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The Influence of Stress on Human Memory: Differences among Subjected Timing of Acute Stress

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Abstract

In this study, we compared the differences in influence of three stress subjection timings on memory using words stimuli with three valences, positive, negative, and neutral. Sixty-three participants were divided into four conditions, pre-learning stress, on-learning stress, post-learning stress, and control condition. Participants in stress conditions were exposed to acute white noise stress. The results showed differences in the delayed recall memory performances among the three stress timing conditions, and definite valence influences. Compared to the non-stressed condition, impaired neutral delayed recall was observed in the post-learning stress condition. Pre- and on-learning stress showed lower positive memory compared to the other valences within their condition. Since memory performance was not significantly different from the control condition in either the pre-learning or on-learning stress timing conditions, learning after/or under stress did not seem to impair memory performance. Among the three stress timing conditions, post-learning stress seems to most affect human memory.

Keywords: acute stress, memory, timing, post-learning, pre-learning, valence

1. Introduction

The word "stress" is commonly used in modern society, and most of us experience stressful events throughout our daily lives. Stress can be detrimental to human health, as well as to cognitive or behavioral performance. Indeed, concerning the influence of stress on human memory, many studies have reported that participants who are exposed to a stressor prior to a memory test show inferior memory performance (e.g., Buchanan & Tranel, 2008; Kuhlmann, Piel, & Wolf, 2005).

However, some studies have reported that stress can lead to enhanced memory performance. When researchers provide participants with an acute stressor before (i.e., pre-learning stress) or after (i.e., post-learning stress) stimulus learning, stress provides a memory enhancing effect. Some researchers have reported that pre-learning stress tends to impair neutral memory but either enhancing (Jelicic, Geraerts, Merckelbach, & Guerrieri, 2004) or having no influence (Smeets, Jelicic, & Merckelbach, 2006) on positive and negative emotional memory. Others studies have found that post-learning stress can enhance memory performance. These studies used stimuli such as words (Smeets, Otgaar, Candel, & Wolf, 2008), pictures (Cahill, Gorski, & Le, 2003; Preuss & Wolf, 2009; Yonelinas, Parks, Koen, Jorgenson, & Mendoza, 2011), or a short film or story (Andreano & Cahill, 2006; Beckner, Tucker, Delville, & Mohr, 2006).

In addition to the influence of pre-learning and/or post-learning stress, there is also the possible manipulation of the timing of stress subjection to consider; specifically, the presentation of acute stress during memory learning (on-learning stress). Unlike some studies that found an enhancing effect of pre-learning stress, Schwabe and Wolf (2010) found that when people learn under stress, their memory performance is impaired, irrespective of whether the material is emotionally charged or neutral.

To date, different stress manipulation timings (i.e., pre-learning, on-learning, and post-learning) have been used in various previous studies; therefore, it is sometimes difficult to accurately compare the effects of acute stress on memory found in those previous studies, especially since many of them used different learning tasks, as well. To the best of our knowledge, Smeets et al. (2008) was the only study to use negative emotional and neutral words lists and to compare pre-learning and post-learning stress conditions with a retrieval condition (stress before memory test) in one experiment. This study found enhancing effects of acute stress on emotional negative memory in the post-learning stress condition. The results also confirmed that stress before retrieval impaired memory, as was observed in previous studies (e.g., Buchanan & Tranel, 2008; Kuhlmann et al., 2005). No stress effect was found in the pre-learning condition. However, the researchers were unable to investigate and compare the influence of on-learning to other stress exposures, nor were they able to investigate the influence of stress on positive memory material.

In this study, we proposed to investigate the differences in memory effects observed in relation to three stress subjection timing conditions. Our study design accounted for a comparison of pre-learning, on-learning, and post-learning stress to all be completed in the same experiment. To investigate whether the effect of stress on memory is dependent on content valence, we used memory material composed of positive and negative emotional words, as well as neutral words. This study is the first to compare the stress timing effects of pre-, on-, and post-learning stress manipulations using learning material with three valences.

