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Timing matters: Negative emotion elicited 5 min but not 30 min or 45 min after learning enhances consolidation of internal-monitoring source memory

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ABSTRACT

Two experiments examined the time-dependent effects of negative emotion on consolidation of item and internal-monitoring source memory. In Experiment 1, participants ($n = 121$) learned a list of words. They were asked to read aloud half of the words and to think about the remaining half. They were instructed to memorize each word and its associative cognitive operation ("reading" versus "thinking"). Immediately following learning they conducted free recall and then watched a 3-min either neutral or negative video clip when 5 min, 30 min or 45 min had elapsed after learning. Twenty-four hours later they returned to take surprise tests for item and source memory. Experiment 2 was similar to Experiment 1 except that participants, without conducting an immediate test of free recall, took tests of source memory for all encoded words both immediately and 24 h after learning. Experiment 1 showed that negative emotion enhanced consolidation of item memory (as measured by retention ratio of free recall) regardless of delay of emotion elicitation and that negative emotion enhanced consolidation of source memory when it was elicited at a 5 min delay but reduced consolidation of source memory when it was elicited at a 30 min delay; when elicited at a 45 min delay, negative emotion had little effect. Furthermore, Experiment 2 replicated the enhancement effect on source memory in the 5 min delay even when participants were tested on all the encoded words. The current study partially replicated prior studies on item memory and extends the literature by providing evidence for a time-dependent effect of negative emotion on consolidation of source memory based on internal monitoring.

1. Introduction

Episodic memory is composed of two elements, one of which is item memory, which refers to memory for a piece of information itself (e.g., a word or a picture) and is usually tested by free recall and recognition. Another element of episodic memory is source memory, which refers to the contexts under which a piece of information was acquired (e.g., the font color of a word or spatial location of a picture) (e.g., Doerksen & Shimamura, 2001; Johnson, Hashtroudi, & Lindsay, 1993; Kensinger & Corkin, 2003; Slotnick, Moo, Segal, & Hart, 2003; Wang & Fu, 2011). According to Johnson et al. (1993), source memory can be based on three types of monitoring: external monitoring (e.g., distinguishing between memories for what one saw and what one heard), internal monitoring (distinguishing between what one thought about and what one read aloud), and reality monitoring (distinguishing between what one saw and what one imagined).

Studies have shown behavioral dissociation between item and source memory. For instance, participants had better memory for items embedded in bizarre sentences than embedded in common sentences, but their source memory (for spatial locations) was not affected by bizarreness (Macklin & McDaniel, 2005). Studies also showed better item memory for emotional words relative to neutral words; however, no reliable difference was observed in source memory for these two categories of stimuli (Davidson, McFarland, & Glisky, 2006). Furthermore, there has been evidence showing neural dissociation between item and source memory such that these two memories respectively depend on functions of the medial temporal lobe and the frontal lobe (Glisky, Polster, & Routhieaux, 1995; Janowsky, Shimamura, & Squire, 1989).

Memory consolidation refers to the process through which an initial fragile memory trace gradually becomes stable over time, or the process via which a labile short-term memory undergoes the transition into long-term memory (Dudai, 2004; McGaugh, 2000). The success of this transition has been shown to be dependent on the hippocampus. For instance, although patients with damage to the hippocampus had great difficulties in forming new memories, they tend to have intact memory for remote past (Squire, 1992). It has thus been proposed that at an early stage when memory has been newly formed, retrieval of memory traces

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depends on the hippocampus; with the passage of time memory traces are gradually transferred to the neocortex and the corresponding memory retrieval eventually becomes independent of the hippocampus (Squire & Alvarez, 1995).

Memory consolidation can be subject to the influences of many factors such as sleep (Alger, Lau, & Fishbein, 2012), muscle tension (Nielson, Wulff, & Arentsen, 2014), smoking (Colrain, Mangan, Pellett, & Bates, 1992), stress hormones (e.g., Roozendaal, 2000), and progesterone levels (Felmingham, Fong, & Bryant, 2012), but one critical factor that has gained increasing attention is emotion induced after learning. In fact, ample evidence has shown the enhancement of post-learning emotion on consolidation of item memory. For instance, in a study by Nielson, Yee, and Erickson (2005), participants learned a word list and then were assigned into a control or a negative condition, in which they respectively watched a 3-min emotionally neutral video (about tooth brushing) or emotionally negative video (about dental surgery). The results showed that free recall performance at a 30 min or 24 h delay test was significantly higher in the negative than in the control condition. In addition, recognition memory in the 24 h delay was also significantly better in the negative than in the control condition. Because emotion was induced after learning, thus ruling out any effect on attention or encoding, the above study suggests an enhancement of negative emotion on consolidation of item memory. Such an enhancement effect has been found in a number of other studies (e.g., Liu, Graham, & Zorawski, 2008; Nielson & Arentsen, 2012; Nielson & Meltzer, 2009; Nielson & Powless, 2007; Wang & Fu, 2010). In addition, it has been shown that post-learning positive emotion, whether elicited by intrinsic reward (Nielson & Bryant, 2005) or by a comic video (Nielson & Powless, 2007), can enhance consolidation of item memory and the enhancement effect has been demonstrated to remain whether the learning stimuli are negative or positive (Nielson & Powless, 2007, but see Liu et al., 2008).

However, the majority of the prior studies used only item memory tasks, so there is a question: Does the enhancement effect extend to consolidation of source memory? This question has been investigated. In a study by Wang and Fu (2010), participants learned a list of words along with their font colors. After an immediate test, they watched a neutral, positive or negative video. A 25-min delay test showed that post-learning negative emotion enhanced consolidation of item memory (measured by delayed recognition memory) only in females; nevertheless, they found little effect on consolidation of the external-monitoring source memory (for two font colors of words). Another study by Smeets et al. (2006), however, found that post-learning stress enhanced consolidation of both item and source memory (based on internal monitoring). Although it is difficult to treat stress and emotion as identical, the finding from Smeets et al. (2006) may provide insights into the effect of post-learning negative emotion.

