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RESEARCH ARTICLE

The role of emotion arousal in the retrieval practice effect

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Abstract
Many studies have shown that practicing retrieval produces better memory retention compared to restudy. Though previous literature has provided valuable insights about the retrieval practice effect, it is still unclear how emotion arousal influences the retrieval practice effect, and whether the effect would be manifested in recollection or familiarity processes. To answer these questions, in the current study, negative and neutral words were used as stimuli and participants were asked to perform a recognition test or restudy the words after initial study. At the end of the experiment, a final recognition test with involving the remember–know paradigm was shown. Behavioral data were collected with EEG recorded throughout the experiment. The behavioral retrieval practice effect was only found for the neutral but not the negative words. Consistently, significant ERP differences between the restudy and retrieval practice conditions were only found for neutral, but not negative items, which was a component from 700 to 900 ms at left-posterior electrode cluster. Moreover, we found that the effects of emotion arousal on the retrieval practice effect were mainly reflected in the recollection process. These findings provide behavioral and neural evidence that emotion arousal can influence the retrieval practice effect.

Keywords Retrieval practice effect · Emotion arousal · Recollection · Retrieval mode · EEG/ERP

> I mean that in learning (by heart, for example), when we almost know the piece, it pays better to wait and recollect by an effort from within, than to look at the book again.
>
> William James, 1890.

Introduction

Recent studies have widely shown that tests can not only measure learning, but also produce learning itself (Chan et al. 2018; Pan and Rickard 2018; Roediger and Karpicke 2006; Roediger and Butler 2011; Roediger and Karpicke 2018; Rowland 2014). The phenomenon that retrieval practice can enhance learning and memory more than restudy is referred to as the retrieval practice effect. In a classical retrieval practice paradigm, participants are asked to study some materials (i.e., initial study). Next, they either take a test on the materials (i.e., initial test) or restudy the materials. Finally, they take a final test to evaluate their memory performance of the materials. The retrieval practice effect has been widely demonstrated using various materials in both laboratory studies and classroom-based studies (Karpicke 2017; Rowland 2014).

Though the existing literature has provided valuable insights about the retrieval practice effect, several important questions remain unanswered. First, how does emotion arousal influence the retrieval practice effect? Our everyday surroundings besiege us with different types of signals. The signals are not memorized with equal priority. Previous studies have widely shown that emotion arousal influences memory (Jia et al. 2019; Kensinger 2009; Kensinger and Ford 2019; Mather and Sutherland 2011; Schaefer et al. 2011). However, it is still unclear how emotion arousal influences the retrieval practice effect. Two interesting studies tested this idea (Emmerdinger et al. 2017; Jia et al. 2018). In one study, participants studied cue-target picture pairs and the target was either neutral or negative, then one-third of the

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pairs were tested (only presented the cue picture to reinstate the target one), one-third were restudied, and the remaining third served as control pairs. After 1 week, memory performance for all of the cue-target pairs was tested. Though the retrieval practice effect was found, no significant difference between negative and neutral conditions for the beneficial effects of retrieval was found (Emmerdinger et al. 2018). Another study (Jia et al. 2018) used negative and neutral words, and participants were asked to study the association between the word and background (circle or square). Then, half of the associations were restudied and the other half of associations were tested (only presented the word to reinstate the background). A final source memory test was conducted and found that the memory of neural and negative items similarly benefited from the retrieval practice condition, similar to Emmerdinger et al. (2018). Nonetheless, these two studies (Emmerdinger et al. 2018; Jia et al. 2018) evaluated the role of emotion arousal in the retrieval practice effect from an associative memory perspective using either cue-target or source memory paradigm. The influence of emotion arousal on associative memory (the association between the emotional item and the adjacent information) is different from the influence of emotion arousal on memory of single items (Bisby and Burgess 2013; Bisby et al. 2016; Madan et al. 2012). Thus, it is unclear how emotion arousal would influence the retrieval practice effect if single emotional items are used. There is evidence that single emotionally arousing items are often remembered better than neutral items (for review, see Buchanan 2007; Kensinger 2009; Labar and Cabeza 2006), which is referred to as memory advantage of emotional items. Thus, one possibility is that the retrieval practice effect would be larger for emotional items compared to neutral items. As noted by the distribution-based bifurcation model, retrieved but not non-retrieved items in the retrieval practice condition were strengthened (Halamish and Bjork 2011; Kornell et al. 2011). As a result, the memory advantage of emotional items can possibly benefit the retrieval practice effect. Another possibility is that the retrieval practice effect would be larger for neutral items compared to emotional items, because the memory advantage of emotional items might lead to high performance for restudy condition, which can override the benefits produced by the retrieval practice condition.

Second, how does the effect of emotion arousal on the retrieval practice effect manifest in different recognition processes (i.e., recollection and familiarity)? The dual-process theory posits that recognition process depends on two distinct memory processes: familiarity and recollection (Yonelinas 2002). Familiarity (corresponding to 'know') is a fast and automatic process accompanied by feelings of occurrence without any details, whereas recollection (corresponding to 'remember') is a slower process along with conscious retrieval of encoding episodic details (Yonelinas 2002). The remember/know paradigm has been used to dissociate recollection from familiarity (e.g., Li et al. 2016; Li et al. 2017; Wang et al. 2018; for a review, see Yonelinas 2002). Though old/new recognition test has been used as a final test in retrieval practice research (see Roediger and Karpicke 2006 for a review), it cannot determine which recognition process (i.e., familiarity or recollection, or both) would be influenced by the retrieval practice. In addition, the previous studies have shown that emotion influences recollection, but has little or no effect on familiarity (for a review, see Yonelinas and Ritchey 2015; e.g., Dolcos et al. 2005; Sharot et al. 2004). It remains unclear if the selective influences of emotion on recollection would still occur in the retrieval practice effect. Using the remember/know paradigm in the final test, our experimental design provides the opportunity to determine how the effects of emotion arousal on the retrieval practice effect are manifested in recollection and familiarity.

