The association between superior working memory and trait-rumination

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Abstract

Higher trait-rumination is associated with several psychopathologies. Previous studies showed that an impaired working memory in depressed patients was associated with higher trait-rumination. Meanwhile, in the nonclinical undergraduate population, a few studies reported the association between superior working memory and trait-rumination. To clarify the association between trait-rumination and the individual differences in working memory, we utilised two conceptually different working memory functions: *attentional control* and *removal speed*. Attentional control is involved in continuing to focus on goal-relevant information while blocking goal-irrelevant information and is reflected by working memory capacity. Removal speed is the time required to quickly remove goal-irrelevant information from working memory. Ninety-five undergraduate students took the reading span test and the working-memory-updating task to measure these functions. Results showed that increased trait-rumination was correlated to superior performance in the attentional control as well as the removal speed after controlling depressive symptoms. The current findings suggest that higher trait-rumination in undergraduate students is characterized by superior working memory, which contrasts with prior findings of people with depression. Further studies should examine the roles of superior working memory from the viewpoint of the developmental processes of rumination.

Keywords: rumination; working memory updating; attentional control

Introduction

Rumination refers to repetitive thoughts on the causes, meanings, or consequences of one's depressive mood and is considered as a maladaptive emotion regulation strategy (Nolen-Hoeksema et al., 2008). Excessive rumination leads to flawed problem-solving, pessimistic thinking, and increased depressive symptoms in an individual. Additionally, it is a risk factor of depression and anxiety (Nolen-Hoeksema et al., 2008; Watkins & Roberts, 2020) as well as externalizing and internalizing symptoms (Watkins & Roberts, 2020). Thus, it is essential to uncover the underlying mechanism of excessive rumination for the development of an effective intervention.

Previous research has found that an impaired working memory in depressed patients was associated with excessive rumination (e.g. Joormann & Gotlib, 2008; Zetsche et al., 2018). On the other hand, undergraduate students with high trait-rumination and mild depressive symptoms were not necessarily characterized by deficits of working memory (Altamirano et al., 2010; Nishimura et al., 2020; Onraedt & Koster, 2014). To understand the association between the working memory and trait-rumination in nonclinical undergraduate students, we focused on two different working memory functioning: attentional control and removal speed.

Working memory has a limited capacity for higher cognitive processing (Conway et al., 2008). Working memory blocks goal-irrelevant information and continues to focus only on goal-relevant information to accommodate the large amounts of information being processed (Kane et al., 2008; Kane & Engle, 2003). According to Kane and Engle (2003), individual differences in such *attentional control* determines the working memory capacity. Indeed, it was demonstrated that complex span tasks that measure working memory capacity were strongly associated with the variations of the attentional control task (Heitz & Engle, 2007; Kane & Engle, 2003). Typically, these

attentional-control-related tasks consisted of such tasks as a Stroop task (Kane & Engle, 2003) and a flanker task (Heitz & Engle, 2007).

Superior performances in trait-rumination were found in attentional-control-related-tasks such as the emotionally neutral Stroop task and the operation span task (Altamirano et al., 2010; Onraedt & Koster, 2014). In an experiment by Altamirano et al. (2010), non-clinical and undergraduate students performed a modified Stroop task that had a very low proportion (25%) of incongruent trials and a high proportion (75%) of congruent trials. This manipulation corresponded with that used to measure participants' attentional control in Kane and Engle's (2003) study. The result of Altamirano's study showed that trait-rumination, measured by the Ruminative Responses Scale (RRS), was positively correlated with accuracy in the incongruent condition. In addition, Onraedt and Koster (2014) demonstrated a significant positive correlation between trait-rumination and working memory capacity measured by the operation span task. Notably, the valence of materials on these tasks was emotionally neutral. These findings suggest that trait-rumination is associated with superior attentional control in the context of emotionally neutral tasks.

Meanwhile, when information stored in working memory is no longer relevant, people need to remove this information from their working memory to encode novel information. The efficiency of *removal* has been associated with trait-rumination, especially in people with depression (Joormann & Gotlib, 2008; Joormann et al., 2010; Zetsche et al., 2018). Participants with depression exhibited increased interference from no longer relevant negative materials (intrusion effect) compared to never-depressed participants (Joormann & Gotlib, 2008), as shown by using a modified Sternberg task (Oberauer, 2001). Moreover, this increased intrusion-effect was positively correlated with higher trait-rumination even after controlling for depressive symptoms (Joormann

& Gotlib. 2008). However, the difficulty of removal in people with depression was not found when the valence of the materials was emotionally neutral (Joormann et al., 2010). These findings suggested that increased trait-rumination, especially in people with depression, was associated with the difficulty of removal for negative materials.

