stimuli-independent thoughts (e.g., inner speech, autobiographical memories, or wandering thoughts)."

previous data, we hypothesized a shorter duration of externally oriented thoughts in BD compared to MDD [32]. The second aim was to investigate two measures of thought dynamics of the shift between internally and externally oriented thoughts; these included their frequency (in Hz) and power spectral density (PSD). We hypothesized abnormally slow frequency and decreased power of internal-external thought shift in the depressed groups with especially MDD showing stronger slowness than BD [6, 7, 32]. The third specific aim was to relate the thought dynamics, frequency, and PSD of internal-external thought shifts, to psychopathological symptoms, including brooding rumination. Brooding is a thought style of rumination where the spontaneity of thought dominates over the deliberative control by the subject whereas in reflection the latter is stronger compared to the former [5–7]. Given that in depression the voluntary or deliberative control over one's thought is diminished, we assume that the spontaneous dynamics of the internal-external shift is specifically related to the spontaneity of thought, namely brooding, whose relationship is supposedly related to depression severity [5, 7]. Spontaneity and its dynamics may thus provide the shared feature, i.e., "common currency" [33] of rumination and internal-external thought shift. In contrast, self-reflection is characterized by voluntarily control rather than spontaneous thought dynamics; for that reason, we did not assume that the spontaneous (rather than voluntary) internal-external thought shift is related to the more voluntary controlled self-reflection.

Materials and Methods

Subjects

Participants were 30 healthy controls, 24 MDD, and 30 depressed BD outpatient participants (demographic and descriptive can be found in the online suppl. material S1; for all online suppl.



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material, see www.karger.com/doi/10.1159/000523944). The volunteer, healthy control subjects were screened by a licensed mental health clinician using the SCID-5-RV Screening Form [34]. They did not meet the criteria for any current or lifetime Axis I disorders assessed. They also scored below standardized cut-offs on the Beck Depression Inventory-II (BDI-II). For all groups, the inclusion age criteria were considered to be 18–59 years old. The exclusion criteria for all groups included a history of severe head trauma (TBI), stroke, neurological disease, severe medical illness (e.g., autoimmune disorder), and current alcohol or substance abuse. MDD and BD participants were recruited from the Royal Mental Health Centre affiliated with the University of Ottawa via recruitment emails at the Royal Mental Health Centre, through the internal information bank of patients, Meditech, and direct contact with psychiatrists and mental health centers. It was ensured that MDD and BD were the primary diagnoses. The current depressive mood status for all subjects was verified according to DSM-5 criteria and cut-off scores from the BDI-II. All MDD and BD participants were receiving psychotropic medication (list of medications can be found in the online suppl. material S2).

Psychopathological Scales

We included the following psychopathological scales: (i) BDI-II [35]; (ii) Ruminative Response Scale (RRS) [36]; and (iii) Screening Module of Structured Clinical Interview for DSM-5, research version (SCID-5-RV) [34].

Experimental Paradigm

The behavioral experiment was designed based on the probe-caught ESM to assess the dynamics of MW based on the shift between internal and external awareness. The paradigm was coded and ran using PsychToolbox in MATLAB.

The experiment took place in a quiet room where the subjects sit in a chair facing the keyboard. Before each experiment, subjects received the instruction (shown in Fig. 1). Subjects placed four fingers on the keyboard. All subjects were instructed to start responding by using button presses of their left hand on a 4-point scale (1 = absent; 2 = mild; 3 = moderate; 4 = maximal). The subjects' task was to rate both external and internal thoughts (prompted by a 60-dB beep). The inter-stimulus interval was randomized between 10 s and 30 s with 5 s intervals. A familiarization session (11 responses) preceded the main experiment (shown in Fig. 2a) [26, 37].

Procedure

Subjects were investigated individually. At first, informed consent was obtained. Second, the screening interview was performed by a licensed mental health professional clinician in terms of assessing the inclusion and exclusion criteria. Third, subjects completed the experiment. Finally, they filled out psychological questionnaires.

Fig. 2. a The temporal dynamics of the two components of awareness (internal vs. external direction of thoughts) for a representative healthy subject. **b** Subtraction curve of internal and external rating at each point of time for the representative healthy subject. **c** LOMB-Scargle Periodogram for Unevenly Sample results for the representative healthy control subject. The reported frequency for the subject is 0.07 Hz which has the maximum power, PSD = 411.67.

Analyses

To assess the dynamics of thought during the MW, first, we subtracted external rating from internal rating to obtain one rate for each point of time (shown in Fig. 2b) to calculate the number of occurrence and duration for each direction in MW. Then, using χ^2 and ANOVA methods, the difference between groups was investigated. The homogeneity of variances was assessed using Levene's test ($p > 0.05$).