Although the above studies have indicated the enhancement of emotion particularly on consolidation of item memory, it is unclear whether the enhancement effect depends on the time that emotion is elicited. Abundant evidence from animal studies indicates that there is a time window for a post-training intervention (e.g., injection of drugs) to have a modulation effect. In a study by Gold and van Buskirk (1975), rats received injection of epinephrine immediately, 10 min, 30 min, or 2 h after training. A 24 h-delay test showed that, relative the control rats that received injection of saline, rats that received injection of epinephrine immediately or 10 min, but not 30 min or 2 h, after learning had significantly better memory performance. This time-dependent effect of post-learning drug administration was also observed in other studies, but it seems that the time window varies depending on the specific substance injected. Rutten et al. (2007) examined the effects of different phosphodiesterase inhibitors (vardenafil, rolipram and BAY 60-7550), which were administered directly after, 1 h, 3 h and 6 h after the first trial. A 24 h delay test showed that vardenafil had an enhancement effect only when administered directly after the first trial; rolipram showed an enhancement effect only when administered 3 h after the first trial; for BAY 60-7550 to have an enhancement effect, however, the administration needed to be conducted either directly or 3 h after the first trial. The above studies have provided important insights into the time-dependency in the effect of post-learning intervention of drugs on memory consolidation, yet little has been known about the generalizability of the time-dependency observed in animals to humans.

Studies have shown that in humans there is also time dependency in the effect of post-learning intervention on memory consolidation. For instance, Nielson and Powless (2007) found that post-learning negative and positive emotion enhanced consolidation of item memory for a word list only when emotion elicitation occurred immediately, 10 min, or 30 min, but not 45 min after learning. This time-dependency has also been replicated in a study by Judde and Rickard (2010), in which music was used to elicit emotion. Participants who listened to emotional music 20 min, but not immediately or 45 min after learning, had better delayed recognition memory than the control group who did not listen to music. Therefore, in humans as in animals, there is also a time-dependent effect of post-learning intervention.

It can be seen from the above evidence from animal and human studies that the time window for post-learning intervention differs widely depending on factors such as learning tasks and type of intervention (e.g., drugs versus emotion). Different studies seem to suggest different relationships between the intervention delay (i.e., interval between the end of learning/training and beginning of intervention) and delayed memory performance. The extant human evidence, however, seems to suggest that post-learning emotion has an enhancement effect when induced up to 30 min after learning. Importantly, 45 min after learning there seems to be a stable boundary where emotion loses its effect on memory consolidation. Nevertheless, as demonstrated by animal studies, the effect of intervention may be contingent upon memory tasks. However, the prior studies (Judde & Rickard, 2010; Nielson & Powless, 2007), which showed a time-dependent effect of emotion, only used tasks of item memory. In addition, the studies (e.g., Smeets et al., 2006; Wang & Fu, 2010) which indeed examined source memory did not investigate whether the delay of post-learning intervention can be modulatory. Therefore, the following questions remain: Does the time-dependent effect on consolidation of item memory extend to consolidation of source memory? If so, is the pattern of time-dependency the same as that for consolidation of item memory? Specifically, is 45 min after learning still the boundary where emotion has no effect?

In an attempt to provide answers to the above questions, the current study with two experiments examined the effect of post-learning negative emotion on consolidation of both item and source memory. The importance of the current investigation lies in at least two aspects. First, source memory is an integral element of episodic memory. Despite the abundant studies on the effect on the consolidation of item memory, it is by collecting evidence regarding source memory that a comprehensive understanding of the effect of emotion on consolidation of episodic memory can be achieved. Specifically, if it turns out that differential patterns exist for consolidation of item versus source memory, then it is important to establish a theory on consolidation of source memory separate from the theory based on consolidation of item memory. Second, it has been suggested that post-learning emotion can be used as a strategy of memory intervention (Nielson & Powless, 2007). In order to have a desired effect of intervention, it is crucial to understand whether the enhancement effect on consolidation of item memory can be generalized to consolidation of source memory. In educational settings, students may be required not only to remember a piece of information, but also to remember the corresponding contextual details. Without the knowledge regarding whether post-learning emotion has similar or differential effects on consolidation of item memory and source memory, it can be fruitless or even counter-productive to elicit post-learning emotion for a task that entails source memory, in a way that is beneficial for item memory. Therefore, it is of practical significance to understand whether the effect of post-learning emotion can be contingent upon the nature of a memory task.

It was hypothesized that post-learning negative emotion would have a time-dependent effect on consolidation of item memory, based on the findings from prior studies (Judde & Rickard, 2010; Nielson & Powless, 2007). Specifically, the enhancement effect would be present when emotion was elicited up to 30 min, but not 45 min, after learning. With regard to source memory, it is difficult to make a direct hypothesis due to the scanty prior findings. However, based on the evidence for dissociation between item and source memory (e.g., Glisky et al., 1995), it was hypothesized that the time-dependency in the effect on consolidation of source memory would be different from that in the effect on consolidation of item memory.

2. Experiment 1

2.1. Method

2.1.1. Participants

A total of 121 undergraduates (38 males and 83 females, age range 18–24 years, mean age = 21.09 years, SD = 1.05 years) volunteered to participate in the experiment. One hundred and nineteen participants reported themselves to be right-handed and the remaining two participants reported themselves to be ambidextrous. Informed consent was obtained from all participants.

2.1.2. Stimuli

2.1.2.1. Video clips. Two 3 min video clips were used. For the control group the video clip was about how to repair a VCD drive; for the negative group, the video clip was about a man brutally beating a pregnant woman in a cake shop, a pilot study in which 16 males and 20 females (age range 17–24 years, mean age = 19.86 years, SD = 1.57 years) assessed the effectiveness of the two videos. Participants reported their pleasure and arousal on a 9-point scale (with 1 indicating the least degree and 9 the highest degree) before and after watching a video. They also gave retrospective reports of their pleasure and arousal that they experienced during watching.

A one-way (emotion group: control and negative) ANOVA conducted on post-watching pleasure ratings (with pleasure ratings before watching as the covariate) showed a significant main effect of emotion group, $F(1, 33) = 38.78$, $p < .001$, $\eta^2 = .54$, indicating that participants' pleasure after watching in the negative group (M = 1.77, SE = .26) was lower than that in the control group (M = 4.49, SE = .35).

A similar ANOVA conducted on arousal ratings also showed a significant main effect of emotion group, $F(1, 33) = 6.21$, $p = .02$, $\eta^2 = .16$, indicating that participants' arousal after watching in the negative group (M = 5.86, SE = .37) was higher than that in the control group (M = 4.32, SE = .49).