A working-memory-updating task (Ecker, Lewandowsky et al., 2014) enables direct assessment of variation in the time of removal and detection of removal-specific processing (Ecker et al., 2010; Ecker, Lewandowsky, et al., 2014; Ecker, Oberauer, et al., 2014). Chang et al. (2017) showed that dysphoric ruminators took less time to remove outdated words from working memory when the valence of the to-be-remembered word was negative. However, delayed removal speed was not observed in dysphoric ruminators compared with non-ruminators. Unfortunately, that experiment (Chang et al., 2017) did not include a condition with a neutral valence. In sum, the association between removal speed and trait-rumination in the context of emotionally neutral materials is still unclear.

Notably, a series of studies by Ecker and his colleagues using structural equation modelling revealed that variations in removing no longer relevant information from working memory and working memory capacity, which is equivalent to the variant of attentional control, are dissociable concepts that are independent of each other (Ecker et al., 2010; Ecker, Lewandowsky, et al., 2014; Ecker, Oberauer, et al., 2014). Moreover, variation in removal speed and variation in working memory capacity had little correlation (Ecker, Lewandowsky, et al., 2014; Ecker, Oberauer, et al., 2014). Accordingly, the comparing the performance of two conceptually different tasks would clarify the association between working memory and trait-rumination.

To investigate the relationships between trait-rumination and the working memory functionings, especially attentional control and removal speed, we selected the

following two tasks. First, we used a reading span test (Daneman & Carpenter, 1980), commonly used to measure variation in working memory capacity and attentional control (e.g. McVay & Kane, 2009). Second, we used a working-memory-updating task (Ecker, Lewandowsky, et al., 2014) which can directly measure the time of removal, and thus it is more suitable to measure the difficulty of removal than an interference task such as a modified Sternberg task (Joormann & Gotlib, 2008; Oberauer, 2001).

If trait-rumination is associated with attentional-control-specific superior performance across the different components of working memory, then the RRS score may be associated with a larger working memory capacity in the reading span task but may be not associated with removal speed in the working-memory-updating task. Meanwhile, if trait-rumination is associated with superior performances in both components of working memory, then the RRS score may be associated with both a larger working memory capacity and a faster removal speed.

Materials and Methods

Participants

A priori power analysis suggested 84 participants as the minimum sample size ($\rho = .30$, $1 - \beta = 0.80$, $\alpha = .05$), with parameters based on prior studies (Altamirano et al., 2010: $r = .30$; Onraedt & Koster, 2014: $r = .34$). As a result of recruiting, 95 (71.6% females) undergraduate students (age; $M = 20.59$, $SD = 1.98$, 18-26) participated in the current study.

Questionnaires

The Japanese RRS (Hasegawa, 2013; Treynor et al., 2003) is a 22-item, five-point Likert scale (1 = *almost never* and 4 = *almost always*) designed to measure trait-

rumination. Participants answered the RRS using the paper-and-pencil method. The RRS's total score had good internal consistency and construct validity, and test-retest reliability (Hasegawa, 2013; Hasegawa et al., 2013). The average score of RRS was 46.02 ($SD = 11.94$, range = 25-82). The alpha coefficient was $\alpha = .90$.

The Japanese Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977; Shima et al., 1985) is a 20-item Likert-type scale (0 = *rarely/none of the time* and 3 = *most/all of the time*) designed to measure depressive symptomatology. The participants answered the CES-D using paper and pencil. The CES-D had high test-retest reliability, internal consistency, and constructive validity in Japanese samples. The average score of CES-D was 12.29 ($SD = 9.41$, range = 0-52). The alpha coefficient was $\alpha = .85$.