Second, the frequency and power of shifting between internally and externally oriented thoughts were calculated based on the subtraction rates for each subject. To assess the dynamics of thoughts during MW and their changing pattern over time, a time series analysis method, "LOMB-Scargle Periodogram for Unevenly Sample," was utilized using MATLAB software [38]. LOMB calculates the frequency and PSD of shifting between the internally and externally oriented thoughts for each subject's subtraction curve (shown in Fig. 2b) and reports the maximum PSD and its related frequency (shown in Fig. 2c). PSD shows the strength (energy) of variations as a function of frequency [39]. Subsequently, to assess the difference of variance of frequency and PSD between groups, the ANOVA was applied [40]. Then, the Bonferroni post hoc test was used to calculate pairwise comparisons between groups using SPSS V.26.

In order to investigate the relation between thought dynamic and depressive symptoms (third hypothesis), we calculated the Pearson correlation coefficient for the relation of the PSD with BDI-II scores (as well as specific items, e.g., the lack of energy and decreased concentration items that could be related to the PSD). Moreover, we calculated the Pearson correlation also for the relationship of PSD with brooding-rumination (RRI). Since all three BDI, brooding-rumination (RRI), and PSD correlated with each other, we conducted partial correlation analyses.

Results

Internally and Externally Oriented Thoughts I: Number of Thoughts

To investigate the difference in the number of occurrences internally and externally oriented thoughts between groups, the χ^2 test was utilized (Table 1). As the results show, groups are significantly ($p < 0.01$) different based on the number of internally and externally oriented thoughts, between control and MDD ($p < 0.01$); between control and depressed BD ($p < 0.01$). The control group had a significantly lower number of internally oriented thoughts in comparison with the MDD and BD groups (Table 1). Moreover, the number of internally oriented thoughts in MDD was lower than in depressed BD. The control group had a significantly higher level of externally oriented thoughts than the other groups.

Internally and Externally Oriented Thoughts II: Duration of Thoughts

To examine the difference in duration of internally and externally oriented thoughts between groups, an

Table 1. Results of χ^2 analysis and ANOVA to compare MW dynamics, depression severity, rumination dimensions between groups and pairwise

χ^2	$\chi 2$	df	*p* value	Pairwise (*p*)
Occurrence, *n* Internal-external thoughts	22.73	2	0.001**	HC-MDD (0.001)** HC-BD (0.001)** MDD-BD (0.162)
ANOVA	*F*	df	*p* value	Bonferroni pairwise (*p*)
Internal thoughts duration	3.77	2	0.027*	HC < MDD (0.05)* HC < BD (0.001)** MDD-BD (0.99)
External thoughts duration	3.78	2	0.027*	HC > MDD (0.05)* HC > BD (0.045)* MDD-BD (0.99)
Frequency	5.21	2	0.007**	HC > MDD (0.016)* HC-BD (0.99) BD > MDD (0.018)*
PSD	6.86	2	0.002**	HC > MDD (0.05)* HC > BD (0.001)** MDD-BD (0.87)
BDI	35.71	2	0.001**	HC < MDD (0.001)** HC < BD (0.001)** MDD-BD (0.99)
Brooding rumination	11.28	2	0.001**	HC < MDD (0.005)** HC < BD (0.001)** MDD-BD (0.99)
Self-reflection rumination	2.60	2	0.081	HC-MDD (0.99) HC-BD (0.084) MDD-BD (0.473)

PSD, power spectral density; BDI, Beck Depression Inventory II. * $p < 0.05$. ** $p < 0.01$.

ANOVA test was performed (Table 1). The analysis of the duration of internally oriented thoughts showed a significant difference between the groups: the depressed BD had the longest duration compared to MDD and control groups. The duration of externally oriented thoughts was also significantly different between groups (Table 1). Bonferroni post hoc test revealed a significantly longer duration of externally oriented thoughts in the control group than in BD. Moreover, this duration was longer in the MDD compared to the depressed BD (Table 1).

Thought Dynamics: Frequency and PSD

After obtaining the frequency and PSD for subjects, the difference between groups was calculated by ANOVA. The outcomes showed that there was a significant difference between groups for the frequency (Table 1, shown in Fig. 3a). Individuals diagnosed with MDD had the slowest frequency (0.04 ± 0.02 Hz) and the Bonferroni post hoc test revealed that there was a significant difference between MDD and control groups ($p < 0.05$) as well as between MDD and BD groups ($p < 0.05$), but no difference between the control and BD groups (0.06 ± 0.03 Hz).

Moreover, the same analysis showed that the PSD values of the control group were significantly higher than both MDD and depressed BD groups ($p < 0.05$), while individuals with MDD and depressed BD were not significantly different in this dimension of thoughts dynamics during MW (Table 1, shown in Fig. 3b).

