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RESEARCH

Attentional boost effect: research based on source memory and emotional materials

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Abstract

The attentional boost effect (ABE) refers to the phenomenon that stimuli which appear with targets in a detection task are better remembered than those that appear with distractors. Previous studies have consistently reported a robust ABE in item memory, but inconsistent conclusions have been drawn for source memory. Additionally, regarding the impact of emotional stimuli on the ABE, conclusions have also been inconsistent. The aim of this research was to clarify these inconsistencies. In Experiment 1, participants were asked to memorize different emotional background words (primary task), monitor the symbols above the words, press the spacebar when encountering the "+" (secondary task), and remember the size of the emotional background stimuli (as a source feature). Results revealed that the ABE of negative stimuli was stronger in item memory. For source memory, an ABE was observed only for large fonts. In Experiment 2, participants performed the same task as in Experiment 1, except for recalling the color of emotional stimuli instead of their size. Results indicated a stronger ABE for emotional stimuli in item memory, with no ABE observed in source memory. These findings suggest: (1) Item and source memory are regulated by distinct cognitive processes, leading to differential effects of emotionality on ABE in both types of memory. (2) Contrary to previous literature, emotional stimuli, such as negative words, do not consistently diminish the ABE.

Introduction

In the extant literature on the relationship between attention and memory, it is generally believed that attention is a cognitive system with limited resources (Johnston & Dark, 1986). Increasing the attention given to an item or task is considered to interfere with processing other information. Specifically, compared to full attention (FA), where participants only need to complete a single task, divided attention (DA), requires participants to concurrently complete a task (e.g., a memory task) while engaging in a secondary task. Studies have consistently demonstrated that this divided attention significantly diminishes performance on memory tests (Kinchla, 1992; Mulligan, 2008). However, with further research, Swallow and Jiang (2010) were the first to discover that DA in the learning phase could actually enhance memory performance. They employed scene picture memorization as the primary task, where participants were tasked with remembering a series of scene pictures. Concurrently, target detection was utilized as a monitoring task, which involved presenting white (target) or black squares (distractor) superimposed at the center of the scene pictures. Participants were then instructed to discriminate and respond differently to the target and distractor stimuli as part of the monitoring task. Under the DA condition, participants were instructed to complete both the primary task and monitoring task (responding to the white square but not to the black square), whereas in the FA condition, participants were instructed to ignore the squares and only focus on completing the primary task. Throughout this paper, we refer to the stimuli involved in the primary task, such as scene pictures, as background stimuli, and the targets to be discriminated (e.g., white squares) or the distractor stimuli (e.g., black squares) as monitoring stimuli. It was found that the recognition of background stimuli presented with the target square was better than the recognition of background

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stimuli presented with the distractor square; however, this difference was not observed under the FA condition. Swallow and Jiang (2010) defined this phenomenon of memory enhancement caused by target detection under the condition of DA as the attentional boost effect (ABE). It is worth noting that the ABE was relative; under the DA condition, the enhancement in recognition of target-associated background stimuli was only raised to the same level as in the FA condition, whereas the recognition of distractor-associated background stimuli remains lower than in the FA condition, still illustrating the negative effect of DA on memory performance.

The ABE stands in stark contrast to "common sense" logic, where DA impairs memory performance, therefore, it has received extensive attention from researchers. Numerous studies investigating the ABE have employed varied experimental materials, including verbal cues and images (Rossi-Arnaud et al., 2018; Spataro et al., 2013; Swallow & Jiang, 2010, 2012), utilized different sensory channels such as visual and auditory (Mulligan et al., 2014; Swallow et al., 2012), examined different memory types including long-term, short-term memory, implicit memory (Makovski et al., 2011; Meng & Lin, 2018; Spataro et al., 2013, 2020), and manipulated different experimental tasks like free or cued recall (Mulligan et al., 2014; Spataro et al., 2017, 2021). These studies have consistently affirmed the robustness of the ABE while also discounting several potential explanations including perceptual distinctiveness, attentional cuing, reinforcement learning, perceptual grouping, and oddball processing (Swallow & Jiang, 2010, 2012, 2013). Yet, how can we explain this curious phenomenon of ABE? A convincing explanation, known as the enhanced perceptual encoding hypothesis, suggested that target detection promotes the perceptual encoding of information presented with the target (Swallow & Jiang, 2010). According to this hypothesis, the ABE predominantly manifests during the initial encoding stage, coinciding with behaviorally relevant moments of target detection tasks, and mainly comes from the enhancement of visual information encoding (Swallow & Jiang, 2010, 2012). Neuroimaging research supports this theory, Swallow et al. (2012) observed widespread enhancement in perceptual encoding during target detection tasks, particularly in the early visual cortex, even when auditory targets were presented instead of visual stimuli.