2. Method

2.1 Participants

The sample consisted of 63 undergraduate students (33 female and 30 male), with mean age of 19.1 years (SD=0.83, range 18-21). Participants were divided into four groups, pre-learning stress group (the group stressed before learning task) (n=16, 8 female and 8 male, mean age: 19.1, SD=0.70, range 18-21), on-learning stress group (the group stressed during learning task) (n=15, 7 female and 8 male, mean age: 19.1, SD=0.88, range 18-20), post-learning stress group (the group stressed after learning task) (n=16, 8 female and 8 male, mean age: 19.1, SD=0.78, range 18-21) and control group (n=16, 10 female and 6 male, mean age: 18.9, SD=0.93, range 18-21). All the participants gave written and oral informed consent before the experiment began and were well debriefed after experiment ended.

2.2 Materials and Apparatus

The target stimulus list in learning task comprised 30 two-character compound words, which included 10 neutral words (e.g., “choice” “human”), 10 negative words (e.g., “bankruptcy” “fatigue”) and 10 positive words (e.g., “success” “smile”). All words were chosen from the list provided by Gotoh and Ohta (2001), who investigated the affective valence, frequency of use, ease of learning, and imagery of two-character compound words. Furthermore, we investigated arousal of these words in preliminary search (n=18). A one-way analysis of variance (ANOVA) showed all three word categories (neutral, positive, and negative) differ significantly for valence [$F(2,27)=2094.04$, $p<.001$], but not for arousal [$F(2,27)=.74$, $p=.49$ *ns*]. There were no difference in frequency of use, ease of learning, and imagery [all ps>.10].

All stimuli were presented at the center of a 12.1-inch black computer screen in a 40-point white Gothic font. The entire experiment was programmed in MATLAB 7.0.4, using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997) .

2.3 Subjective Stress Measure

Subjective stress was measured using the Stress subscale of the Japanese version of Stress and Arousal Check List (SACL; Kumashiro, 2002; Mackay, Cox, Burrows, & Lazzerini, 1978). The Stress subscale consists of 17 negative stress adjectives (e.g., “worried”) and reversed positive adjectives (e.g., “pleasant”). Participants indicated the degree to which each adjective describes them “at this moment” on 4 point rating scale (“definitely describes” to “does not describe”), scoring “definitely describes” “more or less describes” as 1 point, and “cannot decide” “does not describe” as 0 points. The total score of the Stress subscale was calculated by adding the 17 item scores. A higher total score is indicative of a relatively greater degree of psychological stress.

2.4 Stress Manipulation

Participants in the stress condition were exposed to 80dB white noise through headphones for 5 min continuously. Noise stress is a stress manipulation that has been widely used in previous studies (e.g., Carter & Beh, 1989; Smith, Whitney, Thomas, Perry, & Brockman, 1997), and known to affect cardiovascular function such as blood pressure. The reason why we chose noise as stress task because noise stress could expose participants to acute stress through headphones during a task, without interrupting their other operation of that task, so that we could design an on-learning stress condition.

2.5 Procedure

After filling out the consent form, participants then filled in a questionnaire including the first time SACL. All the participants were then instructed to perform a computer task wearing headphones. They were informed that the task consists of three blocks of trials, and that they might hear some sound from the headphone while performing the task.

Initially, participants performed a pre-learning block. In this block, participants performed a fixation task. Participants were asked to fixate on the fixation cross, which was presented at the center of computer screen. They were instructed that they should not turn their gaze away from the center of the screen. This task was provided for adjustment of experiment time between each group. The presentation was continued for about 5 minutes, the same length as the learning task described below.

Secondly, participants performed a learning block. This task of block was a modified version of the Visual Verbal Learning Test (Riedel, Klaassen, Deutz, van Someren, & van Praag, 1999), which consists of two repetitions of stimulus presentation and one period of free recall. After presentation of the fixation cross for 1000ms, the word stimulus was presented at the center of computer screen for 2000ms. The interstimulus interval was 2000ms. The list of 30 stimulus words was presented twice in random order. After the second presentation, participants were requested to write as many of the presented words as they could remember (immediate recall).