Finally, we illustrated the thought dynamics by showing the curves of representative subjects from each group (Fig. 4). It can be seen that the power of internal-external thought shift (PSD) is reduced in both MDD and BD, while the frequency of that shift is slower only in MDD but similar in healthy and BD subjects (fewer events in the curves of MDD).

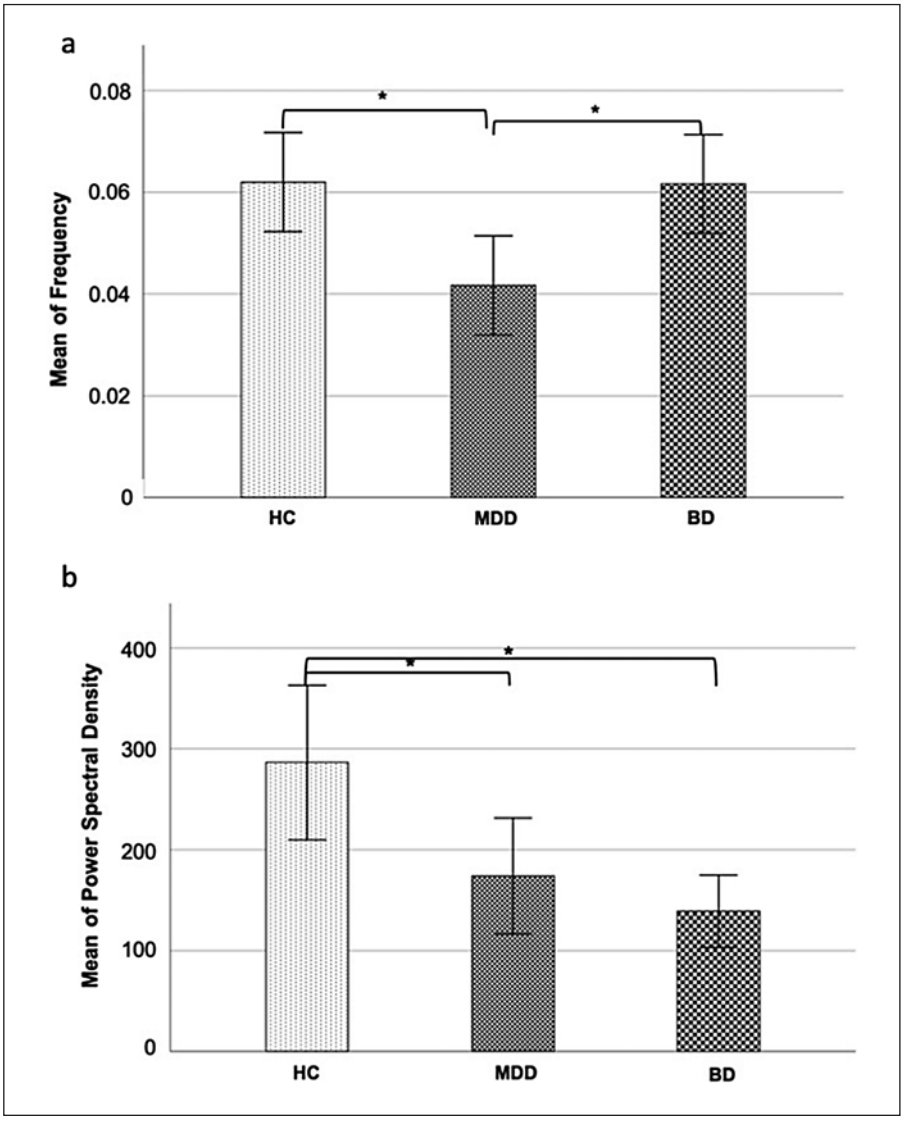

Fig. 3. ANOVA results for the dynamics of thought differences between HC, MDD, and depressed BD groups. **a** Comparing the frequency of shifting between the internal and external thoughts using ANOVA. **b** Comparing the PSD of shifts between the internal and external thoughts (frequency) using ANOVA.

Table 2. Results of Pearson correlation between PSD and depression severity, depressive symptoms, and brooding rumination in HC, MDD, and depressed BD

	MDD & BD		HC	
	PSD	RRS-brooding	PSD	RRS-brooding
BDI	–0.54**	–0.47**	–0.194	0.121
BDI item – loss of energy	–0.40**	0.353**	–	–
BDI item – concentration difficulty	–0.46**	0.343*	–	–

HC, healthy subjects; MDD, major depressive disorder; BD, bipolar disorder; PSD, power spectral density; BDI, Beck Depression Inventory II; RRS, ruminative response scale. *$p < 0.05$. ** $p < 0.01$.