Although there has been significant progress in research on ABE in item memory, previous studies have not reached a consistent conclusion regarding the impact of emotion on ABE. Consequently, this study aims to address this issue specifically. According to the early enhanced perceptual encoding hypothesis, target detection enhances the perceptual encoding of background stimuli at behaviorally relevant moments, thereby facilitating memory for these background stimuli. Therefore, we hypothesize that if the relationship between target detection and perceptual encoding is disrupted, it would impact the ABE. Research also suggested that background stimuli with distinctiveness were processed before target detection occurs, leading to a diminished facilitation of target detection. For instance, in scenarios involving low-frequency words and orthographic rules, the rarity of such words automatically captures participants' attention during early perceptual processing, resulting in enhanced encoding (Criss & Malmberg, 2008; Gounden & Nicolas, 2012). This renders the facilitation produced by target detection redundant, disrupting the connection between target detection and enhanced perceptual encoding, thereby weakening ABE (Mulligan et al., 2014; Spataro et al., 2015). Emotional background stimuli, especially negative ones, primarily engage automatic processes (Talmi & McGarry, 2012; Talmi et al., 2007). Following this rationale, it is anticipated that the ABE for negative stimuli would be attenuated since they undergo heightened perceptual processing during early encoding stages, making the attentional facilitation induced by target detection redundant within the ABE paradigm. Conversely, if the ABE for negative emotional stimuli is affected, it would provide evidence for the early enhanced perceptual encoding hypothesis. In a study by Meng et al. (2018), emotional words used as background stimuli demonstrated that the ABE for negative stimuli was notably lower compared to neutral stimuli, indicating an influence of emotion on the ABE. This finding suggests that the distinctiveness of background stimuli diverts attention resources during the early encoding phase, supporting the early enhanced perceptual encoding hypothesis. However, studies utilizing emotional background stimuli have produced inconsistent results. Rossi-Arnaud et al. (2018) used positive, neutral, and negative images and verbal materials as background stimuli, while the monitoring task required identifying red squares. Results indicated that memory enhancement under target detection conditions occurred for all types of stimuli, and the ABE was stronger for negative compared to neutral stimuli. This study proposed that the encoding of negative stimuli in target detection tasks relies not only on automatic processes but also on controlled processes, potentially leading to a stronger ABE of negative stimuli. Swallow and Atir (2019) similarly employed the target detection experimental paradigm, wherein participants were tasked with memorizing background items (pleasure images VS. neutral images) and detecting a square in a specified color (secondary task). Results showed superior memory performance for target-paired items compared to distractor-paired items. However, equally strong ABE for positive and for neutral images occurred. These results underscore the variable impact of emotional background stimuli on the ABE.

However, it's crucial to note that when examining the influence of emotions on memory, arousal emerges as a pivotal factor that demands attention (Anderson et al., 2006). Emotion-enhanced memory (EEM) has been shown to involve two distinct processing mechanisms that crucially depend on differences in arousal levels. For example, Kensinger and Corkin (2004) found that successful encoding of highly arousing negative information seems to activate the amygdalar-hippocampal neural network for automatic processing, whereas encoding of low-arousal negative stimuli seems to activate the prefrontal- hippocampal neural network for controlled processing (see also Kang et al., 2014, for behavioral evidence). Hence, the varying conclusions drawn from studies discussing the emotional impact on ABE may stem from variations in arousal levels. The degree of arousal plays a pivotal role in determining whether emotional background stimuli undergo automatic processing during the initial encoding phase, thereby impacting the redundancy of perceptual encoding enhancement through target detection.We have thus considered and controlled for arousal of stimuli in our experiments.

Another, main focus of this study is also to examine whether target detection facilitates memory in source memory. Although the ABE has garnered considerable attention from researchers, previous studies have primarily focused on item memory (Mulligan et al., 2014; Spataro et al., 2013; Swallow & Jiang, 2013, 2014), with less emphasis on ABE in source memory (the ability to remember the context or circumstances in which information was acquired, such as details about the spatial, temporal, and perceptual aspects of its presentation) (Baddeley, 1982; Johnson et al., 1993). Conclusions drawn from item memory cannot be directly extrapolated to source memory due to differences in behavioral patterns and neural mechanisms (Rugg et al., 2012; Ventura-Bort et al., 2020). Yonelinas' (2002) comprehensive review of three decades of research on item memory and source memory across behavioral, neuropsychological, and neuroimaging domains revealed disparities in behavioral processing and distinct reliance on neural substrates, providing compelling evidence for this distinction. Furthermore, studies on how target detection affects source memory have not reached a consistent conclusion yet. One fundamental difference across these studies that might contribute to the inconsistent results concerns the function of the source feature: In some studies it is just part of the "background stimulus" versus in others it additionally functions as the "monitoring stimulus". For example, Mulligan et al. (2016) used a dual-task detection paradigm across four experiments utilizing words as background stimuli. In Experiment 1, variations in the font and color of the background stimuli were explored, while Experiment 2 manipulated the sensory channels through which background stimuli were presented. Experiments 3 and 4 focused on variations in study lists as source variables. Participants' secondary task was to press the spacebar upon sighting an infrequent red circle while refraining from responding to green circles. The results consistently indicated a stable presence of ABE in item memory but not in source memory. Conversely, Swallow and Atir (2019) employed both valued and neutral images as background stimuli, with the color of the monitoring stimuli as the source variable. Participants learned background stimuli (primary task) and responded to the monitoring stimuli (secondary task), followed by judgments regarding new or old items and judgments regarding the color source. The results provided evidence supporting the existence of ABE in source memory. Moreover, Turker and Swallow (2019) utilized images as background stimuli, with the shape and location of the monitoring stimuli as source variables. Their findings revealed participants' heightened ability to report background characteristics under target detection conditions, thereby furnishing evidence for the ABE in source memory. Mulligan et al. (2022) conducted three experiments employing words as background stimuli, with the color of the monitoring stimuli (the color of a circle appearing below the words) as the source variable. During the testing phase, participants initially made judgments regarding whether items were new or old, followed by color judgments on items deemed old (i.e., selecting red to appear with the target or green to appear with distractor stimuli). The results showed that the source memory was better under the target condition than the distractor condition. Comparing the above results, there is a crucial discrepancy among the four discussed studies, specifically in the function of the source feature. While Mulligan et al. (2016) utilized the features of background stimuli as the source variable without incorporating features of the monitoring task, the three studies demonstrating the presence of the ABE in source memory all employed attributes of monitoring stimuli as the source variable (Mulligan et al., 2022; Swallow & Atir, 2019; Turker & Swallow, 2019). Thus, participants established associations between the monitoring task and the study task (remembering source features) while monitoring the target or distractor. This suggests that the inclusion of features from both background and monitoring tasks in the association may be a pivotal factor in uncovering ABE in source memory. To scrutinize this methodological disparity, Spataro et al. (2022) modified the source variable from the features of the monitoring stimulus to those of the background stimulus. The results confirmed the presence of the ABE in source memory, demonstrating that target detection could enhance the association between background words and their attributes. However, it's noteworthy that another crucial factor potentially influencing the ABE in source memory is retrieval support, which maximally aids participants in reinstating the learning context.