Thirdly, participants performed the post-learning block, with a task similar to that in the pre-learning block, during which the participants fixated on the fixation cross for about 5 minutes.

After each block, participants had to answer the SACL.

Participants in the pre-learning stress group heard the 80 dB white noise stressor during the pre-learning block (first fixation task); those in the on-learning stress group heard it during the learning block (learning task); and those in the post-learning stress group heard it during the post-learning block (second time fixation task after the learning task). No sound was played for the control group.

After all three blocks, a non-verbal mental rotation task was administered as a filler task for 10 minutes. Then, the participants in all the groups were administered a delayed recall test. The total duration of the experiment was approximately 70 min, and all participants were tested individually. Finally, the participants were debriefed, paid, and thanked for their participation. After the study, no participant reported any discomfort or pain because of the white noise.

3. Results

3.1 Subjective Stress

The subjective stress score in this study was indexed by the increases in the Stress subscale of SACL (increases=Stress subscale scores of the post SACL-Stress subscale scores of the pre SACL).

In each of the three stress groups, there were one stressed block and two non-stressed blocks in the task; in the control group, there were three non-stressed blocks. To compare the subjective stress scores of the stressed blocks to the non-stressed blocks, the mean scores of non-stressed blocks were calculated for pre-learning block, learning block and post-learning block, separately. A one-way ANOVA showed there were no differences between groups in each non-stressed blocks (all ps>.10). The mean subjective stress in each of the stressed blocks compared to the non-stressed blocks is shown in Figure 1.

A Bonferroni corrected independent t-test comparing each of the stress scores of three stressed blocks with the mean scores of non-stressed blocks showed that the subjective stress score of stressed block in pre-learning stress group was significantly higher than the mean stress score of non-stressed pre-learning blocks [stressed, M=3.50; non-stressed, M=0.81; $t(15)=2.89$, $p<.05$], same to the stressed block in on-learning stress group with non-stressed learning blocks [stressed, M=1.60; non-stressed, M=-0.63; $t(14)=2.02$, $p<.05$] and in post-learning stress group with the non-stressed post-learning blocks[stressed, M=1.75; non-stressed, M=-1.29; $t(15)=3.54$, $p<.01$]. The results showed that the stress manipulation was effective in three stressed conditions.

3.2 Memory Performance: Immediate Recall

Numbers of correctly recalled items were summed for neutral, negative and positive words, separately. The proportion of correct recall was calculated by dividing correctly recalled numbers by the total of number of words presented 10.

Immediate recall performance was analyzed using a 4(Group: pre-learning stress group vs. on-learning stress group vs. post-learning stress group vs. control group)×3(Valence: neutral vs. positive vs. negative) ANOVA with valence as repeated factor. ANOVA showed there were no difference in immediate recall performance between 4 groups, as evidenced by the absence of significant main effect of Group [$F(3,59)=0.46$, $p=.71$ *ns*] and Group×Valence interaction [$F(6,118)=1.38$, $p=.23$ *ns*], but there was a significant main effect of Valence [$F(2,118)=5.98$, $p<.05$]. Ryan's method corrected post hoc analyses on main effect showed that on the time of immediate recall, positive words was significantly lower than negative words ($p<.001$) and neutral words ($p<.05$), not depend on whether stressed or not.