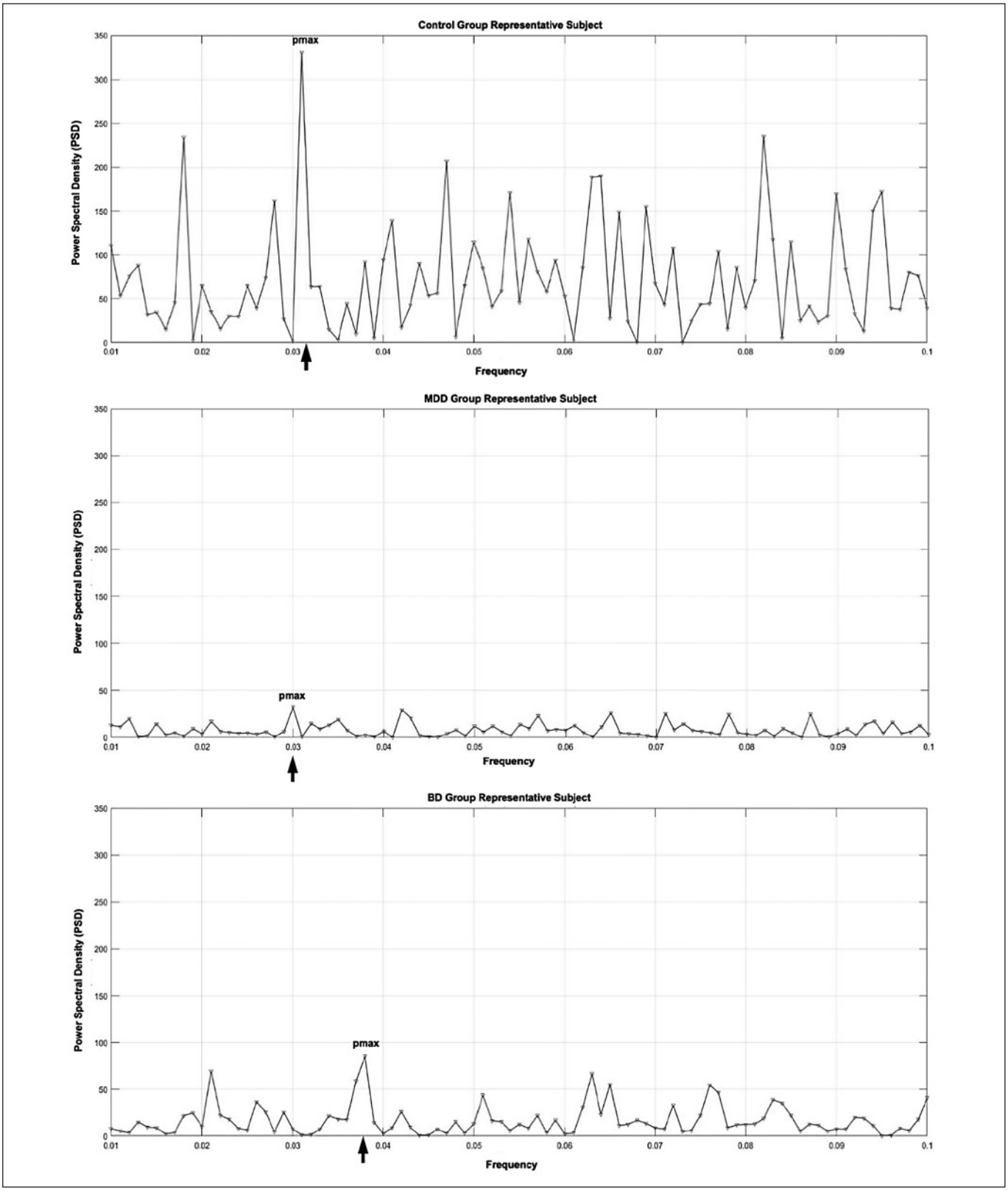

Fig. 4. Illustration of the temporal dynamics of thoughts – representative subjects from HC, MDD, and depressed BD groups with the same range of frequencies of shift but different PSDs.

Table 3. Correlation of thought dynamic (PSD) with clinical measures of depression (BDI, RRS-brooding, and RRS-self-reflection)