Unlike other studies (Mulligan et al., 2016; Swallow & Atir, 2019), Spataro et al. presented participants with identical learning materials (e.g., color, size, etc.) during the test phase as in the study phase, requiring participants only to make familiarity-based recognition decisions from multiple options without the need for recall retrieval. We speculate that, in addition to source variables being characteristic of background stimuli, retrieval support may also be another important factor influencing ABE in source memory, deserving further investigation. In summary, the emergence of this result prompts researchers to reconsider the ABE in source memory - what factors genuinely influence ABE in source memory? It inspires us to further explore ABE in source memory.

Emotion is also an important factor influencing source memory, presenting distinct effects from its impact on item memory. Wang and Fu (2012) observed a reduction in item memory for negative stimuli, while positive emotion showed no discernible effect on item memory. Interestingly, neither positive nor negative emotions affected source memory. Pereira et al. (2023) conducted a meta-analysis of fifty-three studies, discussing the impact of the emotional valence and arousal of learning items on source memory. The results revealed differential effects of valence and arousal on source memory. While valence-based findings indicated that emotional stimuli impair source memory, arousal-based analyses found that high and medium arousal levels facilitate source memory. Furthermore, results were modulated by stimulus-related factors (e.g., the type of material) and task-related factors (e.g., the type of source memory task). In conclusion, systematic research has explored how emotions affect source memory, despite variations in research results. However, there is currently no systematic research on whether and how emotional items influence ABE in source memory. The subsequent work aims to address this gap.

Current research

The current research employed emotionally valenced words, controlling for arousal levels, as background stimuli to address the following inquiries: (1) Is ABE consistently observed in both item memory and source memory? (2) How does emotion affect ABE in item memory? Specifically, does emotional stimuli undergo automatic processing or a dual processing of automatic and controlled mechanisms? (3) What is the impact of emotion on ABE in source memory. Drawing from the approach employed by Spataro et al. (2022), this study adopts the classical dual-task detection paradigm and employs words as background stimuli, with the size and color of the background stimuli (rather than the monitoring stimuli) as the source variables. However, two modifications have been implemented: (1) the stimuli consist of emotional words with varying valences, and (2) participants are tasked with completing a two-alternative-forced-choice (2AFC) memory task.

Experiment 1

Experiment 1 examined the presence of the ABE in both item memory and source memory using emotionally words as background stimuli, with the font size of the background stimuli considered as a source variable. Additionally, it explored the influence of emotional valence on ABE in both item memory and source memory. Confirming the ABE in source memory would help rule out potential methodological differences, such as whether the source feature belongs to the "background stimulus" versus the "monitoring stimulus". Furthermore, if ABE is observed to be less prominent for emotional background stimuli, especially negative ones, compared to neutral stimuli, it would support the hypothesis of the automatic encoding of emotional stimuli and provide evidence for the early enhanced perceptual encoding hypothesis.

Method

Participants

Prior to the experiment, G*Power 3.1 was utilized to determine the sample size (Faul et al., 2007). According to the current research design, we set the parameters as follows: repeated measures ANOVA within-subjects, effect size $f = 0.25$, statistical power $1-\beta = 0.9$, $\alpha = 0.05$, resulting in a calculated sample size of 16 participants. Drawing on two of the most relevant references from existing and current research, one study by Meng et al. (2018) explored the influence of emotionality on ABE, utilizing a similar dual-task experimental paradigm for target detection in a $2 \times 2 \times 2$ within-subject design (with participant counts of 34 and 30 across two experiments). The other study, by Mulligan et al. (2016), investigated ABE in source memory, emphasizing background stimuli features as source variables, and also employed a similar paradigm with 32 recruited participants. As a result, we determined our final sample size to be 32 participants (21 women, aged 18–25 years, Mage = 24.03, $SD = 0.82$). Post hoc analysis revealed that with effect size $f = 0.25$, $\alpha = 0.05$, and number of measurements = 12, the statistical power exceeded 0.99 ($1-\beta$). All participants were right-handed, had normal or corrected-to-normal vision, and volunteered to participate. No data were excluded from the analysis.

Design and materials

In Experiment 1, we used a 2 (interference type: target, distraction) × 2 (font size of background material: large, small) × 3 (emotional valence of background material: positive, neutral, negative) within-subject design.

A total of 362 emotional words were randomly selected from the Chinese Emotional Color Two-Character Word Database (CECTWD) (Fan et al., 2017). Valence was assessed using 9-point Likert scales, where 1 indicated the highest negative level and 9 indicated the highest positive level, with scores closer to 5 indicating a more neutral emotional state. The emotional valence of positive, negative, and neutral words were 7.37 ± 0.18; 2.49 ± 0.27 and 5.58 ± 0.29, respectively. The F- test results showed that the main effect of word valence was significant, F (2, 361) = 7774.28, $p < 0.001$, and the post-hoc test showed that the differences between any two of the three scores were significant ($p < 0.001$). Twenty -two words were used in the practice phase, while the remaining 340 words comprised 80 positive, 80 negative, and 180 neutral words that were used in the formal experiment. We designated 120 words to be used as critical items (i.e., 40 positive, neutral, and negative words); 100 words (neutral words) as filler words excluded from the recognition test; and 120 new words (i.e., 40 positive, neutral, and negative words) as items in the recognition phase alongside critical items. All types of learning items were randomly presented. An equal number of neutral, positive, and negative words were presented with large versus small font. Additionally, an equal number of large (small) positive, neutral, and negative words were presented alongside target or distractor stimuli. Furthermore, all words were balanced in terms of arousal, word frequency, stroke, and structure.

Procedure

The experiment utilized Eprime 2.0 to compile the experimental program, consisting of three stages: learning, buffering, and testing. It was conducted in a quiet laboratory environment, following the experimental procedure outlined below.

Before commencing the experiment, participants were provided with thorough instructions to ensure their understanding of the experimental rules and procedures. This was followed by a practice phase comprising 22 trials, including 4 filler trials. Additionally, the instructions were reiterated prior to the formal experiment.