In summary, the aims of the current study are to examine the role of emotion arousal in the retrieval practice effect and test how the effect is represented in recollection and familiarity. To answer these questions, we employed a three-phase retrieval practice effect paradigm and used both neutral and negative words as stimuli. Emotion could be described by two affective dimensions called valence and arousal (Russell 1980; Russell and Barrett 1999). The valence dimension describes the extent to which an emotion is positive or negative, while the arousal dimension describes the intensity of an emotion from calming/subduing to exciting/agitating. Negative and positive stimuli typically have higher arousal compared to neutral stimuli, as illustrated by multiple affective databases (IAPS: Lang, Bradley & Cuthbert; IADS: Bradley and Lang 1999). Therefore, we focused on negatively arousing stimuli with relatively higher arousal instead of selecting low arousal stimuli, consistent with the previous emotional memory studies (Ponzio and Mather 2014; Finn and Roediger 2011). We used the term emotion arousal to indicate the effects of 'negative, high arousal' compared to neutral condition. Participants were asked to learn the neutral and negative words in an initial study. In a subsequent phase, for the retrieval practice condition, the studied words were presented as old items in the subsequent recognition test (retrieval practice phase) together with the new items. For the restudy condition, the words were restudied again with some new words. Note that new items are presented in both retrieval practice and restudy conditions, which is different from most studies in the overall retrieval practice literature. Forty minutes later, all studied stimuli were tested in a final test. To examine how the effect is represented in recollection and familiarity, we used remember/know paradigm in the final test that allowed for differentiation of recollection and familiarity (Rajaram 1993).

We also used the event-related potentials (ERPs) to differentiate the neural correlates between restudy task and retrieval practice task, because ERPs technique can be used to better capture the temporal dynamics of underlying neurocognitive processes during the ongoing tasks. Previous studies have shown that ERPs' difference between restudy and retrieval practice task is related to the magnitude of the behavioral retrieval practice effect (Gao et al. 2016; Jia et al. 2018). For example, Gao et al. (2016) found more positive ERPs elicited by new items in retrieval practice condition than in restudy condition from 300 to 900 ms, and the increased ERP difference was associated with the larger retrieval practice effect in later final test. Intriguingly, studies also suggested that the ERPs' difference might indicate a cognitive state of retrieval mode (Gao et al. 2016; Jia et al. 2018). Retrieval mode is a cognitive state in which an individual consciously thinks of the past when he/she encounters a potential cue (Tulving 1983; Rugg and Wilding 2000). The episodic context account suggests that retrieval mode plays an important role in the retrieval practice effect (Karpicke 2017; Karpicke et al. 2014). Several behavioral studies have investigated the role of retrieval mode in the retrieval practice effect by comparing one condition (thinking back to the study phase, i.e., in a retrieval mode) to the other condition (not thinking back to the study phase, i.e., not in a retrieval mode). For example, Karpicke and Zaromb (2010) established the importance of retrieval mode in the retrieval practice effect by showing that intentional retrieval of items led to larger benefits of memory retention compared to generating the target words without recollection. In another behavioral study, participants studied word lists, and then, either restudied the words (non-episodic task) or made list discrimination judgments by indicating in which list each word had occurred (episodic task), with all else held constant (Whiffen and Karpicke 2017). The findings showed that adopting a retrieval mode enhanced subsequent free recall compared to restudying the words.

Based on existing literature, we had the following predictions. First, for the neutral items, we expected to replicate the previously observed retrieval practice effect using similar paradigms (Gao et al. 2016; Jia et al. 2018), which reflected in enhanced memory retention for the retrieval practice relative to the restudy. Correspondingly, we predicted that the ERPs elicited by the neutral new items in retrieval practice condition would be more positive than the ERPs elicited by the neutral new items in restudy condition from 500 to 900 ms, and the location of the ERP effects would be left-posterior electrode cluster as the previous study (Jia et al. 2018) in which similar stimuli set and experimental paradigm were used. Second, we predicted a smaller retrieval practice effect for the emotional items if the memory advantage of emotional items overridden the retrieval practice effect (in which the memory enhancement produced by emotional items in restudy condition would be larger than the memory enhancement produced by retrieval practice condition), and a larger retrieval practice effect for the emotional items if the retrieval practice effect overridden the memory advantage of emotional items. Third, given the evidence that emotion arousal selectively influences recollection of the recognition processes (e.g., Yonelinas and Ritchey 2015), we predicted that the effects of emotion arousal on the retrieval practice effect might be represented in the recollection process.

