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Research paper

Constricted semantic relations in acute depression

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ABSTRACT

Background: It has been suggested that mood influences the breadth of associated information available for retrieval, with positive mood broadening and negative mood constricting the scope of associations. In this study, we asked whether this mood-associations connection is related to controlled processes which were linked to clinical symptoms in depression.
Methods: We used the semantic priming paradigm, which allows the dissociation of automatic and controlled processes by using short and long intervals between prime and target words. We further examined whether the strength of semantic relations (weak or strong) influence the priming effects in both neurotypical and depressed individuals.
Results: Experiment 1, testing neurotypical individuals, showed priming effects for strong semantically-related words regardless of interval length, but priming effects for weak semantically-related words were smaller in short intervals than in long intervals. Experiment 2, testing depressed individuals in long intervals, showed smaller priming effects for weak semantically-related words than shown by neurotypicals, but priming effects for strong semantically-related words which were comparable between the groups.
Limitations: This study cannot determine the source for the differences in priming effects between depressed individuals and neurotypicals, and further studies are needed.
Conclusions: This is the first study to show priming impairments in depressed individuals. We discuss our results in light of leading theories concerning cognitive impairment in depression, as well as the newly emerged field of digital psychiatry.

1. Introduction

One of the hallmarks of the psychiatric evaluation concerns thought process and particularly associative thought. For example, ‘loosening of associations’ is a typical descriptive feature of hypomanic and manic states (e.g., Lake, 2008; Sass and Pienkos, 2015). In the case of clinically depressed mood, patients exhibit thought inhibition featuring hypo-associativity and a constricted form of ruminative thought that is repetitive, automatic, and revolves around negative affect (e.g., Andreasen, 1979; Lake, 2008; Nolen-Hoeksema et al., 2008).

Based on such observations and similar experimental findings (e.g., Brunyé et al., 2013; Harel et al., 2016; Mason and Bar, 2012), it has been suggested that mood influences the breadth of associated information available for retrieval, with positive mood broadening whereas negative mood constricting the scope of thought (e.g., Bar, 2009; Fredrickson, 1998). There is ample evidence that mood affects the scope of associations under positive mood, while studies of the scope of associations under negative mood are sparser. For positive mood, it has been shown in both mood induction studies (e.g., Corson, 2002; Isen and Daubman, 1984; Pinheiro et al., 2013; Storbeck and Clore, 2008) and clinical studies of manic states (e.g., Lake, 2008; Santosa et al., 2007; Sass and Pienkos, 2015) that individuals under positive mood had richer, more remote, and more original associations, even for non-emotional stimuli. For example, participants induced with positive mood rated rare exemplars as more likely to be members of a given category, compared with participants that were in neutral mood (e.g., *elevator*, *camel* and *feet*

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as members of the category *vehicle*; Isen and Daubman, 1984). For negative mood, studies of mood induction showed that it restricted the breath of associations compared with neutral mood (e.g., Bolte et al., 2003; Pinheiro et al., 2013; Storbeck and Clore, 2008; although see Isen and Daubman, 1984; Corson, 2002 for null results). Furthermore, people with acute depression exhibit constricted thought and poverty of association. For example, they produced fewer words in semantic and phonemic fluency tasks (where they were asked to generate as many words as possible in a given time based on either a semantic category cue or a phoneme cue; Henry and Crawford, 2005).

The current study adopts a framework, suggested by many cognitive accounts of depression, which distinguishes between automatic and controlled processes (Beevers, 2005; Hammar, 2003; Hammar et al., 2003; Hartlage et al., 1993; Hasher and Zacks, 1979). Automatic processes occur rapidly, without attention, awareness or intention (e.g., Posner and Snyder, 1975; Schneider and Shiffrin, 1977), and are assumed to be task independent. On the other hand, controlled processes are more effortful, require attention, and are influenced by cognitive capacity and context or task (e.g., Hasher and Zacks, 1979; Posner and Snyder, 1975; Schneider and Shiffrin, 1977). With regard to depression, several studies have linked the clinical symptoms to impairments in controlled processes or in the integration of information from both components (Beevers, 2005; Hammar et al., 2003; Hartlage et al., 1993; Jermann et al., 2005 see Den Hartog et al., 2003 for contradicting empirical results). However, the jury is still out on this question.

One way to address this question is to take a psycholinguistic approach to examine the link between mood and word associations. The semantic priming paradigm allows us to tease apart automatic and controlled processes for word associations in the semantic memory. In the priming paradigm, a target word that follows a related prime word (e.g., "lion" after "tiger") is recognized faster than a target word that follows an unrelated prime word (e.g., "lion" after "doctor"). Such priming effect implies the activation of words that are associated with or semantically-related to the prime word.

Dissociations between automatic and controlled processes in this paradigm are achieved by changing the time interval between the onset of the prime word and the onset of the target word (i.e., stimulus onset asynchrony, or SOA) (e.g., Neely, 1977). Short SOAs, where the target rapidly appears after the prime, are assumed to be governed by automatic processes. The short timing allows only for the spreading of activation through the semantic network, from a given word to its strongly semantically-related words. That is, automatic access to a certain target knowledge follows a *strongly* associated cue that makes that knowledge accessible. Long SOAs, where the target appears long after the prime disappeared, are connected to controlled processes. The long timing permits the full processing of the prime word, and thus the formation of expectations for more remote concepts and words within the context of the task. That is, controlled access to a certain knowledge depends on the generation of expectations for possible concepts within a context, and the inhibition of impossible concepts.