During the learning phase, a 500ms prompt (*) appeared in the center of the screen, followed by random two-character words of different valence and size, with interference symbols (target trials "+" and distracted trials "-") appeared 1 cm directly above the words. Participants were asked to vocalize the words, monitor the size of the fonts, and observe the symbols above them. They were required to press the spacebar when the word appeared with the target symbol "+." Large font was defined as Courier New 70 point, and small font as Courier New 40 point. Words and the corresponding symbols were presented simultaneously for 150 ms, after which the symbols vanished, while the words persisted for an additional 850 ms.

In the learning phase, there were 30 blocks, each comprising six trials, consisting of four critical words and two filler words. The four critical words included two target trials, always positioned in the first or fourth slot (presented with "+"), and two distractor trials, located in the third or sixth position (presented with "-"). All filler words were presented with a "-" positioned elsewhere within a block and were excluded from the recognition test. Between every two blocks, 1–2 filler words were randomly inserted to eliminate the regularity of interference stimulation. The entire study phase consisted of 220 trials (consisting of 100 filler trials and 120 critical trials, with 100 filler trials including 60 within-block trials and 40 between-block trials); the valence and size of the words were presented randomly.

Following the study phase, a 2-minute calculation disruption task was administered, followed by the test phase. In the test phase, 120 critical items from the learning phase were combined with 120 new words and then randomly divided into four blocks for testing. Each word was presented for 1000 ms. Participants were instructed to press a key to make a judgment between old and new words after the words disappear (i.e., they pressed the "f" key for old and the "j" key for new). For words judged as old, participants need to further make source judgments based on font size. If the word was presented in large font during the learning phase, the participant pressed the "q" key, and if it was in a small font, they pressed the "p" key. All recognition tasks are self paced (Mulligan et al., 2016; Spataro et al., 2022).

Results

Learning task performance

We analyzed the target-detection rate of the participants during the learning phase (i.e., the proportion of participants who correctly recognized and responded to the target stimuli "+"). Results showed that the participants correctly detected 97% of the target symbols ($M = 0.97$, $SD = 0.01$). Repeated-measures ANOVA showed no significant differences concerning different fonts and emotional valences ($p > 0.05$). The average detection rate surpassed 95%, indicating that the participants effectively completed the target detection task under all condition.

Recognition phase performance

First, to mitigate the influence of guessing and response bias, the corrected recognition accuracy for items was calculated by subtracting the false alarm rate from the hit rate: Pr=[P (hits) - P (false alarms)] (Snodgrass & Corwin, 1988). In this study, hit rate refers to the proportion of items correctly recognized as old under each condition (type, valence, and size) divided by the total number of standard old items in the corresponding dimension. False alarm rate is the proportion of items incorrectly reported as old when they were not presented during the learning phase, divided by the total number of incorrectly reported + correctly rejected items. Since words were presented in the recognition phase in the same size and without distractor symbols, but with emotional valence labels assigned beforehand, the false alarm rate reported by participants was calculated solely based on emotional dimension. Subsequently, a 2 (interference type: target, distractor) × 2 (font size of background stimuli: large, small) × 3 (emotional valence: positive, neutral, negative) repeated-measures ANOVA of the corrected recognition accuracy of the new and old judgments was executed. The results (Table 1) showed that the main effect of the interference type was significant, $F(1, 31) = 34.52$, $p < 0.001$, $\eta_p^2 = 0.53$, and target trials ($M = 0.31$, $SD = 0.20$) performed better than distractor trials($M = 0.21$, $SD = 0.19$, $p < 0.001$), demonstrating ABE. The main effect of font size was significant, $F(1, 31) = 4.28$, $p = 0.046$, $\eta_p^2 = 0.12$, and words in small fonts ($M = 0.28$, $SD = 0.20$) were remembered better than words in large fonts ($M = 0.25$, $SD = 0.19$). The main effect of emotional valence was not significant, $F(2, 62) = 0.07$, $p = 0.245$. However, a significant interaction effect was found between emotional valence and font size, $F(2, 62) = 5.71$, $p = 0.005$, $\eta_p^2 = 0.16$, simple effect analysis revealed that positive words in small font ($M = 0.33$, $SD = 0.18$) were remembered better than those in large font ($M = 0.24$, $SD = 0.21$, $p < 0.001$), while font size differences were not significant for negative ($p = 0.444$) and neutral ($p = 0.506$) words. More importantly, a significant interaction between interference type and emotional valence was found, $F(2, 62) = 14.44$, $p < 0.001$, $\eta_p^2 = 0.32$, and a follow-up analysis of simple effects revealed that the recognition performance was better for target ($M = 0.38$, $SD = 0.20$) versus distractor trials ($M = 0.16$, $SD = 0.17$, $p < 0.001$) only for negative words, but not for positive ($M_{\mathrm{T}} = 0.31$, $SD_{\mathrm{T}} = 0.22$, $M_{\mathrm{D}} = 0.26$, $SD_{\mathrm{D}} = 0.17$, $p = 0.129$) and neutral words ($M_{\mathrm{T}} = 0.26$, $SD_{\mathrm{T}} = 0.19$, $M_{\mathrm{D}} = 0.22$, $SD_{\mathrm{D}} = 0.21$, $p = 0.091$). The interaction between font size and interference type was not significant, $F(1, 31) = 2.45$, $p = 0.127$, but the interaction among interference type, emotional valence, and font size was significant, $F(2, 62) = 4.80$, $p = 0.012$, $\eta_p^2 = 0.13$, and a follow-up analysis of simple effects revealed that significant differences were observed only for neutral words in large fonts, where target recognition ($M = 0.32$, $SD = 0.19$) was higher than distractor trials ($M = 0.18$, $SD = 0.19$, $p = 0.002$), while no significant difference was found words in small font ($p = 0.296$). For positive words, no significant differences were observed between interference types, regardless of font size (large: $p = 0.192$, small: $p = 0.353$). However, for negative words, target trials ($M_{\mathrm{B}} = 0.35$, $SD_{\mathrm{B}} = 0.20$; $M_{\mathrm{S}} = 0.39$, $SD_{\mathrm{S}} = 0.20$) exhibited better recognition performance than distractor trials ($M_{\mathrm{B}} = 0.16$, $SD_{\mathrm{B}} = 0.15$, $p < 0.001$; $M_{\mathrm{S}} = 0.15$, $SD_{\mathrm{S}} = 0.19$, $p < 0.001$), regardless of font size.