Group	BDI	PSD	RRS-brooding	RRS-self reflection
HC				
BDI				
Pearson correlation	–	−0.194	0.121	0.039
Sig. (2-tailed)	–	0.303	0.524	0.838
N	30	30	30	30
PSD				
Pearson correlation	−0.194	–	−0.052	0.374*
Sig. (2-tailed)	0.303	–	0.785	0.042
N	30	30	30	30
RRS-brooding				
Pearson correlation	0.121	−0.052	–	0.277
Sig. (2-tailed)	0.524	0.785	–	0.138
N	30	30	30	30
RRS-self reflection				
Pearson correlation	0.039	0.374*	0.277	–
Sig. (2-tailed)	0.838	0.042	0.138	–
N	30	30	30	30
MDD				
BDI				
Pearson correlation	–	−0.612**	0.545**	0.229
Sig. (2-tailed)	–	0.001	0.006	0.282
N	24	24	24	24
PSD				
Pearson correlation	−0.612**	–	−0.584**	−0.174
Sig. (2-tailed)	0.001	–	0.003	0.415
N	24	24	24	24
RRS-brooding				
Pearson correlation	0.545**	−0.584**	–	0.194
Sig. (2-tailed)	0.006	0.003	–	0.364
N	24	24	24	24
RRS-self reflection				
Pearson correlation	0.229	−0.174	0.194	–
Sig. (2-tailed)	0.282	0.415	0.364	–
N	24	24	24	24
BD				
BDI				
Pearson correlation	–	−0.566**	0.099	0.153
Sig. (2-tailed)	–	0.001	0.604	0.421
N	30	30	30	30
PSD				
Pearson correlation	−0.566**	–	0.107	−0.313
Sig. (2-tailed)	0.001	–	0.573	0.093
N	30	30	30	30
RRS-brooding				
Pearson correlation	0.099	0.107	–	0.348
Sig. (2-tailed)	0.604	0.573	–	0.060
N	30	30	30	30
RRS-self reflection				
Pearson correlation	0.153	−0.313	0.348	–
Sig. (2-tailed)	0.421	0.093	0.060	–
N	30	30	30	30

* $p < 0.05$. ** $p < 0.01$.

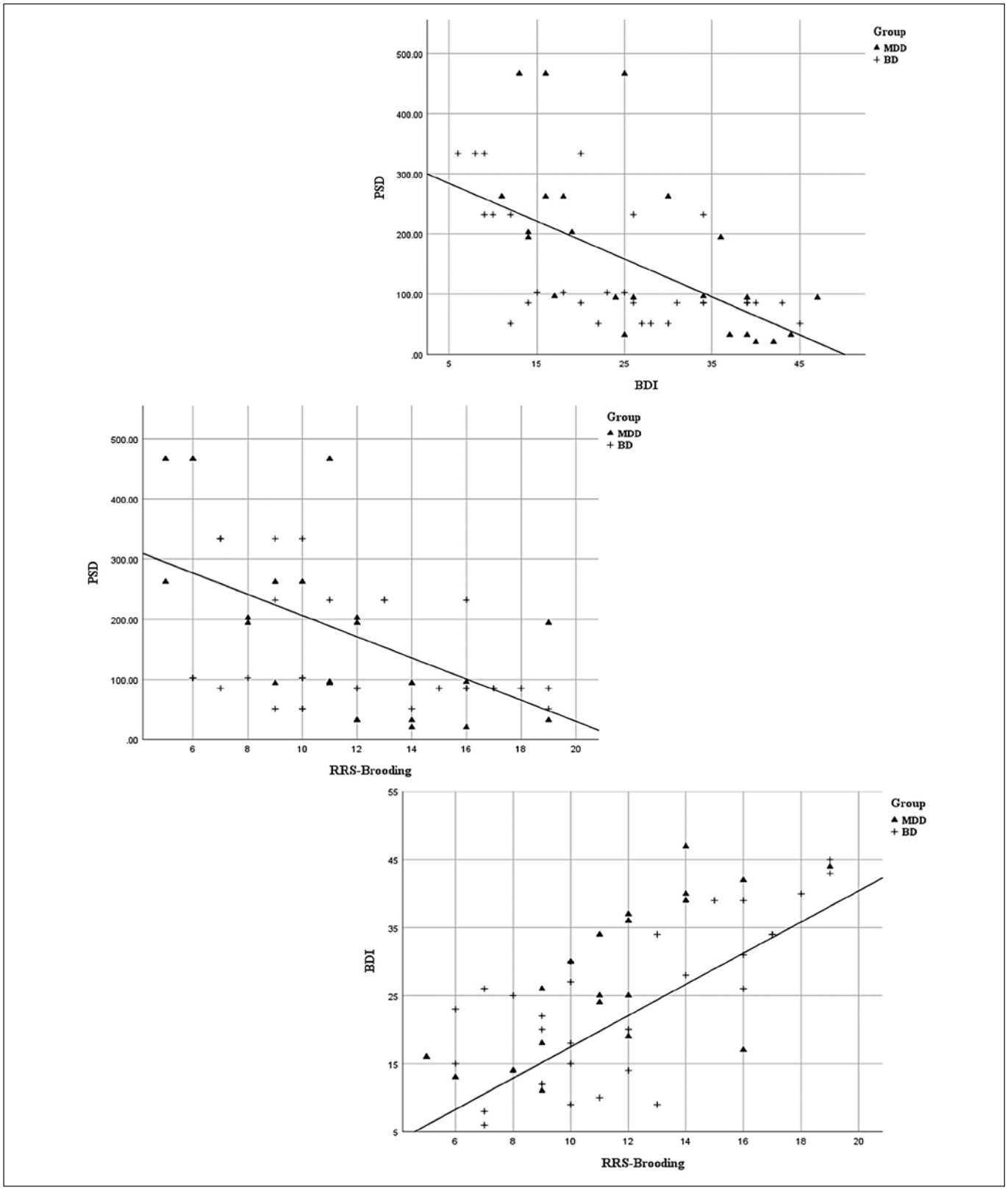

Fig. 5. Correlation between depression severity (BDI), brooding (RRS), and thought dynamic (PSD) in MDD and depressed BD.