A terminology note is required at this point. The use the term "word association" in the psychiatric and clinical literature lumps together both semantic and associative relations. Semantic relations reflect the degree of meaning similarity (e.g., the words "lion" and "tiger" are highly related because they share several semantic features). Associative relations usually refer to the degree of co-occurrence between the prime and target, and can occur without semantic similarity (e.g., the words "lip" and "stick"). There is an obvious overlap between semantic and associative relations (e.g., "lion" and "tiger" are also associated).

Previous research manipulated the strength of semantic-relatedness (defined based on meaning similarity), and observed relations between the length of the SOA and the strength of the semantic relations between the prime and target in their modulation of the priming effect. Specifically, word pairs with strong semantic-relatedness (e.g., "lion" and "tiger") showed priming effects in both short and long SOAs, whereas words with weak semantic-relatedness (e.g., "lion" and "robin") showed priming effects only in longer SOAs (e.g., McRae and Boisvert, 1998). This emphasize the idea that under controlled processes (when the prime is fully processed), distant concept can be brought together, and broader associations can be formed. Based on this finding, we focused on semantic (rather than on associative) relations, utilizing the timing effects, to ask whether controlled processes were impaired in depression, and thus, might underlie the constricted thought characterizing this disorder.

Only a few semantic priming studies were performed with depressed individuals (Besche-Richard et al., 2002; Dannlowski et al., 2006; Georgieff et al., 1998). Despite using different SOAs and different experimental tasks, all of these studies found that depressed individuals had priming effects similar to those observed in neurotypicals. Thus, these studies suggest no impairment in semantic priming in depression. Furthermore, some of these studies (Besche-Richard et al., 2002; Georgieff et al., 1998) used long SOAs when showing priming effects in depressed individuals. Thus, their results do not support the assumption that controlled processes are impaired in depression.

Nonetheless, these studies did not control for the strength of the semantic (or associative) relations between the prime and the target. As we point out above, strong semantic relations can be formed by automatic processes, but weak semantic relations are assumed to be formed only under controlled processes. If so, it is possible to find similar priming effects in depressed individuals and neurotypicals with strongly-related word pairs. However, we expect a reduced priming effect for weakly-related word pairs for depressed individuals compared with neurotypicals. Such findings would reveal an impairment in controlled processes underlying lexical semantics in depression, and could indicate that this is the basis for their observed constricted associative thought. In the current exploratory study, we first verified that the strength of semantic relations influenced the priming effect in neurotypicals (Experiment 1), replicating previous results (McRae and Boisvert, 1998). Once we established that the priming effect was indeed modulated under these conditions, we examined the same stimuli set in a long SOA, in a group of individuals with mild to moderate depression (Experiment 2).

2. Experiment 1: priming effects depend on association strength in neurotypicals

The aim of this experiment was to verify that differences in the strength of semantic relations influenced priming effects in neurotypicals under different SOA conditions. To this end, we created a stimulus set that included word pairs that were either strongly- or weakly-related semantically, as well as unrelated word pairs, as defined by a measurement from WordNet (a database that organizes words based on their meanings, and outlines the informational distance between them; Maki et al., 2004).

2.1. Methods

2.1.1. Participants

61 participants were recruited from a pool of the Harvard Decision Science Laboratory. Nine participants were removed from analysis: two failed to recognize the briefly presented target in the practice and seven had accuracy rates of less than 80%, which indicated poor attention to the task. Thus, a total of 52 participants were included in the final analysis. Demographic data is given in Table 3. All subjects were right handed and native English speakers. Participants were excluded if they reported any Axis 1 psychiatric disorder, any neurological disorder, or taking any psychotropic medication. To specifically test for depression, the participants also completed the Quick Inventory of Depressive Symptoms - Self-Rated (QIDS-SR) questionnaire (Rush et al., 2003). Based on this questionnaire, no one in the group had depression at the time of testing. The participants were randomly assigned to one of the two SOA groups, with 27 participants in the short SOA group and 25 in

the long SOA group. The protocol was approved by the research ethics committee of Massachusetts General Hospital. Written informed consent was obtained from all the participants.

2.1.2. Materials

Word pairs were constructed based on JCN measure (Jiang and Conrath, 1997) from the Wordnet database (Maki et al., 2004), which indicates the semantic distance between words. The 100 strong semantically-related word pairs were chosen from the highest 5th percentile of the JCN measure and the 100 weak semantically-related word pairs were chosen from the lowest 5th percentile of the JCN measure (Table 1). We also controlled for the associative strength of the word pairs by using the forward associative strength (FAS) and the backward associative strength (BAS) from the USF norms (Nelson et al., 2004; Table 1). Of this initial set of word pairs, a Matlab script randomly selected 40 words per experimental condition (i.e., strong and weak relatedness). Additionally, the script randomly created 40 unrelated word pairs to be included as a baseline to determine the priming effect. To construct this condition, the script randomly assigned a target word with a prime word from the initial set (for word pairs that were not selected for the experimental conditions). Finally, the remaining 80 word pairs in the initial set were used for non-words fillers, needed to elicit "no" responses in the lexical decision task. Non-words were created by replacing 2 consonant letters in target words, while keeping the form of the word. These were randomly assigned to the remaining non-used primes. That is, each list included 200 word pairs: 40 strongly-related pairs, 40 weakly-related pairs, 40 unrelated pairs and 80 pairs with non-word targets. The pairs in each condition (and each list) were also controlled for associative strength. Note that each participant saw different pairs in each condition, allowing for better generalization.