Method

Participants

Twenty-eight right-handed volunteers (16 females; $M = 21.6$ years, SD = 2.42) from Capital Normal University took part in the experiment. All had normal or corrected-to-normal vision and spoke Chinese as their first language. A power analysis of behavioral effects based on effect sizes reported in the previous studies was conducted using the method implemented in R (Anderson et al. 2017). The approximate sample size to acquire a power of 0.8 at $p < 0.05$ (alpha prior = 0.1; assurance = 0.8) was 17 based on the effect size ($\eta_p^2 = 0.36$) for the Condition main effect (recognition, source, restudy) from a previous study (Gao et al. 2016). Each participant's written informed consent was approved by the Capital Normal University Institutional Review Board and received monetary compensation for their participation. Six participants were excluded from the ERP analysis because of insufficient artifact-free trials (< 16) in at least one relevant condition or have excessive EEG artifacts (EEG artifacts were exhibited on > 25% of trials), leaving a final sample of 22 participants (13 females; $M = 22.0$ years, SD = 2.12).

Materials

Four hundreds words were selected from Chinese Affective Words System (Wang et al. 2008), including 200 neutral words (70 verbs, 70 nouns, 60 adjectives) and 200 negative words (70 verbs, 70 nouns, 60 adjectives). These words were rated for valence and arousal using 9-point scales (valence: 1 = extremely unpleasant to 9 = extremely pleasant; arousal: 1 = not arousing at all to 9 = extremely arousing). The valence ratings were lower for negative than neutral words [M_{negative} (SD) = 3.05 (0.59), M_{neutral} (SD) = 5.74 (0.58), t (398) = 46.11, $p < 0.001$], and the arousal ratings were higher for negative than neutral words [M_{negative} (SD) = 6.14 (0.69), M_{neutral} (SD) = 4.75 (0.82), t (398) = 18.43, $p < 0.001$]. All the negative and neutral words

were equated for word frequency [$M_{negative}$ (SD) = 1.16 (0.49), $M_{neutral}$ (SD) = 1.18 (0.46), t (398) = 0.61, $p > 0.05$], stroke numbers [$M_{negative}$ (SD) = 17.80 (4.66), $M_{neutral}$ (SD) = 17.29 (4.12), t (398) = 1.16, $p > 0.05$], and familiarity (9-point scales: 1 = extremely un familiar to 9 = extremely familiar) [$M_{negative}$ (SD) = 5.01 (0.47), $M_{neutral}$ (SD) = 5.10 (0.96), t (398) = 18.43, $p > 0.05$]. The ratings of valence, arousal, familiarity are from the database Chinese Affective Words System (Wang et al. 2008), and the ratings of log frequency per word are from the Modern Chinese frequency dictionary (Liu 1990). Words were distributed randomly into two lists, and each list included 100 neutral and 100 negative words. The lists were distributed pseudo-randomly into "old" (previously studied) or "new" (unstudied) conditions and were counterbalanced between participants. Words were presented in white against a black background on a 17-inch computer monitor screen (1024 × 768 pixels), covering a visual angle of approximately 2.5° horizontal by 2.5° vertical.

Design

Four conditions were created from a 2 (Emotion: neutral, negative) × 2 (Learning: retrieval practice, restudy) within-subject factorial design: neutral/retrieval practice, neutral/restudy, negative/retrieval practice, and negative/restudy. The behavioral dependent variable was recognition memory performance measured by a remember/know paradigm (Rajaram 1993) in a final recognition test.

Procedure

Participants sat 80 cm in front of a 17-in computer monitor in an acoustically attenuated chamber. Participants intentionally learned four lists of words: two lists of words for the retrieval practice condition, the other two lists of words for the restudy condition. There were two phases for each of the lists (the first phase: initial study; the second phase: restudy or retrieval practice). The order of the four lists was counterbalanced across participants. Forty minutes later after these lists, a final recognition test was conducted.

In the list for retrieval practice condition, there were an initial study phase and a retrieval practice phase (initial test). In the initial study phase, participants were asked to study and memorize 25 neutral and 25 negative words. The words were presented in a random order. Each trial began with the presentation of a fixation cross presented in the center of the screen for a jittered interval of 1000–1500 ms. A word was then presented for 500 ms followed by a black screen of 500 ms. Participants were asked to indicate if they felt the words as neutral or negative by pressing different keys. After the initial study phase, there was a 5-min break before the retrieval practice phase. Participants were given a recognition memory test of 75 words, including 50 old words presented in the initial study phase and 25 new words never presented before (12 neutral, 13 negative words in one list, or 13 neutral, 12 negative in the other list). Each trial began with the presentation of a fixation cross presented in the center of the screen for a jittered interval of 1000–1500 ms. A word was then presented for 500 ms followed by a black screen of 1000 ms. The words were presented in a random order. Participants were asked to perform an old/new judgment by responding "old" if they thought that the word was presented in the initial study phase, and responding "new" if they thought it never presented before.

In the list for restudy condition, there were an initial study phase and a restudy phase. In the initial study phase, the procedure was identical to that in the retrieval practice condition, except that different word stimuli were used. After the initial study phase, there was a 5-min break followed by the restudy phase. In the restudy phase, the number of stimuli (including 50 old words presented in the initial study phase and 25 new words never presented before) and the presentation of each trial (including the timing of fixation, words, and black screen) were also the same as the retrieval practice condition. Participants were asked to memorize the words and perform the same neutral/negative judgment task as the initial study.

Participants were asked to play video games for 40 min. Then, all the participants completed a final test consisting of 200 old items (100 neutral, 100 negative) from the initial study phase and 100 brand new items (50 neutral, 50 negative) that participants have never seen in the experiment. All of the words were randomly presented. Each word was presented at the center of the screen for 2000 ms with a jittered 1000–1500 ms inter-stimulus interval. Participants were asked to perform a remember (R)/know (K)/new judgment. They were instructed to respond "Remember" by pressing "S" when they can recollect specific details associated with the item, respond "Know" by pressing "D" when they are familiar with the item without specific details, and respond "new" by pressing "J" when an item was never presented in the experiment. The keys designated for each response type were counterbalanced across subjects. EEG signals were continuously recorded throughout the experiment.