Second, for source memory, in order to better differentiate it from item memory, we adopted the conditional source-identification measure (CSIM)(Murnane & Bayen, 1996), referring to the calculation methods used by Kuhlmann et al. (2016) and Li et al. (2023) in their respective studies. The specific calculation involves dividing the number of words correctly attributed to a specific source by the total number of words belonging to either of the two sources under investigation in the current study for each source. A repeated-measures ANOVA on the CSIM values with a 2 (interference type: target, distractor) × 2 (font size of background materials: large, small) × 3 (emotional valence: positive, neutral, negative) was performed. The results (Table 2) showed that the main effect of the interference type was not significant, $F(1, 31) = 1.11$, $p = 0.300$. The main effect of font size was not significant, $F(1, 31) = 0.26$, $p = 0.614$. The main effect of emotional valence was not significant, $F(2, 62) = 0.89$, $p = 0.415$, and the interaction between interference type and emotional valence was not significant, $F(2, 62) = 1.06$, $p = 0.354$. The interaction between font size and emotional valence was also not significant, $F(2, 62) = 1.10$, $p = 0.340$.

Table 1 Means and standard deviation of the his, false alarms of old and new judgments

Variable Types	Big			Small		
	Positive	Neutral	Negative	Positive	Neutral	Negative
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Hits						
Targets	0.51 (0.25)	0.51 (0.20)	0.66 (0.25)	0.59 (0.22)	0.40 (0.18)	0.69 (0.20)
Distractors	0.45 (0.28)	0.37 (0.18)	0.47 (0.24)	0.56 (0.21)	0.44 (0.27)	0.46 (0.24)
False alarms	0.24(0.18)	0.20 (0.13)	0.31 (0.19)	0.24(0.18)	0.20 (0.13)	0.31 (0.19)

Table 2 Means and standard deviations of the CSIM for source identification

Variable Types	Big			Small		
	Positive	Neutral	Negative	Positive	Neutral	Negative
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Targets	0.56(0.03)	0.51(0.05)	0.53(0.04)	0.45(0.03)	0.49(0.05)	0.46(0.04)
Distractors	0.45(0.04)	0.48(0.05)	0.50(0.05)	0.46(0.04)	0.53(0.04)	0.45(0.05)

However, the interaction between interference type and font size was significant, $F(1, 31) = 6.26$, $p = 0.018$, $\eta_p^2 = 0.17$. A follow-up analysis of simple effects revealed that source memory was better under target ($M = 0.53$, $SD = 0.23$) compared to distractor trials ($M = 0.48$, $SD = 0.24$, $p = 0.034$) only for large font, that was, ABE occurred only for large fonts. However, under the small font condition, no significant differences were found in interference type ($p = 0.537$). The interaction between interference type, emotional valence, and font size was not significant, $F(2, 62) = 0.94$, $p = 0.395$.

Discussion

Experiment 1 yielded intriguing findings that diverged from prior research. Specifically, it revealed that the ABE manifested exclusively amidst negative emotional background stimuli in item memory, whereas it remained absent in neutral background stimuli. This contradicted previous findings that demonstrated a robust ABE using neutral background stimuli (Mulligan et al., 2014, 2016; Swallow & Jiang, 2012, 2014). Additionally, these results contradicted the findings of Meng et al. (2018), who reported that negative background stimuli attenuate the ABE. However, the discovery by Rossi-Arnaud et al. (2018) indicating that memory enhancement under target detection conditions favored negative stimuli over neutral stimuli in the DA condition is consistent with our results. This finding, at the very least, challenges the notion that negative stimuli solely undergo automatic processing during encoding, which would otherwise diminish the ABE (Meng et al., 2018).

Moreover, our research indicated that the ABE in source memory was modulated by source features, notably exhibiting memory enhancement only when recognizing stimuli in large fonts. Another noteworthy discovery from Experiment 1 was the influence of emotion on ABE in item memory but not in source memory, thereby supporting the idea that the effects of emotion on item and source memory are mediated by distinct retrieval processes (Leclercq et al., 2014; Ventura-Bort et al., 2020; Yonelinas, 2002).

Experiment 2

Experiment 1 yielded significant findings, such as confirming the role of target detection in promoting associations between background materials and their features unrelated to the monitoring task. However, the results remain inconclusive, particularly due to the absence of the ABE in neutral word item memory and the existence of ABE in source memory only under conditions of large font size. Therefore, Experiment 2 aims to further investigate the influence of emotion on item memory ABE and to validate the impact of emotion on source memory ABE by adjusting the source features of background stimuli. Notably, in Experiment 1, the contrast between the size of the font itself and the size of the "+" and "-" symbols was more pronounced under the condition of large fonts. This may have attracted the participants' attentional resources, facilitating the connection between symbols and words, ultimately demonstrating the ABE. To mitigate the influence of size comparison observed in Experiment 1, Experiment 2 utilized the color of background stimuli as the source feature for participants to remember.

Method

Participants

The calculation of sample size and the setting of effect size are the same as Experiment 1, and 32 participants were ultimately selected to participate in Experiment 2 (24 women, aged 18–25 years, *M*age = 23.73, *SD* = 1.53). All participants were right-handed, had normal or corrected-to-normal vision, and volunteered to participate. After the experiment, two participants' data were deleted due to a device malfunction.

Design and materials

In Experiment 2, a 2 (interference type: target, distraction) × 2 (font color of background material: red, green) × 3 (emotional valence of background material: positive, neutral, negative) within-subjects design was used.