2.1.3. Procedure

Participants were instructed to indicate, as fast and as accurately as possible, whether the second word in a sequence of two words was a word or not by pressing one of two buttons ('1' for word or '2' for non-word). First, participants performed 24 practice trials, with pairs similar to the ones used in the experiment. Then, they performed 2 experimental runs of 100 word pairs each, with a brief break between each run. Data from both runs was included in the analysis. Psychtoolbox was used to implement the task.

Each trial started with a fixation cross presented for 500 ms on 20″ monitors with a resolution of 1680 × 1050 and refresh rates of 60HZ. Then, the prime appeared for 83 ms followed by a 100 ms of a mask for the short SOA group and 500 ms of a mask for the long SOA group (see Fig. 1). In the next step, a 10 ms blank screen was presented followed by the target word or non-word which was presented for 140 ms. Finally, a mask was presented for 280 ms. The prime, fixation cross and masks were presented in black, whereas the target was presented in a light grey color. Timing and colors were selected based on pilot studies to ensure priming effects.

Table 1
Word pair features of the stimuli set[a].

	FAS	BAS	Prime frequency	Target frequency	JCN
Strong semantically-related	0.082 (0.10)	0.05 (0.13)	10.44 (14.15)	39.56 (55.76)	2.70 (0.96)
Weak semantically-related	0.080 (0.12)	0.04 (0.11)	13.72 (22.4)	28.22 (70.85)	20.06 (3.34)
	$p =$ 0.657	$p =$ 0.562	$p = 0.165$	$p = 0.216$	$p <$ 0.002

[a] The table shows mean values (and SD values are given in parenthesis).

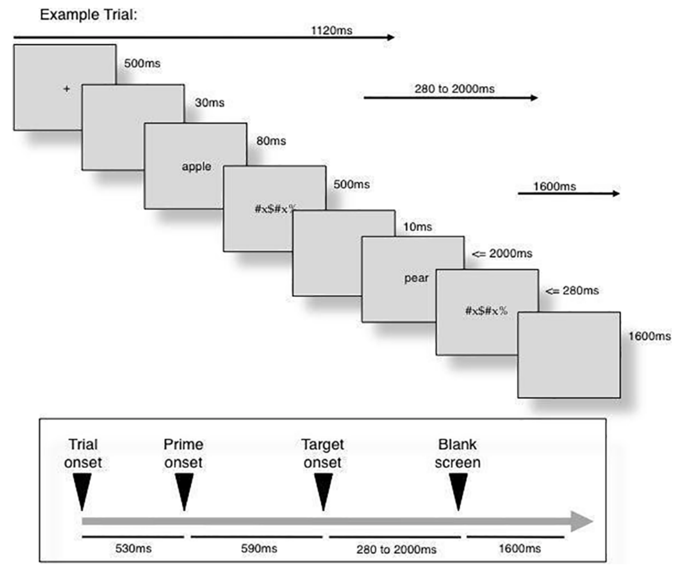

Fig. 1. Illustration of one trial in the long SOA condition. In the short SOA condition, the mask appeared for 100 ms.

2.2. Results and discussion

Our analysis was performed in two steps. We first verified priming effects in each group by comparing the reaction times (RT) in the unrelated words condition to the RT in each of the semantically-related words conditions. Then, we perform the main analysis testing the effects SOA lengths and the strength of the semantic relations. In this main analysis, we used the priming effect (i.e., RT for weak/strong relation condition − RT for unrelated condition) as the dependent variable (following Hesse and Spies, 1996; Moritz et al., 2001). This was done because the RT in the unrelated condition in the short and long SOA were expected to differ based on previous findings (e.g., Peel et al., 2021).[1]

2.2.1. Testing for priming effects

For our analysis, we excluded RT from incorrect trials, as well as RT outliers (+/− 3 standard deviations from the mean RT of each participant), resulting in exclusion of approximately 4.4% of all trials. Using paired *t*-tests, we compared each semantically-related condition to the unrelated condition in each group, adjusting for multiple comparisons. In all instances, RTs were faster for the related conditions compared with the unrelated condition ($p < 0.01$; Table 2). This verifies the semantic priming effect.

2.2.2. Testing for SOA and semantic relatedness effects

We conducted a mixed-effect ANOVA with SOA length as a between-subject factor (short, long) and semantic-relatedness as a within-subject factor (strong, weak). Our dependent variable was the priming effect, calculated by subtracting the RT of each semantic condition from the RT of the unrelated condition in each group. This analysis revealed a significant main effect of semantic relatedness ($F_{(1,50)} = 11.296$; $p < 0.001$) and a significant interaction ($F_{(1,50)} = 6.587$; $p = 0.013$; Fig. 2), with no main effect of SOA length ($F_{(1,50)} = 0.587$; $p = 0.447$). Follow-up pair-wise comparisons showed that priming for strong semantically-related pairs did not differ between the two SOA groups ($t_{(50)} = 0.312$; $p = 0.755$). However, the priming for the weak semantically-related pairs was stronger in the long SOA group than in the short SOA group ($t_{(50)} = 1.738$; $p = 0.044$). Furthermore, within the short SOA, strong

[1] This was also statistically verified in our data, comparing the RTs in the unrelated condition between short and long SOAs ($t(50) = 2.604$, $p = 0.006$).

Table 2
Reaction times (RT) in neurotypicals (NT) in Experiment 1 and depressed individuals (Dep) in Experiment 2, comparisons to the unrelated conditions are reported[a].