Furthermore, one sample t tests showed that, in the negative group, pleasure during watching was significantly lower than 5 (i.e., the middle point of the scale), $t(22) = -10.97$, $p < .001$, whereas in the control group, pleasure during watching did not significantly differ from 5, $t(12) = .23$, $p = .82$. In addition, in the negative group, arousal during watching was significantly higher than 5, $t(22) = 4.91$, $p < .001$, whereas in the control group, arousal during watching was significantly lower than 5, $t(12) = -1.98$, $p = .07$.

2.1.2.2. Words. A total of 58 two-character Chinese words were used, including 6 words for the practice phase. The remaining 52 words, many (71%) of which were selected from a pool of 333 words (Wang & Fu, 2010), were used for the formal learning phase. All words had been rated regarding pleasantness, arousal, abstractness, and familiarity on 9-point scales. Similar to a prior study by Kensinger and Corkin (2003), two words were set at the beginning and 2 words at the end of the learning list to buffer primacy and recency effects. The other 48 words were evenly divided to form two sets of 24 words (see Appendix A), matched on pleasantness ($M_{set1} = 4.96$, $M_{set2} = 4.91$, $p = .65$), arousal ($M_{set1} = 4.67$, $M_{set2} = 4.73$, $p = .65$), familiarity ($M_{set1} = 6.27$, $M_{set2} = 6.39$, $p = .52$), abstractness ($M_{set1} = 4.92$, $M_{set2} = 4.81$, $p = .66$) and word frequency ($M_{set1} = .010$, $M_{set2} = .013$, $p = .61$). Furthermore, the above two sets of words were used, in a counterbalanced manner, as targets in the learning stage and distractors in the testing session.

2.1.3. Design and procedure

A 2 group (emotion group: control and negative) and elicitation delay (5 min, 30 min and 45 min) factorial design was used, with emotion group and elicitation delay representing the two between-subjects factors. The determination of the levels of elicitation delay was primarily based on prior studies (e.g., Nielson & Powless, 2007). Participants were randomly assigned to the 6 experimental conditions such that for the control group there were respectively 21, 19 and 20 participants assigned to the above three conditions of elicitation delay and for the negative group there were respectively 19, 22 and 20 participants assigned to the above three conditions of elicitation delay.

The experiment was developed using E-prime 1.1 (Psychology Software, Inc.). Arriving at the laboratory and being seated, participants gave informed consent. Then they carried out several practice trials of learning, during each of which a fixation cross appeared for 1 s, followed by a word (Courier New, font size = 40) at the center of a screen for 3 s. Above the word was a hint that prompted them either to "read aloud" or to "think about" the word. At the end of each trial was a blank screen lasting for 1 s. They were instructed to memorize each word as well as the associated cognitive operation they carried out (i.e., "reading" versus "thinking") and were informed of a subsequent memory test.

Next came the formal learning stage consisting of 28 trials (4 trials for buffering primacy and recency effects), each of which had a procedure identical to that in the practice stage. Participants conducted two blocks of learning so as to avoid floor effect especially with regard to the relatively difficult task of source memory. The formal learning stage took about 5 min.

Immediately after the learning, participants carried out a free recall test within 3 min. They were asked to write down as many words as possible that they thought had occurred in the previous learning stage. Then they were randomly assigned to watch an emotionally neutral or negative video clip after 5 min, 30 min or 45 min had elapsed after the end of learning. They rated their pleasure and arousal both before and after watching a video on a 9-point scale that was used in the pilot study. They also gave retrospective reports of their pleasure and arousal that they experienced during watching. During the periods other than that for watching a video, they filled out some questionnaires, including arousal predisposition scale (Coren, 1990), emotion reappraisal and suppression scales (Gross & John, 2003), Beck Depression Inventory (Beck, 1967) and State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). They also carried out mathematical tasks (e.g., counting backwards by 3 from 2000). The amount of time for these filler tasks was identical for participants across the six experimental conditions.

Twenty-four hours later, participants returned to the laboratory. They first rated their pleasure and arousal on a 9-point scale as described above and then they took surprise memory tests beginning with free recall within 3 min. Afterwards they entered the block containing 48 trials for tests of recognition and source memory.

The previously encoded 24 words (excluding the 4 words serving to buffer primacy and recency effects) were mixed with 24 new words and then randomly presented at the center of a screen. During each trial, a fixation cross appeared for 1 s, followed by a word, below which there were two option buttons representing "I learned this word" and "I did not see this word". When participants gave an affirmative response, they were asked to decide whether they read aloud or thought about the word during the initial learning stage. They were instructed to be as accurate as possible without rushing to make a response. Finally they were thanked and asked to leave the laboratory.

Table 1
Number of participants in the 6 conditions for final analyses of free recall, recognition and source memory in Experiment 1.

Emotion groups	5-min delay	30-min delay	45-min delay
Control	$N = 18$ 5 males, 13 females	$N = 18$ 6 males, 12 females	$N = 18$ 6 males, 12 females
Negative	$N = 18$ 6 males, 12 females	$N = 19$ 6 males, 13 females	$N = 15$ 5 males, 10 females

2.1.4. Statistical analyses

All statistical analyses were conducted using SPSS 13.0. Accuracy of free recall was determined by the number of correctly recalled words divided by the total number of learned words. Accuracy of recognition memory (*Pr*) was calculated by subtracting false alarm rates from hit rates (Snodgrass & Corwin, 1988). Accuracy of source memory was obtained by the percentage of correctly recognized words for which the sources ("reading" versus "thinking") were correctly identified.

To examine the effectiveness in emotion induction, a one-way ANOVA (emotion group: control and negative) was respectively conducted on post-watching pleasure and arousal ratings, with the pleasure and arousal ratings before watching as the covariates. To examine the effect on memory consolidation, a one-way ANOVA was conducted on delayed recall performance with the immediate recall performance as the covariate. The ANOVA was also conducted on delayed recognition and source memory. In addition, an ANOVA was also conducted on delayed hit rates and false alarm rates.

Data points of 7 participants were not collected due to participants' absence in the 24 h delay test or computer malfunction. The data of 2 participants whose delayed free recall performance was zero and data of 2 participants whose delayed recognition performance was lower than zero were excluded. Four participants whose source memory performance was detected as outliers (with SPSS "explore") were excluded from the analyses. Eventually, data of 106 participants were incorporated in the analyses. The number of participants was presented in Table 1.