A total of 362 emotional words were randomly selected from the CECTWD (Fan et al., 2017). The valence values were rated on a 1–9 Likert scale, with positive, negative, and neutral words were 7.09 ± 0.09; 2.92 ± 0.12 and 5.59 ± 0.27, respectively. The F-test revealed a significant main effect of valence, $F(2,361) = 8612.02$, $p < 0.001$, and the post-hoc test indicating significant differences between all word types ($p < 0.001$). All words were balanced in terms of arousal, word frequency, stroke, and structure. Other settings remained consistent with those utilized in Experiment 1.

Procedure

The experimental procedure mirrored that of Experiment 1, with one notable alteration: the source variable transitioned from the font size of the background stimuli to the font color (i.e., red and green). Words of different colors and valences were randomly presented, and participants engaged in a 2-minute disruption task following the study phase. During the test phase, the words were presented for a duration of 1000 ms. After that, participants distinguished between old and new words. Additionally, participants further identified all words judged as old by indicating the font color using the "q" key for red or the "p" key for green. All recognition tasks are self-paced (Mulligan et al., 2016; Spataro et al., 2022).

Results

Learning task performance

Similar to Experiment 1, we initially assessed the accuracy of the target detection tasks. Results showed that participants correctly detected 96% of the target symbols ($M = 0.96$, $SD = 0.05$). Additionally, a repeated-measures ANOVA showed that variations across different colors and emotional valences were not statistically significant ($p > 0.05$). With an average detection rate surpassing 95%, it suggests that participants proficiently completed the target detection task.

Recognition phase performance

Similarly, the corrected recognition accuracy index Pr (hit - false alarms) was calculated (Snodgrass & Corwin, 1988). A 2 (interference type: target, distractor) × 2 (font color of background materials: red, green) × 3 (emotional valence: positive, neutral, negative) repeated-measures ANOVA was conducted to analyze the corrected recognition accuracy of new and old judgments. The results (Table 3) revealed that the main effect of the interference type was significant, $F(1, 29) = 28.47$, $p < 0.001$, $\eta_p^2 = 0.50$. Target trials ($M = 0.32$, $SD = 0.19$) performed better than distractor trials ($M = 0.21$, $SD = 0.18$), demonstrating the presence of ABE. The main effect of color was significant, $F(1, 29) = 6.41$, $p = 0.017$, $\eta_p^2 = 0.18$, with words in red fonts ($M = 0.29$, $SD = 0.18$) being remembered better than words in green fonts ($M = 0.25$, $SD = 0.18$). The main effect of emotional valence was also significant, $F(2, 58) = 5.13$, $p = 0.009$, $\eta_p^2 = 0.15$, with negative words ($M = 0.31$, $SD = 0.19$) being recognized more accurately than positive ($M = 0.24$, $SD = 0.16$, $p = 0.016$) and neutral words ($M = 0.25$, $SD = 0.19$, $p = 0.004$). Furthermore, the interaction between interference type and emotional valence was significant, $F(2, 58) = 4.45$, $p = 0.016$, $\eta_p^2 = 0.13$. Subsequent simple effects analyses showed that for positive and negative words, the recognition of target trials ($M_P = 0.31$, $SD_P = 0.17$; $M_N = 0.38$, $SD_N = 0.19$) was better than that of distracted trials ($M_P = 0.17$, $SD_P = 0.15$, $p < 0.001$; $M_N = 0.25$, $SD_N = 0.19$, $p < 0.001$). No significant differences were found for neutral words ($p = 0.130$). The interaction between emotional valence and color was significant, $F(2, 58) = 3.64$, $p = 0.033$, $\eta_p^2 = 0.11$, simple effect analysis revealed that, for positive words, recognition was better for red fonts ($M = 0.29$, $SD = 0.16$) compared to green fonts ($M = 0.20$, $SD = 0.17$, $p = 0.004$), while color differences were not significant for neutral words ($p = 0.471$) and negative words ($p = 0.141$). However, neither the interaction between interference type and color ($F(1, 29) = 0.001$, $p = 0.973$) nor the three-way interaction between interference type, emotional valence, and font color ($F(2, 58) = 0.50$, $p = 0.608$) reached significance.

In source memory, the recognition index CSIM under different conditions was calculated, a 2 (interference type: target, distractor) × 2 (font color of background materials: red, green) × 3 (emotional valence: positive, neutral,

Table 3 Means and standard deviations of the hits, false alarms of old and new judgments

	Red			Green		
Variable Types	Positive *M (SD)*	Neutral *M (SD)*	Negative *M (SD)*	Positive *M (SD)*	Neutral *M (SD)*	Negative *M (SD)*
Hits						
Targets	0.64(0.21)	0.46(0.20)	0.71(0.20)	0.54(0.24)	0.50(0.23)	0.67(0.24)
Distractors	0.48(0.23)	0.43(0.22)	0.58(0.26)	0.42(0.23)	0.43(0.23)	0.53(0.22)
False alarms	0.28(0.19)	0.22(0.18)	0.31(0.19)	0.28(0.19)	0.22(0.18)	0.31(0.19)

negative) repeated-measures ANOVA was performed. The results (Table 4) demonstrated that neither the main effect of interference type (F (1, 29) = 1.09, $p = 1.090$), nor the main effect of font color ($F(1, 29) = 0.06$, $p = 0.809$), nor the main effect of emotional valence ($F(2, 58) = 0.42$, $p = 0.661$) reached significance. In terms of interaction, a significant interaction between emotional valence and font color emerged, $F(2, 58) = 6.09$, $p = 0.004$, $\eta_p^2 = 0.17$. Simple effect analysis revealed that for red font recognition, positive words ($M = 0.53$, $SD = 0.21$) performed better than neutral words ($M = 0.47$, $SD = 0.23$, $p = 0.031$), while the difference between positive and negative words in red font recognition was not significant ($p = 0.846$). For green font recognition, neutral words ($M = 0.56$, $SD = 0.20$) performed better than positive ($M = 0.46$, $SD = 0.17$, $p = 0.007$) and negative ($M = 0.48$, $SD = 0.19$, $p = 0.018$) words, whereas the difference between positive and negative words in green font recognition was not significant ($p = 0.607$). However, neither the interaction between the interference type and font color ($F(1, 29) = 1.98$, $p = 0.170$), nor the interaction between interference type and emotional valence ($F(2, 58) = 0.08$, $p = 0.922$), nor the three-way interaction between interference type, emotional valence, and font color ($F(2, 58) = 1.23$, $p = 0.299$) reached significance.