SOA	Short SOA NT		Long SOA NT		Dep	
Unrelated word pairs	706.725 (121.92)		796.484 (126.52)		806.374 (151.42)	
Strong semantically-related	661.478 (111.29)	$t(26) = 6.34; p < 0.001$	754.481 (118.9)	$t(24) = 5.57; p < 0.001$	753.23 (133.9)	$t(20) = 4.87; p < 0.001$
Weak semantically-related	685.650 (117.29)	$t(26) = 2.99; p = 0.023$	757.721 (117.92)	$t(24) = 5.26; p < 0.001$	784.213 (152.34)	$t(20) = 3.21; p = 0.008$

[a] The table shows mean values (and SD values are given in parenthesis).

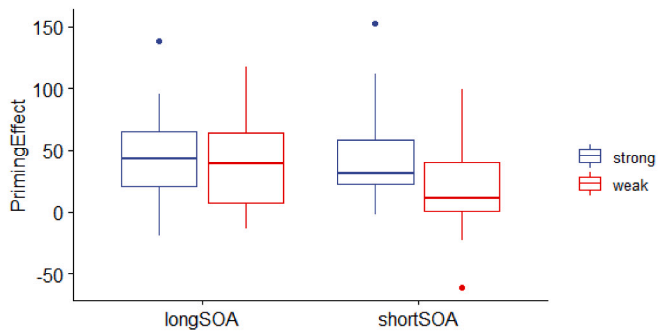

Fig. 2. Results for the neurotypicals in Experiment 1, comparing short and long SOAs.

semantically-related pairs produced a stronger priming effect than the weak semantically-related pairs ($t_{(26)} = 2.413; p < 0.001$). However, no difference was found between the two semantic relation conditions in the long SOA ($t_{(24)} = 0.546; p = 0.589$).

These results confirm the assumption that controlled processes (governing the long SOA) permit semantic links between words placed farther away in the semantic network. That is, when a word is fully processed it can be connected with another word that is only weakly related to it. Such loose or weak semantic links do not occur in short SOAs, which only allow for shallow processing of the word. That is, when automatic processes of spreading of activation occur, only strong relations between words can be formed.

3. Experiment 2: priming effects in people with depression

This experiment tested the hypothesis that controlled processes are impaired in depression, contributing to the constricted associations under negative mood. We tested people with a mild to moderate depressive episode under long SOA. We focused on this SOA because controlled processes allow for the formation of weaker semantic relations between words, as shown in Experiment 1. If indeed controlled processes are impaired in depression, we expect participants with depression to show reduced priming effects for the weak semantically-related pairs.

3.1. Methods

3.1.1. Participants

21 participants suffering from mild to moderate depressive episode were recruited for the study. Sample size was determined based on previous studies of lexical decision in the priming paradigm in depression (Besche-Richard et al., 2002; Georgieff et al., 1998). Depressed subjects were recruited through the Depression Outpatient Clinic (DCRP) of Massachusetts General Hospital and through an ad in the volunteer section of Craigslist. All of the subjects went through a phone screening procedure, as well as a full psychiatric assessment with the Structured Clinical Interview for DSM IV (SCID) by a trained psychiatrist (EVH). All of the depressed participants met the criteria for a DSM-IV diagnosis of Major Depressive Disorder (MDD). Depressed individuals with psychotic features or under psychotropic medications at the time of the study and 4 weeks prior, or depressed individuals who met criteria for a current co-morbid diagnosis of any Axis I disorder, other than social anxiety disorder, were not included in the study. Additionally, none had drug or alcohol abuse in the year prior to the experiment. Participants also performed the Hamilton Rating Scale of Depression (HRSD), a 17-item scale for the severity of depressive symptoms, as well as the QIDS-SR. Demographic data for the participants is given in Table 3. Three additional participants were excluded from the analysis for poor performance. The protocol was approved by the research ethics committee of Massachusetts General Hospital. Written informed consent was obtained from all the participants.

3.1.2. Materials and procedure

The same materials and procedure as in Experiment 1 were. Only the long SOA was used.

3.2. Results

Like in the analysis of the neurotypicals in Experiment 1, we first verified priming effects in the depressed group, by comparing RTs in each semantic-related condition to RT in the unrelated condition. This showed priming effects for both conditions ($p < 0.008$; Table 2).

For the main analysis, we included the long SOA group of NTs from Experiment 1 as a control group. We performed a mixed effect ANOVA with group as a between-subject factor (depressed, NT) and semantic-relatedness as a within-subject factor (strong, weak). As in Experiment 1, our dependent variable was the priming effect (i.e., RT for weak/strong relation condition – RT for unrelated condition). This analysis revealed a main effect of semantic-relatedness ($F_{(1,44)} = 11.615; p = 0.001$), and an interaction ($F_{(1,44)} = 7.588; p = 0.009$; Fig. 3), but no main effect for group ($F_{(1,44)} = 0.096; p = 0.758$). Follow-up pairwise comparisons showed that depressed participants had a smaller priming effect for the weak semantically-related pairs than for the strong semantically-related pairs ($t_{(20)} = 3.722; p < 0.001$). Furthermore, there was no significant difference between the depressed and the NTs in the strong semantically-related pairs ($t_{(44)} = 0.792; p = 0.43$), but in the weak semantically-related pairs, NTs showed larger priming effect than the depressed participants ($t_{(44)} = 1.686; p = 0.049$).