EEG recording and analysis

Continuous EEG (range 0.05–100 Hz; sampling rate 500 Hz) was recorded from 62 Ag/AgCl electrodes embedded in an elastic cap (Neuroscan QuickCaps) from standard and extended 10–20 locations (Picton et al. 2000). Voltage was referenced to the left mastoid online and re-referenced offline to the average of the left and right mastoids. Four additional electrodes were attached on the outer canthi of both eyes and above and below the left eye to monitor eye movements. Impedance was kept below 5 kΩ and signals

were amplified with a NeuroScan SynAmps system (NeuroScan Inc. Sterling, Virginia, USA). EEG data were digitally filtered with a bandpass of 0.05–40 Hz and epochs were segmented beginning 200 ms prior to stimulus onset with a length of 1700 ms. Waveforms were corrected relative to the 200 ms pre-stimulus baseline period. Trials containing voltages exceeding ± 75 μV were excluded before averaging. EOG blink artifacts were corrected using a linear regression estimate (Semlitsch et al. 1986). Experimental procedures were executed using presentation (Neurobehavioral Systems, Inc.).

Three time windows (300–500 ms, 500–700 ms, and 700–900 ms) and left-posterior electrode sites were selected based on the previous findings (Gao et al. 2016; Jia et al. 2018). ERP amplitudes were averaged over the left-posterior cluster (CP5, CP3, CP1, P5, P3, and P1) for ERP analyses. For the analysis of retrieval mode, ERPs for new items were contrasted between the retrieval practice task and the restudy task. New items were used to avoid the contamination of retrieval success (Gao et al. 2016; Jia et al. 2018).

Repeated measures analyses of variances (ANOVAs) and paired *t* tests were used to analyze the data. An alpha level of .05 was used for all statistical tests.

Results

Behavioral results

Retrieval practice test

For the retrieval practice condition, recognition performance was estimated by discrimination scores (Pr) [P(hits)-P(false alarms)] (Snodgrass and Corwin, 1988), and no significant difference was found between neutral words and negative words on Pr scores, $M_{neutral}$ (SD) = 0.62 (0.18), $M_{negative}$ (SD) = 0.64 (0.14), t (27) = 1.30, p = 0.204.

Final test

A summary of memory performance, including hit rates, false alarm rates, miss rates, and correct rejection rates is shown in Table 1. To have better estimates of memory performance that consider both hit rates and false alarm rates, Pr scores for R and K responses were calculated, respectively, for each condition (see Table 2). To examine the role of emotion arousal in the retrieval practice effect and how the effects manifested in recollection and familiarity, A 2 (emotion: neutral, negative) × 2 (learning: retrieval practice, restudy) × 2 (response: remember, know) ANOVA was conducted on the Pr scores, the results revealed that the main effect of emotion [F (1, 27) = 25.00, p < 0.001, η_p^2 = 0.48], learning [F (1, 27) = 6.59, p = 0.016, η_p^2 = 0.20], and response [F (1, 27) = 56.20, p < 0.001, η_p^2 = 0.68] were significant, emotion × learning interaction was significant, F (1, 27) = 11.27, p = 0.002, η_p^2 = 0.30, emotion × response interaction was significant, F (1, 27) = 19.08, p < 0.001, η_p^2 = 0.41, and emotion × learning × response interaction was also significant, F (1, 27) = 7.11, p = 0.013, η_p^2 = 0.21. Follow-up analyses were conducted for the emotion × learning × response interaction for each type of response, respectively. For R responses, emotion × learning interaction was significant, F (1, 27) = 15.90, p < 0.001, η_p^2 = 0.37, pairwise comparisons revealed that Pr scores were higher for

Table 2 Final recognition test: Pr scores of remember and know responses for each condition (± SD)

	Restudy		Retrieval Practice	
	PR_R	PR_K	PR_R	PR_K
Neutral	0.36 ± 0.16	0.15 ± 0.15	0.42 ± 0.16	0.15 ± 0.14
Negative	0.43 ± 0.14	0.01 ± 0.16	0.40 ± 0.15	0.04 ± 0.16

PR_R Pr scores for remember responses (hit rates of remember responses—false alarm rates of remember responses). *PR_K* Pr scores for know responses (hit rates of know responses—false alarm rates of know responses)

Table 1 Final recognition memory test: mean hit, miss rates for the old words for each condition (neutral/retrieval practice, neutral/restudy, negative/retrieval practice, and negative/restudy) (± SD), and mean correct rejection and false alarm rates for the new words for each condition (± SD)

	Old						New		
	Restudy			Retrieval practice					
	Hit_R	Hit_K	Miss	Hit_R	Hit_K	Miss	CR	FA_R	FA_K
Neutral	0.45 ± 0.17	0.33 ± 0.15	0.21 ± 0.14	0.50 ± 0.17	0.33 ± 0.13	0.17 ± 0.11	0.71 ± 0.15	0.09 ± 0.09	0.18 ± 0.11
Negative	0.59 ± 0.18	0.28 ± 0.15	0.13 ± 0.10	0.56 ± 0.19	0.31 ± 0.17	0.13 ± 0.12	0.55 ± 0.15	0.16 ± 0.13	0.27 ± 0.14