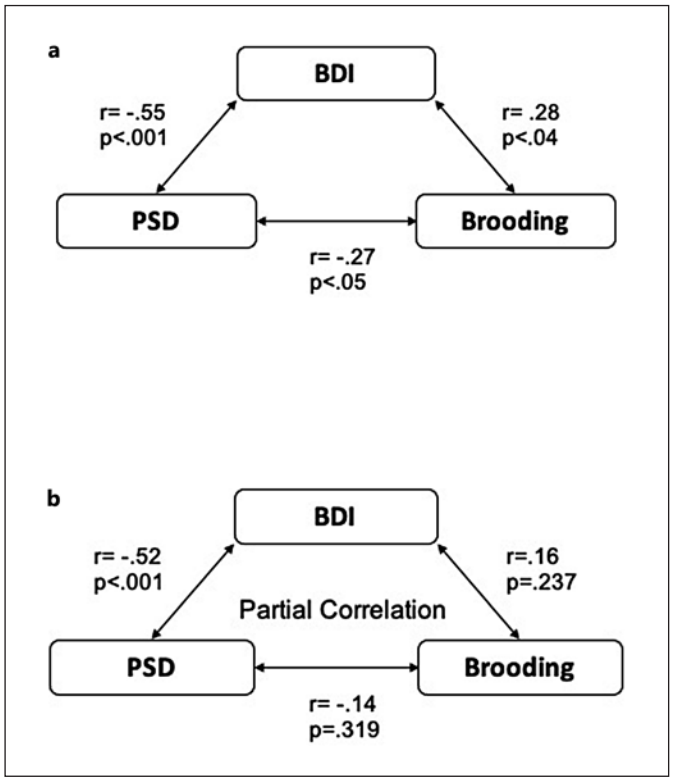

Fig. 6. a, **b** Partial correlations model showing the statistic of each correlation controlling for the effect of the third variable in the model.

From Thought Dynamics to Rumination

To investigate the relationship between the dynamics of thoughts and depression, the correlation between the PSD (of the thought dynamics), and clinical depression measures (BDI-II, RRS: brooding and self-reflection) was calculated in all depressed subjects including both MDD and depressed BD. This yielded significant negative correlations of the thought dynamic's PSD with both BDI-II and RRS-brooding (Table 2; Fig. 5): the less power in internal-external thoughts shift, the higher the degrees of both depressive symptoms (BDI) and brooding rumination (RRI). Specifying the depressive symptoms, we obtained significantly negative correlation of PSD with two specific BDI items, loss of energy and concentration difficulty (Table 2; see also [41]).

Importantly, these correlations only hold for brooding-rumination but were not present for self-reflection ($p > 0.1$) (which, as above, also did not differ significantly between healthy and depressed subjects) (Tables 1, 3). It shall be mentioned that these correlations were obtained only in MDD & BD but not in healthy subjects (see Tables 2, 3). Intriguingly, the healthy subjects showed a slightly positive correlation between PSD and reflection ($p = 0.04$, Table 3): the faster frequency in the thought shift, the more self-reflection.

There were also some differences between MDD and BD: PSD and BDI correlated with brooding only in MDD but not in BD (Table 3). Since all three, power of switching the direction of thoughts (PSD), depression severity (BDI), and level of brooding rumination (RRS) correlated with each other (Fig. 6a), their relationship was further investigated computing partial correlation for each pair controlling for the effect of the third variable, respectively (Fig. 6b). The partial correlation coefficients were calculated to investigate the hypothesis that the severity of depressive symptoms can explain the relationship between PSD and brooding. The result of partial correlation yielded (i) no significant association between PSD and brooding while controlling for the effect of BDI ($p = 0.319$), (ii) a significant association between PSD and BDI while controlling for the effect of brooding ($p < 0.001$), and (iii) no significant association between BDI and brooding while controlling for the effect of PSD ($p = 0.237$) (see Fig. 6b). Altogether these results showed an intrinsic relation of PSD and depressive symptoms which is key in the manifestation of brooding rumination. Specifically, the relation between PSD and brooding is, in part, related to depression severity, as well as the relation between depression severity and brooding is, in part, related to PSD. Hence, one can say that PSD is the missing link between depression severity and brooding.