4. General discussion

The aim of the present exploratory study was to assess whether controlled processes are impaired in individuals with mild to moderate depression, taking a psycholinguistic approach of testing semantic connections between words. Our main finding is the reduced priming effects for weak semantically-related words in long SOAs in depressed individuals compared with neurotypical controls. This finding supported our hypothesis according to which constricted semantic relations will be observed under conditions that involve controlled processes (i.e.,

Table 3
Demographic and clinical data for the participants.

	Depressed subjects	Healthy controls	
Age [years (SD)]	39 (12.9)	36.1 (16.6)	$p = 0.44$
Sex (M/F)	10/11	15/10	
Education [years (SD)]	14.1 (1.8)	14.8 (2)	$p = 0.14$
QIDS score (SD)	18.8(4.9)	5.18 (4.34)	
HRSD (SD)	17.2 (4.9)		

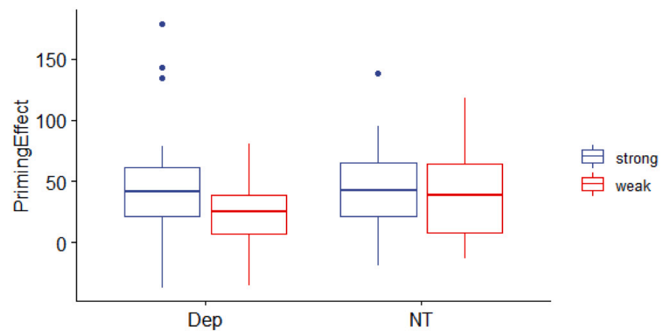

Fig. 3. Results for the comparison between neurotypicals (NT) and Depressed individuals (Dep) in long SOA. Data for the NT group is taken from Experiment 1.

long SOAs).

4.1. Findings in neurotypicals

Experiment 1 served as baseline, testing neurotypical controls in both short SOAs, governed by automatic processes, and long SOAs, governed by controlled processes. Priming effects for the strong semantically-related words were similar in both SOAs. In contrast, reduced priming effects for the weak semantically-related words were observed in the short SOA compared with the long SOA. This finding indicates that the formation of connections within the semantic network of word pairs that were located remotely of each other were enabled under long SOAs. This is in line with previous findings that show priming effects in long SOAs, but not in short SOAs, for word pairs with a low degree of semantic feature similarity (e.g., McRae and Boisvert, 1998). Priming effects under long SOAs have been observed when words had associative relations, controlled for semantic relations (Thompson-Schill et al., 1998; note that previous research examining the role of associative strength using FAS database might show other descriptive pattern of results, however semantic relations were not controlled in that study, Hutchison et al., 2013). Our results show the reverse pattern as well, with an observed priming effect for semantic relations, controlled for the strengths of associative relations. All in all, our results indicate that the broadening effect observed under long SOAs is not specific to associative relations.

Our results suggest that controlled processes, which govern long SOAs, support weak semantic relations. Confirming our initial assumption that controlled processes motivate broadening of semantic relations, we could examine whether the same applies to depressed individuals (Experiment 2) who are assumed to have impaired controlled processes (Beevers, 2005; Hammar, 2003; Hartlage et al., 1993; Jermann et al., 2005).

4.2. Findings in patients with depression

Experiment 2 was the main experiment in this study, focusing on semantic-relatedness effects in depression. It showed that depressed individuals and neurotypicals had similar priming effects for strong semantically-related word pairs in the long SOA. In contrast, the groups differed when testing the weak semantically-related words: the depressed individuals show reduced priming effects for these word pairs (compared with strong semantically-related words), whereas neurotypicals did not. Under the assumption mentioned above, that long SOAs allows for broadening effects in the semantic network, this finding suggests that the activations in the semantic network of individuals with depression are more constricted than those of neurotypicals.

Our results entail several observations. First and foremost, we showed similar priming effects in the two groups in one of our conditions. This suggests that the connections in the semantic network of depressed individuals are not overall weak. Second, considering the type of relations that did not differ between the two groups, the strong semantically-related words, it is reasonable that individuals with depression were able to link these words through the spreading of activation in the semantic network. That is, the typical priming effect for strong semantic relations suggests that the automated processes are intact in individuals with depression. Finally, considering the type of relations that did show a different priming effect in the two groups, weakly-related word pairs, it is reasonable to assume that depressed individuals had difficulties in generating expectations based on the task in order to create more distant connections within the semantic network. That is, the smaller priming effect for weak semantic relations in depressed individuals suggests that their controlled processes are impaired. These findings are in line with the assumption that depression interferes with controlled processes, but not with automatic processes.

Interestingly, previous studies failed to show priming differences between depressed individuals and neurotypicals. Dannlowski et al. (2006) targeted automatic processes by using short SOAs and a pronunciation task, a task which does not require making any explicit decision (i.e., participants are asked to read the target word). Under the assumption that automatic processes are minimally impaired in individuals with depression (e.g., Hammar, 2003; Hartlage et al., 1993; Jermann et al., 2005), no differences in priming effects between them and neurotypicals are to be expected in these conditions. Hence, the results from that study are consistent with our findings.

The other two studies that tested priming in depression (Besche-Richard et al., 2002; Georgieff et al., 1998) used long SOAs, with the conventional lexical decision task (as used in the current study). These studies showed similar priming effects for depressed individuals and neurotypical controls, unlike our results. Note that these studies did not quantify the strength of relations between the word pairs they tested. It is possible that they used strongly-related word pairs. This could have prompted the spreading of activation in the semantic network (i.e., automatic processes), rather than the activation of controlled processes. In fact, we assume, based on the criteria reported in those studies, that the relations between the words in each pair were relatively strong. Under such conditions, we expect no differences between the groups. Additionally, these studies did not control for other factors in their pair selection, such as associative strength. If the words selected for those studies were highly associated, this could also have promoted stronger relations between words (e.g., Thompson-Schill et al., 1998), and thus contribute to the lack of differences between the depressed individuals and neurotypicals.