Hit_R hit rates for remember responses, *Hit_K* hit rates for know responses, *Miss* miss rates of classifying old words as new words, *CR* correct rejection rates for new words, *FA_R* false alarms rates of classifying new words as old words for remember responses, *FA_K* false alarms rates of classifying new words as old words for know responses

the retrieval practice than the restudy condition for neutral words, M_{restudy} (SD) = 0.36 (0.16), $M_{\text{retrieval practice}}$ (SD) = 0.42 (0.16), t (27) = 4.29, $p < 0.001$, Cohen's $d = 0.81$, and no significant difference was found between the retrieval practice and the restudy condition for negative words, M_{restudy} (SD) = 0.43 (0.14), $M_{\text{retrieval practice}}$ (SD) = 0.40 (0.15), t (27) = 1.47, $p = 0.15$. For K response, no significant interaction was found, F (1, 27) = 1.26, $p = 0.273$, only main effect of emotion was significant, F (1, 27) = 38.49, $p < 0.001$, $\eta_p^2 = 0.59$, Pr scores were higher for neutral than negative words, M_{neutral} (SD) = 0.30 (0.28), M_{negative} (SD) = 0.04 (0.30). Taken together, the behavior results indicated that the retrieval practice condition had better memory retention than the restudy condition only for the neutral words, but not for the negative words. Furthermore, the memory enhancements were reflected in R, but not in K responses.

To investigate the graded effect of arousal, the high arousal negative items were categorized into relatively low arousal negative items and relatively high arousal negative items using a median split. The results consistently suggested that retrieval practice effect was only found for the neutral words, but not for the low arousal and high arousal negative words on remember responses, even though there was a reverse retrieval practice effect (Pr scores of restudy > Pr scores of retrieval practice) for low arousal negative words (see Supplemental Material). Moreover, we also conducted A 2 (emotion: neutral, negative) × 2 (learning: retrieval practice, restudy) ANOVA on the Pr scores that calculated after the correction of K scores by the formula [Khit/(1-Rhit)] (to obtain independent estimates of familiarity) (Yonelinas & Jacoby, 1995). The findings also showed testing effect for neutral but not for negative words (see Supplementary Material for details).

ERP results

A 2 × 2 ANOVA was conducted with factors of emotion (neutral, negative), learning (retrieval practice, restudy) for each time window using the mean amplitudes of the left-posterior cluster (see Table 3). The mean numbers of artifact-free trials for neutral/restudy condition, neutral/retrieval practice condition were 21.4 (ranges 16–25) and 22.6 (ranges 17–25), respectively. The mean numbers of artifact-free trials for negative/restudy condition, negative/retrieval practice condition were 22.9 (ranges 18–25) and 22.1 (ranges 17–25), respectively.

For 300–500 ms, the main effect of emotion was significant, F (1, 21) = 10.61, $p = 0.004$, $\eta_p^2 = 0.34$, showing that ERPs elicited by the negative new items were more positive than ERPs elicited by the neutral new items. No other significant difference was found (ps > 0.05). Thus, at 300–500 ms, no significant ERP differences were found between the retrieval practice and the restudy condition for both neutral and negative words (see Fig. 1).

Table 3 Summary of the repeated measures ANOVA conducted on the ERPs data

Effect ANOVA (emotion × learning)	Time window		
	300–500 ms	500–700 ms	700–900 ms
Emotion main effect	$F = 10.612$	$F = 0.646$	$F = 1.394$
	$p = 0.004$	$p = 0.431$	$p = 0.251$
	$\eta_p^2 = 0.336$	$\eta_p^2 = 0.030$	$\eta_p^2 = 0.062$
Learning main effect	$F = 1.418$	$F = 0.029$	$F = 3.852$
	$p = 0.247$	$p = 0.867$	$p = 0.063$
	$\eta_p^2 = 0.063$	$\eta_p^2 = 0.001$	$\eta_p^2 = 0.155$
Emotion × learning	$F = 2.617$	$F = 9.283$	$F = 6.286$
	$p = 0.121$	$p = 0.006$	$p = 0.021$
	$\eta_p^2 = 0.111$	$\eta_p^2 = 0.307$	$\eta_p^2 = 0.230$

For 500–700 ms, the emotion × learning interaction was significant, F (1, 21) = 9.28, $p = 0.006$, $\eta_p^2 = 0.31$. Follow-up analyses were conducted for each emotion type. For neutral words, no significant difference was found between the retrieval practice and the restudy condition, t (21) = − 1.04, $p = 0.309$. For negative words, no significant difference was found between the retrieval practice and the restudy condition, t (21) = 1.336, $p = 0.196$. These findings showed that no significant ERP differences between the retrieval practice and the restudy condition were found for both neutral and negative words (see Fig. 1).

For 700–900 ms, a significant emotion × learning interaction was found, F (1, 21) = 6.27, $p = 0.021$, $\eta_p^2 = 0.23$. Follow-up analyses were conducted for each emotion type. For neutral items, ERPs elicited by the retrieval practice condition were more positive than ERPs elicited by the restudy condition, t (21) = − 2.88, $p = 0.009$, Cohen's $d = 0.61$. For negative words, no significant difference was found between the retrieval practice and the restudy condition, t (21) = − 0.61, $p = 0.551$. These findings showed that significant ERP differences between the retrieval practice and the restudy condition were found only for the neutral words, but not for the negative words (see Fig. 1).