Working Memory Updating Task (Ecker, Lewandowsky, et al., 2014)

The flow of the working-memory-updating task was programmed by Microsoft Visual Basic 2010 Express and was presented on a laptop. The task flow can be seen in Figure 1. The task procedures were chosen by referring to prior research (Ecker, Lewandowsky, et al., 2014) to measure removal speed. There were three phases: (1) encoding phase, (2) updating phase, and (3) test phase. In the encoding phase, three different white numbers appeared in three separate white rectangle frames on a black background. The numbers and frames were displayed for 2,000 ms. Participants were then tasked to remember the combination of the numbers and the position of the corresponding frames. In the updating phase, after a 200 ms or 1,500 ms cue-target interval (CTI), a randomly chosen frame was then bolded and turned red in colour. The reaction times (RTs) in the short CTI (200 ms) condition consisted of both encoding and removal processing because the interval was too short to remove items that were indicated as irrelevant. Meanwhile, the RTs in the long CTI (1,500 ms) involved only

encoding processing because the interval was long enough to complete the removal of items. The CTI was chosen randomly at each step. The interval between the clearing of the number and the end of the CTI was 2,000 (i.e. 1800 + 200 or 500 + 1500) ms in all updating steps. Following the CTI, a new number appeared in the red frame.

Participants would then click the mouse button as quickly as possible once they had memorized the numbers and the position of the corresponding frames. The time from the presentation of numbers to clicking was measured as the RT. Following clicking, the numbers would vanish, and the frame colours would return to white. At a 90% chance, a frame was bolded and turned red in colour, that is, the updating phase was repeated. The maximum number of repetitions of updating steps was 21 times. Updating phases had a 10% chance of ending and moving to the test phase. In the test phase, a question mark was shown in one of the three frames, and participants typed the last number shown in the frame using the numeric keypad. The tests were repeated three times to test the participants' recall and memory for the last number shown in each of the three frames. After the test phase, the encoding phase then started again. In total, 28 trials were conducted with the participants.

Figure 1. The task flow of the working-memory-updating task. (1) Encoding phase: participants encoded the three different numbers and the position. (2) Updating phase: one of the three frames was bolded and coloured as red, and a new number appeared. Participants substituted a new item for the old item in the position, and then clicked the mouse. The cue-stimulus interval (CTI) was 200 ms (short) or 1500 ms (long). The task assumed the long CTI consisted of both encoding and removal processing whereas the short CTI consisted of removal processing only. Updating phases were repeated in 90%

and moved into the test phase in 10%. (3) Test phase: Participants typed the corresponding items into frames.

Following the process of a prior study, we included RTs within three standard deviations (SD) from the mean and deleted RTs on trials that were answered incorrectly in the test phase from the analysis (Chang et al., 2017; Ecker, Lewandowsky, et al., 2014). As a result, a total of 7.63% observations were removed from the analysis. We calculated the removal speeds by using the following formula that was adopted from previous studies (Chang et al., 2017; Ecker, Lewandowsky, et al., 2014).

$$Removal\ speed = \frac{mean\ RT(CTI\ short) - mean\ RT(CTI\ long)}{mean\ RT(CTI\ short)}$$

Reading Span Test (Osaka & Osaka, 1994)

Stimuli were presented using Microsoft PowerPoint 2010 on a laptop that was manipulated manually by the experimenters. Subsequently, participants vocally read a sentence on display and memorized an underlined target word from the sentence. Differing from the original version (Daneman & Carpenter, 1980), the position of the underlined target was not at the end of a sentence (Osaka & Osaka, 1994) in the Japanese version. As soon as participants finished the vocalization of a sentence, an experimenter manually presented the next sentence. Again, participants vocalized a sentence and remembered a new underlined target word in addition to the pre-memorized target words. The number of serially presented sentences ranged from two to five in different conditions. After participants vocalized the last sentence, the experimenter requested them to write the target words using paper and pencil in the correct order. Participants carried out five trials per condition, and the number of

sentences gradually increased (i.e. two-sentence condition followed by three-sentence condition). The working memory capacity was defined by the partial scoring method (Osaka & Osaka, 1994), which is the number of correctly recalled words, if not necessarily in order. The analysis was conducted with R 3.6.3 (R Core Team, 2020).

Procedure

After providing informed consent in written, participants answered the RRS and CES-D in the laboratory. Afterwards, they performed the working-memory-updating task and reading span test in the same order. They were either given a ¥500 gift certificate or partial course credit in exchange for their participation.