2.2. Results

2.2.1. Participants' characteristics

Participants' age and other characteristics (arousal predisposition, emotion reappraisal, emotion suppression, state anxiety, trait anxiety, and depression) from the questionnaires filled out as filler tasks were obtained and presented, along with the inferential test results, in Table 2.

2.2.2. Manipulation check for emotion elicitation

The ANOVA on pleasure ratings showed a significant main effect of emotion group, $F(1, 97) = 88.51$, $p < .001$, $\eta^2 = .48$, indicating that pleasure ratings after watching was lower in the negative ($M = 2.04$, $SE = .20$) than in the control group ($M = 4.75$, $SE = .20$). The ANOVA on ratings of arousal also showed a significant main effect of emotion group, $F(1, 97) = 9.43$, $p = .003$, $\eta^2 = .09$, indicating that arousal ratings after watching was higher in the negative ($M = 5.62$, $SE = .29$) than in the control group ($M = 4.38$, $SE = .28$). These results, along with those from the pilot study, indicated that both the neutral and negative videos used in the current study were effective.

Furthermore, one sample *t* tests showed that, in the negative group, pleasure during watching was significantly lower than 5 (i.e., the middle point of the scale), $t(50) = -18.03$, $p < .001$, whereas in the control group, pleasure during watching did not significantly differ from 5, $t(52) = -1.33$, $p = .19$. In addition, in the negative group, arousal during watching was significantly higher than 5, $t(50) = 2.30$, $p = .026$, whereas in the control group, arousal during watching was marginally significantly lower than 5, $t(52) = -1.98$, $p = .054$.

2.2.3. Effects on memory consolidation

The immediate and delayed free recall performances were presented in Table 3.

The ANOVA on free recall performance showed a significant main effect of emotion group, $F(1, 99) = 5.67$, $p = .02$, $\eta^2 = .05$, indicating a higher delayed recall performance in the negative ($M = .28$, $SE = .01$) than in the control group ($M = .24$, $SE = .01$). The main effect of elicitation delay was not significant, $F(2, 99) = 1.15$, $p = .32$, $\eta^2 = .02$. The interaction between emotion group and elicitation delay was not significant (see Fig. 1A), $F(2, 99) = .27$, $p = .76$, $\eta^2 = .005$.

Hit rates and false alarm rates were presented in Table 4. The ANOVA showed no significant main effects nor interactions on hit rates or false alarm rates (all $ps > .30$) except for the significant main effect of elicitation delay on hit rates, $F(2, 100) = 3.09$, $p = .05$, $\eta^2 = .06$, indicating lower hit rates in the 30-min elicitation delay ($M = .74$, $SE = .03$) than in the 5-min ($M = .83$, $SE = .03$) ($p = .02$) or 45-min elicitation delay ($M = .81$, $SE = .03$) ($p = .06$).

The ANOVA on delayed recognition accuracy (*Pr*) showed a non-significant main effect of emotion group, $F(1, 100) = .35$, $p = .56$, $\eta^2 = .003$, indicating similar recognition memory in the control ($M = .51$, $SE = .03$) and negative groups ($M = .48$, $SE = .03$). The main effect of elicitation delay was not significant, $F(2, 100) = 1.64$, $p = .20$, $\eta^2 = .03$. The interaction between emotion group and elicitation delay was not significant, $F(2, 100) = .21$, $p = .82$, $\eta^2 = .004$.

One-sample *t* tests showed that in all the six conditions, delayed source memory performance was significantly above chance level except for the negative group in the 30 min delay where source memory was marginally higher than 0.5 ($p = .057$). The ANOVA showed non-significant main effects of emotion group and elicitation delay, $F(1, 100) = .41$, $p = .52$, $\eta^2 = .004$, and $F(2, 100) = 1.07$, $p = .35$, $\eta^2 = .02$, respectively. The interaction between emotion group and elicitation delay was significant, $F(2, 100) = 4.46$, $p = .014$, $\eta^2 = .08$ (see Fig. 1C). Further analyses showed that there was a trend for a significant main effect of emotion group in the condition of 5 min elicitation

Table 2
Participants' age and other characteristics (arousal predisposition, emotion reappraisal, emotion suppression, state anxiety, trait anxiety, and depression) as reflected from questionnaires that were filled in as filler tasks in Experiment 1. Values in parentheses stand for standard errors.

Groups	Age	Arousal predisposition	Emotion reappraisal	Emotion suppression	State anxiety	Trait anxiety	Depression
Control	21.39	35.50	29.39	13.67	41.72	45.78	9.61
(5-min delay)	(.30)	(1.26)	(1.15)	(1.15)	(1.94)	(1.86)	(1.66)
Control	21.06	31.83	29.00	15.00	43.89	44.78	11.94
(30-min delay)	(.30)	(1.26)	(1.15)	(1.15)	(1.94)	(1.86)	(1.66)
Control	20.82	36.53	28.06	15.18	45.94	49.18	13.18
(45-min)	(.31)	(1.30)	(1.19)	(1.18)	(2.00)	(1.91)	(1.71)
Negative	21.00	37.28	27.94	13.44	45.39	47.00	9.28
(5-min delay)	(.23)	(1.38)	(1.25)	(.94)	(1.43)	(1.68)	(2.03)
Negative	21.11	36.39	27.39	12.78	44.22	47.67	12.44
(30-min delay)	(.23)	(1.38)	(1.25)	(.94)	(1.43)	(1.68)	(2.03)
Negative	21.27	36.47	29.67	15.73	41.87	46.27	11.20
(45-min)	(.27)	(1.52)	(1.37)	(1.03)	(1.57)	(1.84)	(2.23)
p values	$p = .75$	$p = .14$	$p = .70$	$p = .47$	$p = .27$	$p = .47$	$p = .71$

Table 3
Immediate and delayed free recall performance in the six experimental conditions in Experiment 1. Values in parentheses stand for standard errors.