Discussion

The goal of the current study was to examine the role of emotion arousal in the retrieval practice effect and test how the effect is manifested in different recognition processes (i.e., recollection and familiarity). Behavioral results indicated that the retrieval practice enhanced memory retention compared to the restudy for the neutral but not for the negative items. In addition, the enhancement effects were reflected in the recollection, but not the

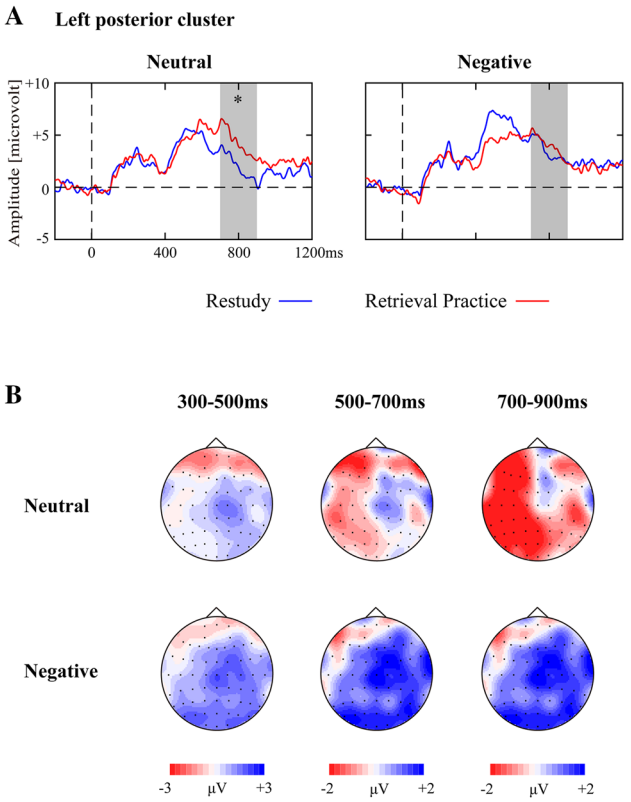

Fig. 1 **a** ERP effects on the left-posterior cluster for the neutral and negative items. The left waveforms showed the contrast between the average ERPs elicited by the neutral new items in restudy phase and the neutral new items in retrieval practice phase (*$p < 0.05$). The right waveforms showed the contrast between the average ERPs elicited by the negative new items in restudy phase and the negative new items in retrieval practice phase. The grey area stands for the ERP difference between the restudy and the retrieval practice condition from 700 to 900 ms. **b** Topographic maps of the retrieval practice/restudy ERP differences for the neutral and negative items for 300–500 ms, 500–700 ms, and 700–900 ms time windows

familiarity process. Consistent with behavioral findings, ERP results showed more positive ERPs for the retrieval practice compared to the restudy condition from 700 to 900 ms at left-posterior cluster for the neutral, but not for the negative items. To our knowledge, this is the first study, showing that emotion arousal can influence the retrieval practice effect. By showing the consistent pattern of retrieval mode ERPs, this study also provides support for the episodic context account as the potential theoretical interpretation of these effects. Below, we begin by discussing the basic retrieval practice effect, followed by discussing the effects of emotion arousal on the retrieval practice effect, and then, we discuss the effects on recollection and familiarity processes.

The basic retrieval practice effect

Behavioral findings for neutral items replicated the typical retrieval practice effect from the previous studies when initial recognition was used in the retrieval practice paradigm (e.g., Gao et al. 2016; Jia et al. 2018; Pan and Rickard 2018; Rowland 2014). Recognition test has been used as an initial test in retrieval practice research. Most evidence has supported that retrieval practice under initial recall typically yields larger testing benefits relative to the retrieval practice under initial recognition (Karpicke et al. 2014; Rowland 2014; e.g., Carpenter and DeLosh 2006; Duchastel 1981; McDaniel et al. 2007). For example, one meta-analysis study found that cued recall and free recall yielded larger testing effects than recognition even when feedback and initial test performance were controlled (Rowland 2014). Their findings are consistent with the retrieval effort hypothesis that more effortful or difficult test should have larger retrieval practice effects (e.g., Bjork 1994; Pyc and Rawson 2009). Nevertheless, it is important to emphasize that the retrieval practice effect is a robust phenomenon generalizable to multiple test formats, and retrieval in the format of recognition also has an effect on subsequent learning and memory.

Moreover, the behavioral findings of the retrieval practice effect for neutral items also support that adopting retrieval mode would enhance subsequent memory retention compared to experiencing the items, but not thinking back to a study episode. These findings replicated the previous behavioral studies evaluating episodic context account (Karpicke and Zaromb 2010; Whiffen and Karpicke 2017). The state of traveling back to the study episode is called retrieval mode and it was taken as the underlying mechanism for the retrieval practice effect (Karpicke et al. 2014; Tulving 1983, 2002; Whiffen and Karpicke 2017). Prior studies have shown that, with all else held constant, enhanced memory retention was found for being in a retrieval mode compared to not being in a retrieval mode (Karpicke and Zaromb 2010; Whiffen and Karpicke 2017). In the current study, subjects experienced the items in both conditions for the same amount of time, and participants need to think back to the prior occurrence of the items for the retrieval practice task, but not for the restudy task.