Discussion

The current study investigated how the internal-external thought contents in MDD and depressed BD individuals, exhibit special changes over time, i.e., thought dynamics. The obtained results indicated that: (i) increased frequency and duration of internally oriented thought contents in both MDD and BD patients (compared to healthy individuals) (ii) decreased frequency and power (i.e., energy); of the shifts between internally and externally oriented thoughts in MDD and BD; (iii) correlation of the power of internal-external thought shifts (i.e., PSD reflecting their energy) with depressive symptoms and rumination (i.e., brooding); (iv) specific findings in MDD (slow frequency) and BD (short duration of externally oriented thoughts). Together, these results demonstrate, for the first time, reduced thought dynamics and how that relates to rumination and depressive symptomatology in MDD and BD. These findings offer a novel understanding

of thought and rumination in depression, which carry major implications for both the clinical diagnosis and therapy of depression in MDD and BD.

From Thought Contents to Thought Dynamics I: Slower Frequency of Internal-External Thought Shifts

The presence and higher level of internally oriented thoughts with an increase of self-focused thoughts are well known in depression [5, 24, 28, 42]. This converges well with our first finding of an increased number of internally oriented thoughts in depressed MDD and BD compared to healthy individuals. Converging with previous findings by Vanhaudenhuyse et al. [26] and Demertzi et al. [37], our healthy subjects show a frequency of 0.06 (±0.03) Hz in their internal-external thought shifts. Most interestingly, the frequency of internal-external thoughts shift was significantly lower in depression, specifically in the MDD group, that is, 0.04 (±0.02) Hz as compared to 0.06 Hz in healthy and BD subjects. This means that internal-external thought shifts occur around every 17 s (as corresponding to 0.06 Hz) in healthy subjects and around 25 s (as corresponding to 0.04 Hz) in depressed MDD – the depressed MDD are much slower in their thought shifts and consecutively spend more time in especially internally oriented thoughts as internally oriented thoughts also showed a longer duration in our results.

The direction of the thought (internal vs. external) is accompanied by differential temporal characterization: shorter duration of externally oriented and longer duration of internally oriented thoughts. Changes in the number and duration of thought contents, in turn, were accompanied by changes in the thought dynamics of internal-external thought shifts. Whether such increased slowness in internal-external thought shift is related to the well-known perception of decreased inner time speed as being too slow [24, 28] remains subject to future investigation.

From Thought Contents to Thought Dynamics II: Decreased Power of Internal-External Thought Shifts

In addition to the frequency, the internal-external thought shift's power was also significantly reduced in depression. Unlike the frequency that was slower only in MDD, the power, i.e., the PSD of internal-external thought shift, was significantly reduced in both MDD and BD. This means that the power or energy of internal-external thought shift is weaker and longer as "powerful" with sharp contrasts of internal-external thought contents as in healthy subjects.

One may also speculate that the reduced power in the internal-external thought shift is related to the often reported lack of mental (and physical) energy of the own thoughts (and body) in depression. We observed a correlation between PSD and depressive symptoms (lack of energy and decreased concentration) in our findings. It remains unclear for now whether such decreased speed of switching between the internal-external thoughts and decreased power, i.e., PSD of internal-external thought shifts measures the energy on a dynamic psychological level of thoughts; this may surface and be manifest in the perception of "lacking mental energy" and "feeling drained" on the subjective level [24, 28]. That remains to be investigated, though.

Neuronally, the shifts of internally and externally oriented thought have been associated with the shift between networks in slow frequency in healthy subjects (approximately 0.02 and 0.09 Hz) [26, 37, 43]. These shifts mainly occur between higher-order networks such as default mode and frontoparietal networks (DMN and FPN, respectively) and lower-order sensory networks such as visual and auditory networks (VN and AN, respectively) [26]. Depressive episodes in MDD and BD [32, 44–46] and, more specifically, brooding rumination [47–50] are characterized by changes in the same networks (DMN, FPN, AN, VN). However, whether the frequency and power of DMN-CEN (default-mode network – central executive network) shifting of their anticorrelation are reduced in MDD/BD and how that is related to their reduced thought dynamics, i.e., frequency and PSD, remains to be investigated in the future. That may reveal whether the dynamics, i.e., frequency and PSD is shared between neuronal (DMN-FPN shifts) and psychological (internal-external thought shifts) level [33, 50] providing their "common currency" [51, 52].

Clinical Implications: Thought Dynamics Is Related to Clinical Symptoms

On a purely psychological level, our results show the importance of thought dynamics for depression symptoms. We observed a significant correlation of thought dynamics (PSD) with both depression symptom severity (BDI) and brooding rumination: the more PSD was decreased, the more symptom severity and increased brooding rumination. That establishes a close relationship of thought dynamics to depression symptoms, including rumination. This suggests the importance of thought dynamics for depressive symptoms, thus pointing to the former's clinical relevance.