Results

As expected, we confirmed that the short CTI condition ($M = 1243.904$ ms, $SD = 446.024$) showed larger RTs than the long CTI condition ($M = 1008.503$ ms, $SD = 399.700$), $t(94) = 15.592$, $p < .001$, Cohen's $d = 1.599$, which was congruent with a previous study (Ecker, Lewandowsky, et al., 2014).

We conducted correlation analysis to examine the relationships between trait-rumination and working memory measures (i.e. removal speed and working memory capacity). The scatter plots are displayed in Figure 2. We adjusted p -values by the Holm method to avoid an increase in family-wise error rate. As expected, trait-rumination was positively correlated with depressive symptoms ($r = .564$, adjusted $p < .001$).

Additionally, working memory capacity and removal speed were not significantly correlated with each other ($r = .088$, adjusted $p = .395$), suggesting that these are independent measures (Ecker, Lewandowsky, et al., 2014; Ecker, Oberauer, et al., 2014). Higher trait-rumination was associated with a larger working memory capacity ($r = .206$, adjusted $p = .045$) and faster removal speed ($r = -.242$, adjusted $p = .018$).

Importantly, the correlation between trait-rumination and these variables were significant even after controlling for depressive symptoms (working memory capacity: $r = .242$, adjusted $p = .023$; removal speed: $r = -.260$, adjusted $p = .023$). However, depressive symptoms were not correlated with working memory capacity ($r = .010$, adjusted $p = .912$) and removal speed ($r = .049$, adjusted $p = .636$).

Figure 2. The correlations between trait-rumination and working memory performances. High working memory capacity and faster removal speed indicate superior performances. Dots represent individual observations, lines represent regression lines, and shaded areas represent 95% confidence intervals.

Discussion

Although some previous studies showed trait-rumination was associated with superior working memory performances (Altamirano et al., 2010; Onraedt & Koster, 2014), its characteristics have not been understood. The purpose of the current study was to investigate the relationships between trait-rumination and the working memory functionings, especially attentional control and removal speed. The findings, which used

a reading span test and working-memory-updating task, revealed that increased trait-rumination is associated superior attentional control and removal speed after even controlling for depressive symptoms.

The current findings agreed with previous studies (Altamirano et al., 2010; Onraedt & Koster, 2014) that showed trait-rumination is associated with superior performances in the modified Stroop task (Altamirano et al., 2010) or complex-span task (Onraedt & Koster, 2014). Meanwhile, the current finding, the association between trait-rumination and faster removal speed, did not correspond with the findings of the previous studies that utilised the removal-related tasks (e.g. Chang et al., 2017; Joormann & Gotlib, 2008; Zetsche et al., 2018). Unlike the current study, these studies utilised emotional material (Chang et al., 2017; Joormann & Gotlib, 2008) or clinical populations (Joormann & Gotlib, 2008). Therefore, it is assumed that the associations between the superior working memory (higher attentional control and faster removal speed) and trait-rumination is limited to a non-clinical undergraduate student population.

There were some limitations in the current study. First, the working memory tasks used in the current study were not comprehensive. For example, some studies that utilised larger sample sizes and many executive function tasks did not show the association between superior performance and trait-rumination for the Stroop task (e.g. Nishimura et al., 2020). Unlike these studies, the current study paid particular attention to attentional control and removal processing. Future studies should examine how the other aspects of working memory would be associated with trait-rumination by controlling the confounding effects on the performance of other factors such as short-term memory or processing speed. Second, the current study used a cross-sectional design, and thus did not permit causal inference. Although the current study did not

demonstrate why and how superior working memory in trait-rumination is related to several psychopathologies, longitudinal designs may enable deeper understanding of the mechanisms.

In summary, the current study showed that trait-rumination is associated with superior working memory across two different working memory tasks. Given that most researchers assume trait-rumination is associated with impaired working memory (Chang et al., 2017; Joormann & Gotlib, 2008), the findings in this current study casted doubt on that assumption. Therefore, further studies should investigate the developmental role of superior working memory for increased rumination by using a longitudinal design, a larger sample size, and comprehensive working memory measures.

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Disclosure of interest

The authors report no conflict of interest

Ethical approval

All procedures involving human participants were conducted in accordance with the ethical standards of the local ethical committee of the university, the 1964 Helsinki Declaration, and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained in written from all individual participants included in

the study.

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