The role of emotion arousal in the retrieval practice effect

One of the most intriguing findings from our study was the effect of emotion arousal on the retrieval practice effect. The stronger retrieval practice effect was observed for the neutral compared to the negative items. More specifically, we found that retrieval practice condition produced better memory retention than restudy condition for the neutral, but not the negative items. Previous behavioral,

electrophysiological, and neuroimaging studies have generally supported that emotional items can be better remembered than neutral items (Kensinger and Corkin 2003; Kensinger et al. 2007; Mather and Nesmith 2008, Schaefer et al. 2011). For example, one study used neutral and negative words as stimuli, and participants were instructed to study and make a concrete or abstract judgment for each word. Fifteen minutes later, a recognition test with a remember–know paradigm was performed. The results found that negative arousal enhanced the remember responses for the negative words compared to the neutral words (Kensinger and Corkin 2003). In the current study, the memory advantage of emotional items led to better performance for the emotional compared to the neutral items for the restudy condition (see Table 2). The better memory performance of emotional items for the restudy condition overridden the benefits produced by the retrieval practice condition, which makes it difficult to produce a differentiation of the retrieval practice and the restudy condition for the emotional items. In addition to the better memory performance of emotional items for the restudy condition, we also observed that retrieval practice did not produce benefits of retrieval for emotional items (see Table 2). One possibility is that the memory advantage of emotional items compared to the neutral items makes it easier for the participants to do the recognition test, which perhaps resulted in less retrieval effort and context reinstatement and reduced the retrieval benefits at the final test (Bjork 1994, 1999; Pyc and Rawson 2009; Karpicke et al. 2014).

Two previous studies have shown that the neutral and negative items might benefit similarly from the retrieval practice condition (Emmerdinger et al. 2018; Jia et al. 2018). At first glance, these findings seem to be contradictory to our current findings. However, one of the differences between the current study and the previous studies (Emmerdinger et al. 2018; Jia et al. 2018) is that the previous two studies used cued recall or source memory test for the retrieval practice condition to examine the role of emotion arousal and retrieval practice in associative memory, whereas the current study used recognition test for retrieval practice condition to examine the role of emotion arousal and retrieval practice in item memory. As a result, the current study supports the notion that the emotion arousal decreases the retrieval practice effect when single items are used. Collectively, this study and previous studies provide valuable hint that the effect of emotion arousal on the retrieval practice effect is not necessarily a simply 'yes' or 'no' question but situation-dependent. Emotion arousal might not influence the retrieval practice effect for associative memory, but it decreases the retrieval practice effect for item memory. However, given the current limited evidence, this hypothesis needs to be further tested using different stimuli sets and experimental procedures.

In addition, consistent with our behavioral results, we also found the ERP effect for the neutral, but not for the negative items at the left-posterior cluster from 700 to 900 ms. Based on the previous studies, the ERP effect that more positive ERPs elicited by retrieval practice trials than restudy trials might indicate retrieval mode (Gao et al. 2016; Jia et al. 2018). Using the same time windows as well as the same electrode clusters as the previous studies (Gao et al. 2016; Jia et al. 2018), our study showed consistent pattern of results between the effects of emotion arousal on the behavioral retrieval practice effect and the effects of emotion arousal on the ERPs effect. In one previous study (Jia et al. 2018), participants were asked to either restudy or perform a source memory test for the neutral and negative items, and then, a final source memory test was conducted. The ERP effects were found for both the neutral and negative items at 500 ms to 900 ms, and consistently, behavioral results revealed that memory of neutral and negative items similarly benefited from the retrieval practice condition. Taken together, the consistent behavioral and ERP effects in the current study suggest that emotion arousal can influence the retrieval practice effect of item memory when the recognition test was used. Of note, according to multiple-stage memory model of memory, memory processes might be divided into two processes (Shallice and Burgess 1996). The "descriptor processes" specify the type of trace that would satisfy the demands of retrieval tasks. The "memory editor processes" are assumed to be involved in checking the memory outputs meeting with specifications. The current study measured retrieval mode by analyzing neural activity elicited by unstudied items of episodic task versus non-episodic task, which is contended as an uncontaminated index of the descriptor processes before the memory editor processes occur.

The effects of emotion arousal on the retrieval practice effect are manifested in recollection

We found that the influence of emotion arousal on the benefit of testing was reflected on R responses but not K responses. In particular, for K responses, the retrieval practice effect was not found regardless of neutral or negative items. The findings that retrieval practice manifested in recollection but not familiarity are consistent with our previous study (Gao et al. 2016) in which both initial recognition and final remember/know paradigm were used. Interestingly, in another previous study (Chan and McDermott 2007), when initial recall and final remember/know paradigm were used, they found that initial recall enhanced R responses, but not K responses. Recall relies more heavily on recollection, whereas recognition relies on both recollection and familiarity. Thus, initial recognition

might induce the retrieval practice effect that is reflected on both familiarity and recollection. However, the current study and previous study (Gao et al. 2016) suggest that recollection is also preferably influenced even when recognition was used as the initial test. These findings were consistent with Chan and McDermott (2007) that the retrieval practice effect could be revealed if the final test encouraged the retrieval of some details accompanied with the items. These findings are also consistent with some theories of the retrieval practice effect. For example, the episodes' context account suggested that participants could reinstate the prior study episodes and incorporate it with the current episodes, which could provide more distinct cues available for subsequent recollection (Karpicke 2017; Karpicke et al. 2014). Elaborative retrieval account proposed that retrieval practice activated more semantically cue-relevant information and incorporated them with targeted items, leading to elaborated memory traces (Carpenter and Delosh 2006; Carpenter 2011). Roediger and Butler (2011) also suggested that initial test led to an elaboration of memory traces; thus, more details related to the items can be accessed in the future test. In addition, the current study further showed that the influence of emotion arousal on the retrieval practice effect was reflected on the recollection rather than the familiarity, which is in line with the previous literature documenting that emotion influences recollection, but has little or no effect on familiarity (for a review, see Yonelinas and Ritchey 2015).