Emotion groups	Elicitation delay					
	5-min		30-min		45-min	
	Immediate	Delayed	Immediate	Delayed	Immediate	Delayed
Control	.37 (.03)	.27 (.04)	.29 (.03)	.21 (.03)	.30 (.03)	.24 (.03)
Negative	.36 (.03)	.34 (.04)	.27 (.03)	.23 (.03)	.28 (.03)	.27 (.03)

delay, $F(1, 34) = 3.03$, $p = .09$, $\eta^2 = .08$, indicating higher source memory in the negative group ($M = .68$, $SE = .03$) than in the control group ($M = .60$, $SE = .03$). The main effect of emotion group was also significant in the condition of 30 min elicitation delay, $F(1, 35) = 6.53$, $p = .015$, $\eta^2 = .16$, indicating lower source memory in the negative group ($M = .55$, $SE = .03$) than in the control group ($M = .65$, $SE = .03$). However, the main effect of emotion group was not significant in the condition of 45 min elicitation delay, $F(1, 31) = 1.27$, $p = .27$, $\eta^2 = .04$.

The analyses also showed that for the control group, source memory did not significantly differ across the three conditions of elicitation delay, $F(2, 51) = .48$, $p = .62$, $\eta^2 = .02$. For the negative group, nevertheless, source memory significantly differed across the three conditions of elicitation delay, $F(2, 49) = 6.55$, $p = .003$, $\eta^2 = .21$, indicating that source memory in the condition of 30 min elicitation delay ($M = .55$, $SE = .03$) was significantly lower than in the conditions of 5 min ($M = .68$, $SE = .03$) ($p = .002$) and 45 min delay ($M = .67$, $SE = .03$) ($p = .006$) and similar source memory in the conditions of 5 min and 45 min elicitation delay ($p = .81$).

Experiment 1 showed that post-learning negative emotional arousal enhanced consolidation of memory as measured by delayed free recall and source memory performance. These findings were consistent with the results from prior studies (e.g., Nielson et al., 2005) and extended the literature by showing that the effect of emotional arousal can extend to source memory as a critical aspect of episodic memory. However, in Experiment 1, participants took an immediate test of free recall, whereas there was no immediate test of source memory. In addition, the paradigm used in Experiment 1 had the disadvantage of restricting source memory to recognition memory (i.e., hit responses). To avoid the problems mentioned above, Experiment 2 was conducted in which participants took tests of source memory for all encoded words both immediately and 24 h after the end of learning.

3. Experiment 2

3.1. Method

3.1.1. Participants

A total of 75 undergraduates (25 males and 50 females, age range 17–23 years, mean age = 19.57 years, $SD = 1.00$ year) volunteered to participate in the experiment. All participants reported themselves to be right-handed except for one participant who reported herself to be ambidextrous. Informed consent was obtained from all participants.

3.1.2. Stimuli

The video clips and words were the same as those used in Experiment 1.

3.1.3. Design and procedure

A one-way (emotion group: control and negative) design was used, with emotion group representing the between-subjects factor. In the control and negative groups there were respectively 37 (12 males and 25 females) and 38 participants (13 males and 25 females).

The procedure of encoding was the same as in Experiment 1. Immediately after the learning, however, participants took a test for source memory. They were presented with 28 words (including the four words used to buffer primacy and recency effects) and for each word they were asked to judge whether they had "read" or "thought about" it during the previous learning stage. The immediate test took about 5 min.

Following the immediate test, they were randomly assigned to watch an emotionally neutral or negative video clip. They rated their pleasure and arousal both before and after watching a video on a 9-point scale that was used in the pilot study. They also gave retrospective reports of their pleasure and arousal that they experienced during watching. As in Experiment 1, after watching a video, participants filled out some questionnaires (e.g., arousal predisposition scale) and executed some mathematical tasks (e.g., counting backwards from 2000 by 3).

Twenty-four hours later, participants returned to the laboratory to take surprise memory tests. They were again presented with the 28 words (including the 4 words used to buffer primacy and recency effects) and were asked to decide whether they had "read" or "thought about" each word. They were encouraged to be as accurate as possible. Following the delayed tests, they were thanked and asked to leave the laboratory.

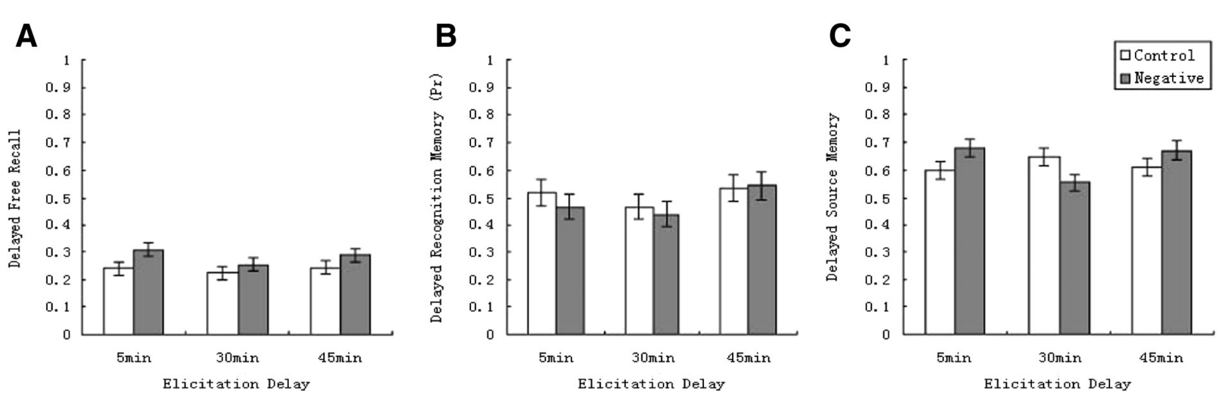

Fig. 1. (A) Regardless of elicitation delay, delayed free recall performance was higher in the negative than in the control group. (B) Regardless of elicitation delay, delayed recognition did not significantly differ between the control and negative groups. (C) There was a significant interaction between emotion group and elicitation delay. With a 5 min delay of emotion induction, there was a trend for source memory to be higher in the negative group than in the control group. With a 30 min delay of emotion induction, however, lower source memory was observed in the negative group than in the control group. The main effect of the emotion group was not significant in the 45 min delay of emotion induction.

Table 4
Hit rates and false alarm rates in the six experimental conditions. Values in parentheses stand for standard errors.

Emotion groups	Elicitation delay					
	5-min		30-min		45-min	
	H	FAR	H	FAR	H	FAR
Control	.83 (.04)	31 (.04)	.73 (.04)	.26 (.04)	.80 (.04)	.26 (.04)
Negative	.82 (.04)	.35 (.04)	75 (.04)	.31 (.04)	.83 (.04)	.28 (.05)

3.1.4. Statistical analyses

To examine the effectiveness in emotion induction, a one-way ANOVA (emotion group: control and negative) was respectively conducted on post-watching pleasure and arousal ratings, with the pleasure and arousal ratings before watching as the covariates. To examine the effect on source memory consolidation, a one-way ANOVA was conducted on source memory accuracy, with source memory in the immediate test as the covariate.