Discussion

Experiment 2 revealed the ABE in item memory, particularly pronounced with emotional background stimuli, which contradicted previous research findings (Meng et al., 2018). Our finding also suggested that during the dual task of target detection, emotional stimuli not only undergo automatic processing at the encoding stage but may also undergo dual processing involving automatic and controlled processes (Rossi-Arnaud et al., 2018). This phenomenon may stem from the combined influence of emotional stimuli processing and source tasks on the ABE, leading to different results compared to examining emotional words alone.

However, ABE was not evident in source memory, aligning with Mulligan et al.‘s (2016) study but conflicting with findings from other researchers (Mulligan et al., 2022; Swallow & Atir, 2019; Turker & Swallow, 2019). Similarly, Experiment 2 demonstrated that emotion exerted distinct effects on item memory versus source memory. Specifically, an interaction between interference types and emotion was observed in item memory, while emotion did not impact the ABE in source memory, thereby supporting the distinct roles of emotion in item and source memory (Leclercq et al., 2014; Ventura-Bort et al., 2020; Yonelinas, 2002). Furthermore, the current study identified some interactions between font color and emotional valence, which jointly influence item recognition and source identification. However, as these are not the focus of this paper, we did not extensively explore them. Nevertheless, these findings provide directions for future research and can serve as entry points for future studies.

General discussion

To explore the consistent presence of ABE in item and source memory and understand the influence of emotion on ABE across both memory types, this study employed the dual-task detection paradigm. Emotional words were utilized as background stimuli, with varying features (font size in Experiment 1 and font color in Experiment 2) acting as source variables. Two experiments were conducted to unveil noteworthy and meaningful findings, detailed as follows.

Firstly, both experiments in item memory revealed better memory performance for target trials compared to distractor trials. However, this pattern differed between the two experiments. In Experiment 1, for negative words, recognition of target-paired items surpassed that of distractor-paired items. Conversely, Experiment 2 showed superior memory performance for target trials over distractor trials under both positive and negative emotional conditions, indicating emotion's moderating effect on the ABE in item memory. This finding aligns somewhat with Rossi-Arnaud et al.‘s (2018) study, suggesting that negative stimuli elicit a stronger ABE than neutral stimuli. However, our results diverge significantly from existing conclusions. On the one hand, we observed a more pronounced ABE in emotional background stimuli, contrary to prior research (Meng et al., 2018). According to the perceptual encoding enhancement hypothesis, the memory advantage associated with target detection stems from the encoding enhancement of the perceptual information presented by the target, primarily occurring early in encoding and operating through the visual processing system (Swallow & Jiang, 2010, 2012). Therefore, the premise for the existence of ABE is that perceptual feature encoding

Table 4 Means and standard deviation of the CSIM for source identification

Variable Types	Red			Green		
	Positive *M (SD)*	Neutral *M (SD)*	Negative *M (SD)*	Positive *M (SD)*	Neutral *M (SD)*	Negative *M (SD)*
Targets	0.56(0.04)	0.49(0.04)	0.54(0.03)	0.44(0.03)	0.55(0.04)	0.49(0.04)
Distractors	0.50(0.04)	0.45(0.04)	0.53(0.04)	0.49(0.03)	0.57(0.04)	0.46(0.03)

isn't enhanced before target detection; otherwise, attention redundancy arises, weakening the ABE (Smith & Mulligan, 2018). Meng et al. (2018) found that the ABE with negative background stimuli was smaller than with positive stimuli. Research indicates that processing negative emotional stimuli is mostly automatic, rapidly and automatically occupying attention resources (Jiang & Zhou, 2004; Li et al., 2005). Therefore, when incidental processing occurs, negative stimuli capture attention and complete processing early in encoding stages, redundant with the encoding enhancement caused by early target detection, resulting in a lesser ABE intensity for negative stimuli (Meng et al., 2018). However, in this study, participants were explicitly instructed to monitor target stimuli, distinguish word valences, and attend to the source features of the background stimuli, enhancing cognitive load and altering attention usage. To maintain a high level of task performance, participants intentionally invested more cognitive resources to make their attention more focused and reduce the sensitivity of attention distraction (Sörqvist & Marsh, 2015). Therefore, intentional control predominated, balancing the automatic processing priority of negative stimuli in the early encoding stage. Consequently, there may be multiple processing routes, both automatic and controlled, resulting in a stronger ABE for emotional stimuli. Additionally, we shouldn't overlook differences in arousal levels. Meng et al. (2018) only found ABE in low-arousing negative stimuli, while the stimuli in our study all had medium arousal levels (M_{Exp1}=5.53, M_{Exp2}=5.61), potentially contributing to the disparate experimental outcomes. Research indicated that the emotional stimuli of high and low arousal levels worked through different neural circuits. Specifically, low-arousing stimuli activated prefrontal-hippocampal neural network for controlled processing, whereas highly arousing information activated the amygdalar-hippocampal neural network for automatic processing (Kensinger & Corkin, 2004). Consequently, when stimuli lack high arousal levels, they don't receive priority for automatic processing, allowing the benefits of early enhanced perceptual encoding to persist, thus manifesting ABE. Future research employing brain functional imaging technology may offer insights into this mechanism, given that automatic and controlled processing entail distinct neural pathways, providing empirical evidence.