Our exploratory study provides critical evidence, not demonstrated by previous studies, that controlled processes in word associations are impaired in depressed individuals. This finding provides a starting point for our understanding of the source of constricted associations and the ruminative thought pattern seen in depression. The ability to generate weak connections between words is established in neurotypicals by controlled processes, as shown in Experiment 1. This ability is reduced in depressed individuals due to impaired controlled processes.

Yet, our study cannot determine the source for the observed differences in priming effects. Future studies should unpack the impaired components underlying the constricted word associations in depression. One possibility is that controlled access to semantic memory, as examined here, involves cognitive control. This component is assumed to be one of the most pronounced neuropsychologically-impaired function in depression (e.g., Disner et al., 2011; Gotlib and Joormann, 2010; Millan et al., 2012). Cognitive control is assumed to include multiple goal-directed functions that facilitate and constrain our processing of information and behavior (Friedman and Miyake, 2017; Shenhav et al., 2013; Ridderinkhof et al., 2004). This includes updating of information in working memory or inhibition of inappropriate information or responses. To allow the formation of weak and remote connections between words, one has to process inconspicuous aspects of the prime's meaning and to use top-down processing in order to enable the activation of weakly associated concepts or words.

Although we designed our experiment to focus on impaired controlled processes in depressed individuals (by using long SOA in the priming paradigm), the literature on depression also shows motivational deficits (e.g., Pizzagalli et al., 2008; Zald and Treadway, 2017). One could argue that our findings that depressed individuals showed reduced priming effects are the result of their lack of motivation to succeed in this task. Yet, keep in mind that differences between neurotypicals and depressed individuals were observed only in the more demanding weakly-related pairs condition. That is, our results support a distinction between automatic and effortful (controlled) processes also under a motivational explanation.[2]

In our exploratory study, we tested depressed individuals only in long SOAs, because this is where we hypothesized that they would show distinct pattern compared with NT. For a full picture of semantic priming effects in depressed individuals, a study where these effects are tested in short SOAs is needed. Yet, as noted, our main interest was to test whether facilitation occurred for weak semantic relations in depression. Because reduced facilitation for weak semantic relations was observed in neurotypicals in the short SOA, we did not include such group in Experiment 2.

Furthermore, the depressed individuals in our study suffered from mild to moderate major depressive disorder, as indicated by their HRSD scores. Even in this mild to moderate condition, we have seen reduced priming effects for weakly-related word pairs. Previous studies of priming in depression tested individuals who were diagnosed with major depression (e.g., Besche-Richard et al., 2002; Dannlowski et al., 2006; Georgieff et al., 1998) and show no differences in priming effects compared with NT. We assume that the difference between the studies is in the type of stimuli used (i.e., the addition of weakly-related word pairs in long SOA), rather than the intensity of depression, because it is likely that higher intensity of depression will induce greater impairment. However, future research, using the same conditions as in the current study, is needed.

4.3. Conclusion

We would like to make a final note regarding our procedure for selecting the experimental stimuli. We used WordNet (Maki et al., 2004), a large database of English words which uses quantitative measures to create semantic networks. Using this database allowed us to make objective selection of word pairs, and divide them into coherent groups of strong and weak relations, controlled for associative strength. Objective and quantitative measures are critical for developing tools for digital psychiatry, which can be used to augment and extend the abilities of healthcare professionals in diagnosing and assessing mental states. With the growth of this field, the search for objective measures that capture behavioral and cognitive processes is a major effort for researchers. Still, psycholinguistic research in psychopathology is limited, and focuses mostly on text analysis in social media (e.g., Trifan et al., 2020). The priming effect tested in this study may be more sensitive than observation in detecting thought process abnormalities in depressed individuals. Incorporating this knowledge with lexical analysis of social media communication can aid in automatic detection of deterioration or improvement. Future studies of priming effects in depression should therefore examine changes in individuals longitudinally.

To conclude, our study is the first to show reduced semantic priming effects in depressed individuals, by examining weakly-related word pairs. We show this effect in long SOAs governed by controlled processes, thus lending support to theories that argue that depression is characterized by impaired controlled, and not automatic, processes. The availability of rich associations is critical for associative processing and for thought progression. Reduced associative processing might underlie ruminative thought as suggested by Bar (2009). Cognitive interventions that will promote associative thinking can potentially reduce ruminative thought and serve as therapeutic modalities for depression.

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The funders had no role in the study.

CRediT authorship contribution statement

EVH: Conceptualization, Methodology, Data analysis, Writing; **ES**: Data analysis, Writing; **RT**: Project administration, Data analysis; **MF**: Conceptualization, Recruitment; **MB**: Conceptualization, Methodology, Writing, Funding acquisition.

Declaration of competing interest

The authors do not have any conflicts of interest or financial disclosures.