3.2. Results

3.2.1. Participants' characteristics

Participants' age and other characteristics (arousal predisposition, emotion reappraisal, emotion suppression, state anxiety, trait anxiety, and depression) from the questionnaires filled out as filler tasks were obtained and presented, along with the inferential test results, in Table 5.

3.2.2. Manipulation check for emotion elicitation

The ANOVA on pleasure ratings showed a significant main effect of emotion group, F (1, 75) = 133.33, $p < .001$, $\eta^2 = .64$, indicating lower pleasure ratings in the negative ($M = 2.09$, $SE = .19$) than in the control group ($M = 5.33$, $SE = .20$). The ANOVA on arousal ratings also showed a significant main effect of emotion group, F (1, 75) = 13.35, $p < .001$, $\eta^2 = .15$, indicating higher arousal ratings in the negative ($M = 6.15$, $SE = .26$) than in the control group ($M = 4.78$, $SE = .27$). Taken together, the results indicated the effectiveness of the videos used in the current study.

3.2.3. Effects on memory consolidation

The immediate and delayed source memory performances were presented in Table 6.

One-sample t tests showed that in the two emotion groups, both immediate and delayed source memory performances were significantly above chance level (all ps < .001). The ANOVA on delayed source memory (with immediate source memory as the covariate) showed a significant main effect of emotion group, F (1, 75) = 5.89, $p = .018$, $\eta^2 = .07$, indicating higher delayed source memory in the negative group ($M = .77$, $SE = .02$) than in the control group ($M = .71$, $SE = .02$).

4. Discussion

The purpose of the current study was to investigate the time-dependent influences of negative emotion on consolidation of item and internal-monitoring source memory. The findings were the following: 1) Negative emotion enhanced consolidation of item memory

Table 6
Immediate and delayed source memory performance in the two emotion groups in Experiment 2. Values in parentheses stand for standard errors.

Groups	Immediate	Delayed
Control	.81 (.02)	.69 (.02)
Negative	.85 (.02)	.78 (.02)

(as measured by retention ratio of free recall) regardless of delay of emotion elicitation; and 2) When elicited at a 5 min delay, negative emotion tended to enhance consolidation of source memory. Nevertheless, when elicited at a 35 min delay, negative emotion reduced consolidation of source memory. When elicited at a 45 min delay, negative emotion had little effect on consolidation of source memory. To the best of our knowledge, this is the first study that has discovered a time-dependent effect of video-clip induced negative emotion on consolidation of source memory.

Confidence in the current results may be based on several factors. First, the results could not be attributed to differences in characteristics of participants across experimental conditions. Participants were randomly assigned to the various experimental conditions, which provided the basis for the assumption that the participant groups were comparable. Although random assignment does not necessarily mean that no differences existed between these groups, participants across the conditions did not significantly differ on age, arousal predisposition, emotion suppression, emotion reappraisal, state anxiety, trait anxiety and depression scores. Particularly, the fact that participants did not differ on state anxiety suggested that the effects of videos on emotion were restricted around the watching period and did not extend into other periods of time. Second, participants across the experimental conditions underwent identical experimental procedures and instructions in the same laboratory except for the different videos for emotion induction and the different delays until watching videos. Furthermore, efforts were made to make sure that all participants spent similar amounts of time filling out the questionnaires and executing the mathematical tasks. Third, participants across the conditions did not significantly differ on pleasure ($p = .49$ and $p = .44$ respectively in Experiments 1 and 2) and arousal ($p = .65$ and $p = .35$ respectively in Experiments 1 and 2) immediately before the delayed memory tests were conducted 24 h after learning. Therefore, the effects observed in the current study cannot be attributed to any differences regarding emotional states before delayed tests.

4.1. Enhancement effect of negative emotion on consolidation of item memory

Consistent with prior studies (e.g., Liu et al., 2008; Nielson et al., 2005), the current study showed that post-learning negative emotion enhanced consolidation of item memory as measured by recall performance. Thus, the current study, along with the existent literature, provides the converging evidence for the robust enhancement effect of negative emotion on item memory as measured by free recall performance. Furthermore, the current study extends the literature by showing that the enhancement effect can remain at least with three elicitation delays. Nevertheless, it is worth noting that although there was no significant interaction between emotion group and elicitation delay on retention ratio of free recall performance, the analyses showed that the size of emotion group was the largest in the 30 min elicitation

Table 5
Participants' age and other characteristics (arousal predisposition, emotion reappraisal, emotion suppression, state anxiety, trait anxiety, and depression) as reflected from questionnaires that were filled in as filler tasks in Experiment 2. Values in parentheses stand for standard errors.

Groups	Age	Arousal predisposition	Emotion reappraisal	Emotion suppression	State anxiety	Trait anxiety	Depression
Control	19.54 (.16)	33.73 (.83)	28.41 (.66)	13.84 (.66)	40.73 (1.21)	44.11 (1.32)	7.76 (1.19)
Negative	19.56 (.16)	35.00 (.79)	28.20 (.63)	13.78 (.63)	41.39 (1.15)	44.88 (1.25)	7.66 (1.13)
p values	$p = .93$	$p = .27$	$p = .82$	$p = .95$	$p = .69$	$p = .67$	$p = .95$

delay, thus suggesting that a moderate length of delay in emotion induction seems to be optimal for consolidation of item memory as measured by retention of free recall. However, considering the small effect size derived from the interaction analyses, caution must be exercised when drawing any conclusion regarding the time-dependency in the effect of post-learning emotional arousal on consolidation of memory as measured by free recall.