Implications

The present study has some interesting practical implications. In everyday life, people frequently encounter many emotional items or events. For example, imagine driving through a place, where you had a car accident before. Would retrieval of that event influence your subsequent memory storage and retrieval? and how would that differ when you retrieve a neutral event? Our findings suggest that our emotional memory traces are not enhanced by retrieval the same as neutral memory traces (but see Emmerdinger et al. 2018; Jia et al. 2018; see also Kensinger and Ford 2019 for a review). Future studies should further investigate how valence and arousal influence the benefits of retrieval and how does this interact with different types of retrieval (e.g., cued recall or recognition)? Besides, retrieval of emotional events can not only influence later memory, but also have an effect on mood and depressive symptoms (e.g., Vrijsen et al. 2016).

Limitations and future directions

The results of the present experiment should be interpreted within the context of their limitations. First, our data suggested that the K responses were around chance level for negative words. The low memory performance of the K responses for negative items could be a result of response buttons. For the remember/know paradigm, sometimes, 'guess' response option was given in case that participants guess that the item was studied. Studies have suggested that the 'guess' responses are similar to know responses, but they reflect low confidence recognition responses (Gardiner et al. 1998; Hirshman 1998). Because we did not include 'guess' option in our recognition test, 'guess' response might possibly end up in the know response. However, this argument cannot easily interpret the relatively higher memory performance for neutral items on K responses. Therefore, another possibility is that emotional stimuli tend to have a higher false alarm rates compared to neutral stimuli (e.g., Thapar and Rouder 2009; Dougal and Rotello 2007; White et al. 2014). In this study, the false alarms were mostly reflected in the know response for the negative items. To mitigate the issue of low memory performance of the K responses for negative items, future studies can reduce the number of trials per condition or enlarge the duration of stimuli presentation. However, this could be problematic for ERP research to obtain enough trials, given that trials with artifacts need to be excluded. Second, though we found that the retrieval practice effect was not found regardless of neutral or negative items for the K responses, both recollection and familiarity processes were enhanced by the retrieval practice for the neutral items using an independent estimate of familiarity [K scores: Khit/(1-Rhit)] (Yonelinas and Jacoby 1995) (see Supplemental Material for details). It is still unclear which measure is better to reflect familiarity process (Yonelinas and Jacoby 1995). However, the current study is not designed to examine this question. Third, although we found consistent behavioral results and ERP effects of the influence of emotion arousal on the retrieval practice effect, the ERP findings are still exploratory and are supposed to be interpreted with caution. Despite the term 'retrieval mode' is widely used in literature and is the central concept of the episodic context account (Rugg and Wilding 2000; Morcom and Rugg 2002; Williams et al. 2016; Gao et al. 2016; Karpicke and Zaromb 2010; Whiffen and Karpicke 2017; Karpicke et al. 2014), it is relatively vaguely defined. 'Retrieval mode', similar as the retrieval practice effect, might reflect the operation of multiple underlying cognitive processes. Thus, the 'Retrieval mode' as well as the concept of 'Context reinstatement' in episodic context account (Karpicke et al. 2014; Whiffen and Karpicke 2017) might be generic overarching terms describing the cognitive states of traveling back to the original episode without specifying the exact nature of the cognitive processes. Nevertheless, the ERP makers of retrieval mode that are consistent with behavioral effects can extend the behavioral findings by providing evidence about timing and underlying neural mechanism of the retrieval practice effect. Fourth, the present study

provides evidence on the role of emotion in the retrieval practice effect when recognition test was used as the initial and final test formats. However, a remaining important question is whether the effects generalize to other test formats such as cued recall and free recall tests. Given that the cued recall and free recall tests are the commonly used test formats in retrieval practice research, future studies should investigate how emotional arousal influences the retrieval practice effect when recall tests are used. Fifth, in the present study, a relatively short-term delay (i.e., 40 min) was used. However, it is unclear whether the influence of emotional arousal on retrieval practice effect would change if a relatively long-term delay were used. The enhancement effects of emotional arousal on memory can be revealed for a long-term study-test delay rather than a short-term delay (Yonelinas and Ritchey 2015). Some studies showed absent or even decreased emotional effects on memory when memory tests are given immediately. Retrieval practice research also showed that the benefits of retrieval practice become larger with longer retention intervals (Karpicke 2017). Taking the emotional consolidation effects into account, if the final test was conducted after a long-term delay (e.g., > 24 h), one possibility is that there will still be an emotional influence on retrieval practice effect if the emotional consolidation effects are the same for both retrieval practice and restudy conditions. Alternatively, there might be possible interactions between the emotional effects and delay, resulting in differential pattern of results. Therefore, it is still an opening question whether the retrieval practice effect could be found on negative items after a longer period. Sixth, it should be noted that we only used the negative stimuli to induce emotional arousal. Future studies should further test the interaction between emotion and the retrieval practice effect using positively arousing items.

Conclusion

Overall, the present study tested the role of emotion arousal in the retrieval practice effect. We found enhanced memory retention for the retrieval practice compared to restudy for the neutral items, but not for the negative items. Consistently, ERPs effects of retrieval mode were also found for the neutral items, but not for the negative items. Moreover, we found that the effects of emotion arousal on the retrieval practice effect were more likely reflected in recollection. Taken together, our results provide behavioral and neural evidence for the role of emotion arousal in the retrieval practice effect.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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