Psychopathological symptoms like brooding rumination can be characterized by decreased voluntary or deliberative control over one's own thought combined

with extremely negative emotions. The depressed subject's thoughts are thus "more or less on autopilot," with the subject being unable to exert any control. Our findings suggest that such a lack of voluntary or deliberative control is related to changes in the dynamic of thoughts, that is, decreased power in the shifting between internally and externally oriented thoughts. More generally, our results that increased brooding rumination may, at least in part, be related to changes in the temporal dynamics of thoughts – this entails what recently has been introduced as "Spatiotemporal Psychopathology" [6, 24, 30, 42, 53].

Our findings may open novel opportunities for therapeutic interventions. Psychotherapeutic protocols can be developed based on thought dynamics as a transdiagnostic factor in psychopathology, i.e., rumination-focused cognitive-behavioral therapy [54]. Moreover, our results suggest adding focused attention methods [55, 56] such as mindfulness that focus on shifting the direction of thoughts (internal-external) and it might enhance the power (energy) of shifting and balance the duration of internally oriented thoughts. Modifying the duration and instruction of mindfulness is possibly achievable using the proposed novel approach of thought dynamics. Clinicians can individualize the time of shifting between internally and externally oriented thoughts during mindfulness to enhance its therapeutic efficacy.

Methodological Limitations

The major limitation of this study is recruiting participants which were being actively treated with psychotropic medications. Future investigations can recruit participants undergoing the first episode of their disorders who have not started their medication. Furthermore, the number of occurrence and episodes in MDD and BD patients were not controlled. If further developed in the future, the changes in the dynamics of thoughts (reduced power of internal-external thought shift) may be assumed to drive the manifestation of thought contents, i.e., their duration and number, in brooding rumination.

Given that we investigated the relationship of internally versus externally oriented thoughts, the impact of the context in which the experimental setting took place cannot be neglected. Our investigation took place in a calm quit room, which may have favored tilting the balance of the two types of thoughts towards the internally oriented pole. Therefore, future studies are warranted that compare the impact of different contextual environments on the balance of internally versus externally oriented thoughts.

We show some specific findings in MDD (slower frequency) and BD (longer externally oriented thoughts). However, due to the low case number, these findings must be considered tentative awaiting further confirmation. The slower frequency of thought shift in MDD (compared to both BD and HC) is well in line with other observations of abnormal slowness and decreased energy in MDD on both psychological and neuronal levels [24, 28, 32].

Conclusion

Our findings demonstrate changes in the thought dynamics of MDD and depressed BD. Specifically, we observed a higher number and longer duration of internally oriented thoughts combined with slower frequency and decreased power of internal-external thought shifts. Especially, the decreased power of shifting between the direction of thoughts was closely related to brooding rumination and depression severity with the latter linking power and brooding in yet unclear ways (as per our partial correlation).

Further research building on our study yield insights that carry major clinical implications for diagnosis and therapy of MDD and depressed BD. Our data showed both similarities and differences in thought dynamics of MDD and BD experiencing a high level of depressive symptoms; if further established, this could contribute to differential diagnosis and novel markers for differential diagnosis of MDD and BD depression. Even more important, the changes in the abnormal thought dynamics may facilitate the designing of more individually-tailored psychotherapeutic interventions, to be used to target and stimulate those specific frequencies and/or power ranges related to the respective individual's changed thought dynamics.

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Statement of Ethics

This study was carried out with the approval of the Research Ethics Committee of the University of Ottawa, Institute of Mental Health Research (REB No. 2016004) and in accordance with the World Medical Association Declaration of Helsinki. All aspects of

the experiment were performed according to the relevant guidelines and regulations of the University of Ottawa and its associated research institute. Informed written consent was obtained from all subjects prior to study participation.

Conflict of Interest Statement

There is no conflict of interest from the authors.

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Author Contributions

S.R. and G.N. conceived the idea of the manuscript. All the authors contributed to developing the research design and the investigated variables. S.R. carried out the experiments, time series analysis, and statistical analysis and wrote the manuscript. In particular, A.B. and H.E. supported S.R. in designing the structure of the study, statistical analysis, final approval, and critical revisions. The psychological variables were chosen based on the received guidance from A.B. S.R. was assisted by R.R. in time series analysis, final approval, and coherence of manuscript. G.N. helped S.R. in the conceptualization and designing the experiments and writing the manuscript that, together with A.S., was revised and approved in its last formulation.

Data Availability Statement

All data generated or analyzed during this study are included in this article and its online supplementary material. Further inquiries can be directed to the corresponding author.

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