Nevertheless, unlike prior research (e.g., Judde & Rickard, 2010; Nielson & Powless, 2007; Nielson et al., 2005) but consistent with Liu et al. (2008), the current study observed little effect of negative emotion on recognition memory performance. This does not necessarily mean that the effect observed in prior studies was erroneous; rather, the null effect on delayed recognition memory may be due to the particular experimental tasks and procedures. For instance, in the current study participants had to conduct a relatively difficult task of memorizing both words and the corresponding source information, whereas in some prior studies that showed the enhancement effect, participants were not instructed to memorize words. For instance, in a similar study by Nielson and Powless (2007), participants learned a list of 30 words and were asked to silently repeat those words as they were presented. The task used in the current study may detract from the attentional resources allocated to item information, thus altering the pattern of results regarding the effect on delayed recognition memory. The null effect on memory consolidation as measured by delayed recognition memory appears to suggest that the effect of post-learning negative emotion may be modulated by task complexity or difficulty. In addition, unlike the study by Nielson and Powless (2007), in the current study, in order to avoid a floor effect in the 24 h delay tests, two learning blocks were used, which may have led to memory traces that were initially stronger than those in previous studies. Thirdly, it must be noted that there was a major difference between the experimental design of Nielson and Powless (2007) and ours. In their study, there was only one control condition, with which the experimental conditions were compared. In the current study, however, we used a 2 × 3 factorial design, with emotion condition (control and negative) and elicitation delay (5 min delay, 30 min delay and 45 min delay) being the two independent variables. Thus there were 3 control groups of participants. In the study by Nielson and Powless (2007), after learning a list of 30 nouns and taking an immediate free recall, control participants were then called out to a second room by participant number and dismissed. Thus it is unclear what results would occur if they also had three elicitation delays for control participants. Furthermore, in their study, since the control participants did not watch videos and the length of experimental session in the first day was much shorter for the control group than for the experimental groups, the effect of emotional arousal might have been entangled with the differences in the length of experimental session in the first day.

4.2. Effect of negative emotion on consolidation of source memory

The current study is the first to have discovered a time-dependent effect of video-induced negative emotion on consolidation of source memory, thus extending the literature by indicating that the time-dependency in the effect of negative emotion is not confined to consolidation of item memory as have been shown in many prior studies (e.g., Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003). Importantly, in response to the questions raised in the Introduction, the pattern of time-dependency is not exactly the same as that for consolidation of item memory. Furthermore, combined with the evidence showing that negative emotion, induced during encoding, enhances source memory, the current finding indicates a rather broad facilitating role of negative emotion in different aspects of episodic memory. Nevertheless, the current finding provides the caveat that there is a boundary condition: negative emotion elicited at a 45-min delay did not affect consolidation of source memory, thus strengthening the possibility that 45 min after learning is a boundary when at least negative emotion loses its power to influence memory consolidation.

One novel point from the current study lies in the demonstration of the time-dependent effect of negative emotion in that an enhancement effect occurred only when emotion was elicited 5 min after learning. Furthermore, there seemed to be an impairment effect when emotion was elicited 30 min after learning and the effect seemed to disappear when emotion was elicited 45 min after learning. These findings are generally consistent with prior studies showing the temporal window regarding consolidation of item memory (Judde & Rickard, 2010; Nielson & Powless, 2007), but it is difficult to explain the impairment effect that occurred in the 30-min elicitation delay. One possibility is that, when emotion elicitation occurred 30 min after learning, participants in the negative group had poorer general memory ability, yet analyses of the data from the immediate free recall test provided the evidence that participants did not significantly differ with regard to baseline memory performance. Another possibility is that the participants in the negative group had poorer general capacity of memory retention; however, this seems unlikely because, regardless of elicitation delay, participants in the negative group had better retention ratio than those in the control group.

Nevertheless, a prior study by Wang and Fu (2010) found that post-learning negative emotion enhanced consolidation of item memory (as measured by recognition memory) but did not enhance consolidation of source memory. Several reasons as follows may be possible. First, in their study the source memory task was based on external monitoring (i.e., distinguishing between two font colors), whereas in the current study the source memory task was based on internal monitoring (i.e., distinguishing between two internal operation of “reading” and “thinking”). Interestingly, Smeets et al. (2006) showed the enhancement effect of post-learning stress on consolidation of internal-monitoring source memory. Taken together, it is likely that a source memory task based on internal monitoring rather than external monitoring is more sensitive to the influences of post-learning emotional or stress interventions. Second, in the study by Wang and Fu (2010), memory tests were carried out around 30 min after learning. Because memory consolidation takes time (McGaugh, 2000), it is not surprising to see the enhancement effect in the current study, where participants took memory tests 24 h after learning.

The current finding regarding source memory poses a challenge to the notion that the enhancement effect of post-learning emotion occurs shortly after learning and remains for some time until a certain amount of time (e.g., 30 min) had elapsed after learning. The trajectory for the effect of at least negative emotion may be far more complicated than a linear one and this may partly be due to the complicated nature of memory consolidation, which is subject to a wide variety of factors (Alger et al., 2012; Colrain et al., 1992; Nielson et al., 2014). In the period shortly after learning, during which the trace of source memory can be in a fragile state, elicitation of negative emotion may enhance memory consolidation by activating the amygdala, which, in turn, contributes to the long-term potentiation in the hippocampus (McGaugh, 2002). With the passage of time the trace of source memory is supposed to become more stable, yet negative emotion induced 30 min after learning still reduced consolidation of source memory. One speculation may be that, although becoming more stable over time, the trace of source memory at a certain time following learning can again become sensitive to the disruption of external interferences especially negative emotion, resulting in poorer delayed memory performance. This speculation, though counter-intuitive, seems to be consistent with evidence from an animal study (Igaz, Vianna, Medina, & Izquierdo, 2002), which showed that consolidation of memory (i.e., contextual fear conditioning) relied on two consolidation periods requiring synthesis of new mRNAs. Specifically, it was found that there were two important periods for hippocampal gene expression: around the time of training and 3–6 h after training. Is it possible that in humans memory consolidation also involves multiple critical time windows? This issue may be investigated in future studies.

It is worth noting that in the current study a video clip was used to induce negative emotion. Considering that music had also been used in some prior studies (e.g., Judde & Rickard, 2010), in future studies, therefore, music of varying valence and arousal may be elicited after learning to examine the effect of emotion on consolidation of source memory, an aspect of memory which was not considered in the study by Judde and Rickard (2010).