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References

Andreasen, N.C., 1979. Thought, language, and communication disorders: I. Clinical assessment, definition of terms, and evaluation of their reliability. Arch. Gen. Psychiatry 36, 1315–1321.
Bar, M., 2009. A cognitive neuroscience hypothesis of mood and depression. Trends Cogn. Sci. 13 (11), 456–463.
Beevers, C.G., 2005. Cognitive vulnerability to depression: a dual process model. Clin. Psychol. Rev. 25 (7), 975–1002.
Besche-Richard, C., Passerieux, C., Hardy-Baylé, M.C., 2002. Lexical decision tasks in depressive patients: semantic priming before and after clinical improvement. Eur. Psychiatry 17 (2), 69–74.
Bolte, A., Goschke, T., Kuhl, J., 2003. Emotion and intuition: effects of positive and negative mood on implicit judgments of semantic coherence. Psychol. Sci. 14 (5), 416–421.
Brunyé, T.T., Gagnon, S.A., Paczynski, M., Shenhav, A., Mahoney, C.R., Taylor, H.A., 2013. Happiness by association: breadth of free association influences affective states. Cognition 127 (1), 93–98.
Corson, Y., 2002. Effects of positive, negative, and neutral moods on associative and semantic priming. Curr. Psychol. Cogn. 21 (1), 33–62.
Crocker, L.D., Heller, W., Warren, S.L., O'Hare, A.J., Infantolino, Z.P., Miller, G.A., 2013. Relationships among cognition, emotion, and motivation: implications for intervention and neuroplasticity in psychopathology. Front. Hum. Neurosci. 7, 261.
Dannlowski, U., Kersting, A., Arolt, V., Lalee-Mentzel, J., Donges, U.S., Suslow, T., 2006. Unimpaired automatic processing of verbal information in the course of clinical depression. Depress. Anxiety 23 (6), 325–330.
Den Hartog, H.M., Derix, M.M.A., Van Bemmel, A.L., Kremer, B., Jolles, J., 2003. Cognitive functioning in young and middle-aged unmedicated out-patients with major depression: testing the effort and cognitive speed hypotheses. Psychol. Med. 33 (8), 1443–1451.
Disner, S.G., Beevers, C.G., Haigh, E.A., Beck, A.T., 2011. Neural mechanisms of the cognitive model of depression. Nat. Rev. Neurosci. 12 (8), 467–477.
Fredrickson, B.L., 1998. What good are positive emotions? Rev. Gen. Psychol. 2 (3), 300–319.
Friedman, N.P., Miyake, A., 2017. Unity and diversity of executive functions: individual differences as a window on cognitive structure. Cortex 86, 186–204.
Georgieff, N., Ford Dominey, P., Michel, F., Marie-cardine, M., Dalery, J., 1998. Semantic priming in major depressive state. Psychiatry Res. 78 (1), 29–44.
Gotlib, I.H., Joormann, J., 2010. Cognition and depression: current status and future directions. Annu. Rev. Clin. Psychol. 6, 285–312.
Grahek, I., Shenhav, A., Musslick, S., Krebs, R.M., Koster, E.H., 2019. Motivation and cognitive control in depression. Neurosci. Biobehav. Rev. 102, 371–381.
Hammar, Å., 2003. Automatic and effortful information processing in unipolar major depression. Scand. J. Psychol. 44 (5), 409–413.

[2] Also note that previous research suggests a link between motivation and executive functions. Specifically, motivational processes are guided by goals selected by executive functions (Spielberg et al., 2012). On the other hand, motivational signals play a role in directing attention to certain goals (e.g., Pochon et al., 2002; Savine et al., 2010). An interaction between motivation and cognitive control was also suggested in relation to depression (Crocker et al., 2013; Grahek et al., 2019).