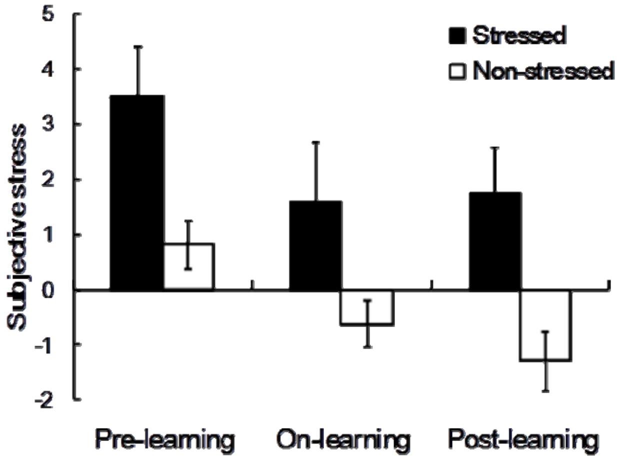

Figure1. Mean subjective stress in each stressed blocks compare to the mean score of those non-stressed blocks

Note. Error bars represent the standard error of mean (*SE*). Post-learning=Stressed at the fixation task block before the learning task, On-learning=Stressed at the learning task block, Post-learning=Stressed at the fixation block after the learning task.

3.3 Memory Performance: Delayed Recall

Figure 2 shows the delayed recall performance of the 4 groups. The proportion of correctly recalled items during delayed recall was analyzed using a 4(Group)×3(Valence) ANOVA, with valence as repeated factor. The ANOVA yielded a significant effect of Valence [$F(2,118)=8.92$, $p<.001$] and Group×Valence interaction [$F(6,118)=2.21$, $p<.05$]. No other main effect was detected. Ryan's method of corrected post hoc analyses supports that, for delayed recall of neutral words between groups, the post-learning stress group tended to show significantly lower performance than the control group ($p<.10$), and its performance was significantly lower than that of the on-learning stress group ($p<.05$). When compared within groups, the post-learning group's performance for neutral words was lower than its performance for negative words ($p<.05$). The pre-learning group's performance for positive words was significantly lower than its negative word performance ($p<.001$), and on-learning group's performance for positive word was lower than both its negative ($p<.05$) and neutral ($p<.001$) word performance.

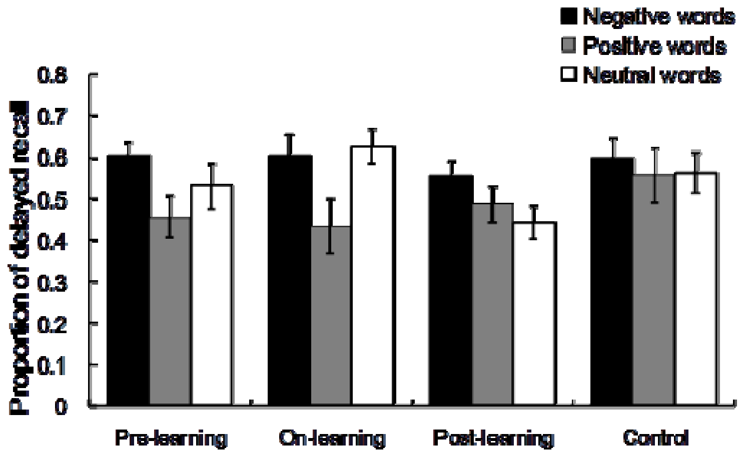

Figure2. Mean proportion of delayed recall in pre-learning stress, on-learning stress, post-learning stress, and control condition

Note. Error bars represent the standard error of mean (*SE*).

4. Discussion

The objective of this study was to compare the differences in influence of three stress subjection timings (pre-learning, on-learning, and post-learning) on memory as a function of word valence (positive, neutral, or negative). This was the first investigation comparing pre-, on-, and post-learning stress timing effects in a single experiment, using word stimuli of three valences as the learning material.

Participants in the three stress groups exhibited significant subjective stress responses in their stressed blocks. As a result of delayed recall, we found the following inter-group effects: for neutral words, post-learning stress showed a tendency toward impaired memory performance compared to the control group, and the post-learning group's performance was significantly impaired compared to the on-learning stress group's performance. We also found some within-group effects. The post-learning stress group's memory performance for the neutral words was significantly lower compared to its negative word memory performance. The pre-learning stress group's memory performance for the positive words was significantly lower than that for the negative words. In addition, the on-learning stress group's memory of positive words was significantly lower compared to both its negative and neutral word memory performance. There was no influence of stress, only memory bias, on immediate recall. The general memory for positive material led to lower performance than either the negative or neutral material.