In Experiment 1, source memory was not tested immediately, so it is difficult to know whether participants in the various conditions had comparable baseline source memory performance. A possible approach is to instruct participants to recall both words and their associated sources in the test immediately after learning. Another issue worth mentioning is that source memory was only tested for learned items judged as "old". Although widely used in a large number of prior studies (e.g., Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003; Wang & Fu, 2010), this paradigm, through which participants have to accurately retrieve an item in order to be asked about its source information, has the disadvantage of restricting source memory evaluation to recognition performance, which, in turn, may greatly impact the interpretation of effect of post-learning emotional arousal on consolidation of source memory. Nevertheless, in Experiment 2, participants did take an immediate test of source memory, in which they were instructed to decide the sources for all encoded items, thus eliminating the possibility that source memory was restricted by recognition performance or, specifically, the number of hits. Still, the results showed that post-learning emotional arousal enhanced consolidation of source memory. Taken together, the current study suggests a rather robust effect of negative emotion elicited 5 min after learning on consolidation of source memory based on internal monitoring. Justification of this statement may be from the fact that the two experiments were conducted at totally different locations with about a one-year gap and with different experimenters.

4.3. Limitations

Although the current study has yielded some interesting findings, there are some limitations worth mentioning. In Experiment 1 participants conducted free recall both immediately and 24 h after learning; but they did not take immediate test of source memory, which would render delayed source retrieval even more difficult than usual. Because participants had more opportunities to retrieve item information than source information, it is necessary to be cautious when drawing the conclusion that post-learning emotion had differential effects on consolidation of item memory and source memory. In addition, in Experiment 1 the four words, which were used to buffer primacy and recency effects, were not presented in the delayed memory test and thus were not included in the subsequent analysis. Nevertheless, the results of Experiment 2, in which source memory for all encoded words was tested, indicate that the enhancement effect of negative emotion on consolidation of source memory may exist independent of whether source memory is restricted by recognition memory.

4.4. Implications

Findings from the current study may have key implications. It has been suggested that post-learning emotional arousal can be used as a strategy for memory intervention in educational settings (Nielson & Powless, 2007). In fact, there has been evidence that post-learning emotional arousal can be used to improve consolidation of memory for lecture materials. For instance, in a study by Nielson and Arentsen (2012), participants were randomly assigned to view a neutral video clip (on cardiovascular health) or a negatively arousing video clip (on dental surgery) after a lecture of psychology. Tests conducted 2 weeks later showed that those who had watched the negatively arousing video clip had significantly better delayed memory for the course materials immediately presented before arousal manipulation than those who had watched the neutral video clip. Although further studies are needed, the finding from their study clearly suggests that attention must be paid to the timing of emotion induction so as to achieve an optimal effect.

Our study contributes to the literature by showing the time-dependency in the effect of post-learning emotional arousal on consolidation of source memory. It is worth noting that the current study examines internal source monitoring whereas external source monitoring may play a more important role in educational settings. Nevertheless, in everyday life it is important to be able to distinguish between what one thought about and what one said. For instance, you may be certain that you have verbally made an important promise to a friend, but in fact you have just thought about the promise in your mind. This kind of incident can be truly embarrassing. The current finding suggests that the consolidation of memory based on internal monitoring can be affected by emotional arousal in a time-dependent manner. Thus for people who have problems with memory based on internal monitoring, post-encoding emotional arousal might be used as a strategy of intervention.

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Appendix A. The two sets of words used in the formal learning phase and their corresponding parameters

Set	Words	Pleasantness	Arousal	Familiarity	Abstractness	Word frequency
1	含量	4.63	4.48	5.85	5.85	0.0027
1	毫米	4.74	4.74	6.32	3.03	0.00342
1	规格	4.79	4.88	5.88	5.04	0.0008
1	工会	4.87	4.26	5.65	4.35	0.0058
1	会议	4.54	4.29	6.39	3.64	0.0244
1	证据	4.65	4.74	5.74	4.94	0.00175
1	制度	4.75	4.54	6.5	5.64	0.0262
1	秩序	5.56	5.19	6.67	5.26	0.0035
1	原因	4.87	5.17	6.87	5.09	0.0115
1	化学	5.11	4.82	6.68	4.64	0.0228
1	过程	5.39	4.46	6.71	5.11	0.0208
1	样品	5.46	5.08	6.17	4.13	0.0008
1	函授	4.56	4.44	4.48	5.41	0.00053
1	功率	5.04	4.63	6.37	5.59	0.0021
1	关系	5.43	4.96	7.04	5.61	0.0474
1	方案	5.65	4.87	6.7	4.7	0.0054
1	限度	4.17	4.33	4.96	5.38	0.0011
1	政策	5.29	4.43	6.43	5.21	0.0176
1	环节	5.33	5.04	5.96	4.83	0.0012
1	质量	5.65	5.17	7.39	4.65	0.0105
1	论文	4.43	4.3	6.8	3.77	0.0035
1	物理	4.52	4.48	6.37	4.81	0.00639
1	类型	4.81	4.37	5.93	5.7	0.0028
1	范围	4.87	4.48	6.57	5.65	0.0103
2	界限	4.5	4.29	6.17	5.63	0.0008
2	意见	4.64	5.18	6.75	5.18	0.0255
2	早期	4.67	4.63	5.52	6.04	0.0028
2	两极	4.78	4.52	5	5.22	0.00076
2	体积	4.93	4.52	6.74	3.89	0.0038
2	学科	4.96	4.63	6.48	5.26	0.0034
2	根源	5	5.33	5.93	5.96	0.0018
2	弹性	5.13	5.17	6.5	5	0.0011
2	当年	5.2	5.43	6.47	4.37	0.00068
2	议会	4.79	4.71	5.18	3.96	0.00167
2	英语	5.71	5.46	7.21	3.29	0.0008
2	印象	5.74	5.56	6.67	5.89	0.00434
2	次序	5.17	5	6.54	4.25	0.0011
2	距离	4.25	4.82	6	3.89	0.00685
2	公式	4.48	4.11	7	5.15	0.0033
2	纬度	4.59	4.11	5.7	4.81	0.0023
2	理论	4.64	4.18	6.64	6.36	0.0279
2	月份	4.7	4.4	7.57	3.07	0.00084
2	下午	4.82	4.68	7.04	3.04	0.01111
2	题材	4.9	4.39	6.06	4.94	0.00137
2	社会	4.93	4.32	6.54	5.71	0.1401

(continued on next page)

(*continued*)

Set	Words	Pleasantness	Arousal	Familiarity	Abstractness	Word frequency
2	眼光	4.93	5.2	5.97	5.57	0.01004
2	结构	5.04	4.09	6.74	4.13	0.0094
2	历史	5.39	4.68	6.86	4.82	0.0516

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