Hammar, Å., Lund, A., Hugdahl, K., 2003. Selective impairment in effortful information processing in major depression. J. Int. Neuropsychol. Soc. 9 (6), 954–959.
Harel, E.V., Tennyson, R.L., Fava, M., Bar, M., 2016. Linking major depression and the neural substrates of associative processing. Cogn. Affect. Behav. Neurosci. 16 (6), 1017–1026.
Hartlage, S., Alloy, L.B., Vázquez, C., Dykman, B., 1993. Automatic and effortful processing in depression. Psychol. Bull. 113 (2), 247–278.
Hasher, L., Zacks, R.T., 1979. Automatic and effortful processes in memory. J. Exp. Psychol. Gen. 108 (3), 356–388.
Henry, J.D., Crawford, J.R., 2005. A meta-analytic review of verbal fluency deficits in depression. J. Clin. Exp. Neuropsychol. 27 (1), 78–101.
Hesse, F.W., Spies, K., 1996. Effects of negative mood on performance: reduced capacity or changed processing strategy? Eur. J. Soc. Psychol. 26 (1), 163–168.
Hutchison, K.A., Balota, D.A., Neely, J.H., Cortese, M.J., Cohen-Shikora, E.R., Tse, C.S., Buchanan, E., 2013. The semantic priming project. Behav. Res. Methods 45 (4), 1099–1114.
Isen, A.M., Daubman, K.A., 1984. The influence of affect on categorization. J. Pers. Soc. Psychol. 47 (6), 1206.
Jermann, F., Van der Linden, M., Adam, S., Ceschi, G., Perroud, A., 2005. Controlled and automatic uses of memory in depressed patients: effect of retention interval lengths. Behav. Res. Ther. 43 (5), 681–690.
Jiang, J.J., Conrath, D.W., 1997. Semantic Similarity Based on Corpus Statistics and Lexical Taxonomy. arXiv preprint cmp-lg/9709008.
Lake, C.R., 2008. Disorders of thought are severe mood disorders: the selective attention defect in mania challenges the kraepelinian dichotomy–a review. Schizophr. Bull. 34 (1), 109–117.
Maki, W.S., McKinley, L.N., Thompson, A.G., 2004. Semantic distance norms computed from an electronic dictionary (WordNet). Behav. Res. Methods Instrum. Comput. 36 (3), 421–431.
Mason, M.F., Bar, M., 2012. The effect of mental progression on mood. J. Exp. Psychol. Gen. 141 (2), 217–221.
McRae, K., Boisvert, S., 1998. Automatic semantic similarity priming. J. Exp. Psychol. Learn. Mem. Cogn. 24 (3), 558–572.
Millan, M.J., Agid, Y., Brüne, M., Bullmore, E.T., Carter, C.S., Clayton, N.S., Young, L.J., 2012. Cognitive dysfunction in psychiatric disorders: characteristics, causes and the quest for improved therapy. Nat. Rev. Drug Discov. 11 (2), 141–168.
Moritz, S., Mersmann, K., Kloss, M., Jacobsen, D., Wilke, U., Andresen, B., Pawlik, K., 2001. 'Hyper-priming'in thought-disordered schizophrenic patients. Psychol. Med. 31 (2), 221–229.
Neely, J.H., 1977. Semantic priming and retrieval from lexical memory: roles of inhibitionless spreading activation and limited-capacity attention. J. Exp. Psychol. Gen. 106 (3), 226–254.
Nelson, D.L., McEvoy, C.L., Schreiber, T.A., 2004. The University of South Florida free association, rhyme, and word fragment norms. Behav. Res. Methods Instrum. Comput. 36 (3), 402–407.
Nolen-Hoeksema, S., Wisco, B.E., Lyubomirsky, S., 2008. Rethinking rumination. Perspect. Psychol. Sci. 3 (5), 400–424.
Peel, H.J., Royals, K.A., Chouinard, P.A., 2021. The effects of word identity, case, and SOA on word priming in a subliminal context. J. Psycholinguist. Res. 51, 1–15.
Pinheiro, A.P., del Re, E., Nestor, P.G., McCarley, R.W., Gonçalves, O.F., Niznikiewicz, M., 2013. Interactions between mood and the structure of semantic memory: event-related potentials evidence. Soc. Cogn. Affect. Neurosci. 8 (5), 579–594.
Pizzagalli, D.A., Iosifescu, D., Hallett, L.A., Ratner, K.G., Fava, M., 2008. Reduced hedonic capacity in major depressive disorder: evidence from a probabilistic reward task. J. Psychiatr. Res. 43 (1), 76–87.
Pochon, J.B., Levy, R., Fossati, P., Lehericy, S., Poline, J.B., Pillon, B., Dubois, B., 2002. The neural system that bridges reward and cognition in humans: an fMRI study. Proc. Natl. Acad. Sci. 99 (8), 5669–5674.
Posner, M.I., Snyder, C.R.R., 1975. Attention and cognitive control. In: Solso, R.L. (Ed.), Information Processing and Cognition: The Loyola Symposium. Erlbaum, Mahwah, NJ, pp. 55–85.
Ridderinkhof, K.R., Ullsperger, M., Crone, E.A., Nieuwenhuis, 2004. The role of the medial frontal cortex in cognitive control. Science 306 (5695), 443–447.
Rush, A.J., Trivedi, M.H., Ibrahim, H.M., Carmody, T.J., Arnow, B., Klein, D.N., Keller, M.B., 2003. The 16-item quick inventory of depressive symptomatology (QIDS), clinician rating (QIDS-C), and self-report (QIDS-SR): a psychometric evaluation in patients with chronic major depression. Biol. Psychiatry 54 (5), 573–583.
Santosa, C.M., Strong, C.M., Nowakowska, C., Wang, P.W., Rennicke, C.M., Ketter, T.A., 2007. Enhanced creativity in bipolar disorder patients: a controlled study. J. Affect. Disord. 100 (1–3), 31–39.
Sass, L., Pienkos, E., 2015. Beyond words: linguistic experience in melancholia, mania, and schizophrenia. Phenomenol. Cogn. Sci. 14, 475–495.
Savine, A.C., Beck, S.M., Edwards, B.G., Chiew, K.S., Braver, T.S., 2010. Enhancement of cognitive control by approach and avoidance motivational states. Cognit. Emot. 24 (2), 338–356.
Schneider, W., Shiffrin, R.M., 1977. Controlled and automatic human information processing: I. Detection, search, and attention. Psychol. Rev. 84 (1), 1–66.
Shenhav, A., Botvinick, M.M., Cohen, J.D., 2013. The expected value of control: an integrative theory of anterior cingulate cortex function. Neuron 79 (2), 217–240.
Storbeck, J., Clore, G.L., 2008. The affective regulation of cognitive priming. Emotion 8 (2), 208.
Spielberg, J.M., Miller, G.A., Warren, S.L., Engels, A.S., Crocker, L.D., Sutton, B.P., Heller, W., 2012. Trait motivation moderates neural activation associated with goal pursuit. Cogn. Affect. Behav. Neurosci. 12 (2), 308–322.
Thompson-Schill, S.L., Kurtz, K.J., Gabrieli, J.D., 1998. Effects of semantic and associative relatedness on automatic priming. J. Mem. Lang. 38 (4), 440–458.
Trifan, A., Antunes, R., Matos, S., Oliveira, J.L., 2020. Understanding depression from psycholinguistic patterns in social media texts. Adv. Inf. Retr. 12036, 402–409.
Zald, D.H., Treadway, M.T., 2017. Reward processing, neuroeconomics, and psychopathology. Annu. Rev. Clin. Psychol. 13, 471–495.