Of the three stress timing conditions, only the post-learning group showed a tendency toward lower neutral memory as compared to the control group. This post-learning stress condition seemed to be most affected by the acute stress manipulation. This result corresponds well to the findings of Smeets et al. (2008), which showed that pre-learning stress did not affect memory, but post-learning stress did. However, no post-learning stress enhancing effect was observed in this study, which is similar to Smeets et al.'s (2006) results that showed how pre-learning stress impairs neutral, but not emotional memory.

For the pre-learning and on-learning stress conditions, memory performance differed as a function of timing conditions. Positive memory performance was lower than that of negative memory in the pre-learning stress condition, and it was lower than both neutral and negative memory performance for in the on-learning stress condition. In both conditions, stress seemed to affect learning task performance, and this could be why the memory effects of these two stress timing were similar. Since memory performance was not significantly different from the control condition in either the pre-learning or on-learning stress timing conditions, learning after/or under stress did not seem to impair memory performance. Regarding pre-learning stress, this result is in line with Smeets et al. (2008), which found no stress effect in the pre-learning group. However, the finding that on-learning stress does not impair memory performance is a new finding and is directly incongruent to Schwabe and Wolf (2010).

Considering how stress affects the memory process (encoding, consolidation, retrieval), it is difficult to separate the memory-dependent effect of stress in this study. Even stress in the on-learning condition seems to directly affect initial memory encoding, because pre-learning stress has mixed effects on consolidation (Schwabe, Wolf, & Oitzl, 2010), on-learning stress seems to also have some influence on memory consolidation. Concerning the post-learning stress condition, previous studies have indicated post-learning stress affects memory consolidation (Wolf, 2008). However, since there is only a 10-minute delay in the memory test, stress could also affect memory retrieval, which is what a previous study reported as one of the causes of impaired memory (e.g., Buchanan & Tranel, 2008; Kuhlmann et al., 2005). The effect of the post-learning stress condition observed in this study could also be a result of the mixed effects of stress on memory consolidation and retrieval. One possible reason for our inability to find an enhancing effect of post-learning stress on memory is that stress in the post-learning group enhanced memory, perhaps especially in relation to the emotional as opposed to the neutral material, but stress occurring before the retrieval impaired it, thus causing lower memory performance as compared to the control group.

Some study limitations should be noted. First, as mentioned above, we were unable to separate those stress effect on memory process. Although it would be quite difficult to design an experiment that completely separates the effects of stress on memory encoding and consolidation, it would be possible in future studies by increasing the memory test time delay so that stress would not be able to affect memory retrieval.

Second, in this study we used 30 randomized words as the memory stimuli, and all of them were targets for calculating memory performance. However, one report indicates that epinephrine (a stress hormone) selectively enhances primary, but not recently, presented memory material (Cahill & Alkire, 2003). We had to control for the primacy and recency effects by adding appropriate filler stimuli in the list of memory materials.

Third, there may have been some influences of acute stress as a result of auditory stimuli. Because we gave the participants a fixation task after the learning task, they were able to freely rehearse the materials they saw in the previous learning session. It is possible it was difficult for people who heard white noise to rehearse words in their minds, which may have led to memory impairments. To exclude this possibility and prove the effects of acute stress, further studies should investigate the effects of stress with a filler task that avoids rehearsal after a learning task.

In summary, the results showed differences in the delayed recall memory performances among the three stress timing conditions, and definite valence influences. Pre- and on-learning did not show inter-condition differences with non-stressed condition, so that learning after/or under stress did not seem to impair memory performance. However, they did show lower positive memory compared to the other valences. Compared to the non-stressed condition, impaired neutral delayed recall was observed in the post-learning stress condition. Among the three stress timing conditions, post-learning stress seems to most affect human memory.

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