On the other hand, regarding neutral valence stimuli, we did not observe memory enhancement in target detection, inconsistent with previous research findings (Rossi-Arnaud et al., 2018). We attribute this phenomenon to a shift in participants' attention allocation and information processing priorities induced by the mixed presentation of stimuli with different emotional valences. Additionally, participants in our study were required to perform multiple tasks, making neutral stimuli less salient and harder to process, while the uniqueness of emotional stimuli became more pronounced. When participants encountered neutral information amidst a series of emotional stimuli, they tended to focus their attention more on task responses (target detection) rather than on memorizing background material, thus inhibiting the benefits of early perceptual encoding enhancement. In Rossi-Arnaud et al.'s (2018) study, stimuli of different valences were not mixed but presented singularly, thus minimizing the impact of organizational structure on both target detection and background stimulus memory.

In summary, our exploration of ABE in item memory reveals that emotions can modulate ABE. We have also identified some results that are inconsistent with existing research. Through our analysis, we speculate that arousal levels may play a significant role in these discrepancies. However, since our current study did not systematically examine arousal levels as a moderating factor for ABE, it would be beneficial for future research to do so. This could help clarify inconsistencies observed across previous studies.

Secondly, regarding the memory results of the background stimuli source features, in Experiment 1, participants exhibited significantly better recognition of large fonts in target compared to distractor trials. However, in Experiment 2, ABE was not observed in the recognition of color source features. In other words, across both experiments, ABE only manifested for large fonts. This outcome could be attributed to the more pronounced contrast between large fonts and target symbols. Compared to small fonts, the contrast between large fonts and symbols is more noticeable, facilitating participants' attention capture and enabling them to process source features while responding to target stimuli. However, this explanation lacks theoretical support. Nevertheless, it prompts future investigations into ABE in source memory to consider controlling for various factors' influences and exploring the salience of source features, such as investigating whether large fonts affect the strength of ABE.

Comparing previous research outcomes, the results of the two experiments on ABE in source memory diverge from prior studies (Mulligan et al., 2016; Swallow & Atir, 2019; Turker & Swallow, 2019). Hence, it's essential to investigate which factors might account for this inconsistency. Previous studies on source memory have controlled for the effects of study materials (images vs. words) and the number of stimuli presented during the learning phase (multiple vs. single). As mentioned earlier, numerous studies have utilized monitor stimulus characteristics as source variables and identified ABE (Mulligan et al., 2022; Swallow & Atir, 2019; Turker & Swallow, 2019). However, the role of source features of background stimuli in ABE in source memory was only confirmed in the study by Spataro et al. (2022), warranting further exploration. Even with our research findings, we cannot conclusively assert that source features from background stimuli also exhibit ABE, thus not entirely ruling out the impact of source feature as part of the "background stimulus" versus "monitoring stimulus" on ABE in source memory. This is due to the fact that we observed in Experiment 1 that target detection could enhance associations between background stimuli and their features unrelated to the monitoring task, demonstrating ABE. However, this trend was not evident in Experiment 2. Considering the discrepancy in font size between Experiment 1 and Experiment 2, it's plausible to exclude the more pronounced contrast between large fonts and target symbols as the contributing factor. This underscores the necessity for future studies to explore other source features and further discuss whether source features from background stimuli consistently exhibit ABE.

Furthermore, the role of retrieval support is another factor that needs consideration. Spataro et al. (2022) suggested that retrieval support might be a crucial factor contributing to the disparities between the outcomes of their study and Mulligan et al. (2016). In their study, participants during the testing phase were presented with words in all the colors they had seen during the learning phase, prompting them to make selections. This approach maximally reinstated the original encoding context of the words. In contrast, in the current study, during the testing phase, both the new and old words were presented in the uniform font size and color, failing to fully reinstate the learning stage context and lacking substantial retrieval support. However, the participants still exhibited ABE toward the source features. While to some extent, the influence of retrieval support can be discounted, drawing this conclusion requires caution because we only observed this trend in the results of Experiment 1. In Experiment 2, where font color of background stimuli served as the source variable, ABE was not found. This prompts us to consider whether it is the source features themselves that are influential, leading to variations in ABE induced by different source variables. This aspect warrants further investigation in future studies.

Additionally, there is another factor to consider in explaining the difference between the current results and previous studies: the difficulty of the task. In the current study, participants engaged in multitasking, encompassing the recall of background stimuli, monitoring target stimuli, discerning word valences, and attending to the source features of background stimuli. Conversely, tasks in earlier studies were less demanding. Therefore, we hypothesize that heightened task difficulty necessitates participants to allocate more limited attentional resources, thereby impacting overall performance in source memory. Research has also found that task difficulty can affect the intensity of ABE. For instance, participants were tasked with a five-alternative-forced-choice (5AFC) task on the source features during the testing phase (a more challenging task compared to binary choice), potentially masking the advantage of target detection, resulting in a floor effect in source memory. Additionally, ABE was only observed when participants' source recognition scores exceeded the median value of the averaged IO scores, thereby diminishing the overall strength of ABE (Spataro et al., 2022). Our findings also diverge from those of Mulligan et al. (2016), despite both studies utilizing font size and color of background stimuli as source variables. A potential explanation for this inconsistency lies in the differing conditions between our study and theirs. In Mulligan et al. (2016), participants were unaware that they would be tested on the material's features, rendering the processing of source characteristics incidental. Conversely, in our study, participants were informed beforehand that they needed to monitor the size or color of the words as they would be tested, thus prompting intentional encoding. Research suggests that encoding intention can impact the processing of background information during target detection tasks. Under intentional encoding conditions, target detection fosters detailed processing of background information (Huang & Meng, 2021), thereby enhancing memory for background source information. This idea is supported by Spataro et al. (2022) (Experiment 3), which also investigated the source features of background stimuli under incidental encoding conditions and found a significant weakening of ABE, highlighting the crucial role of intentional encoding in ABE related to source features unrelated to the monitoring task. Despite our detailed analysis of several reasons contributing to the differences in source memory results between the current study and previous research, it should be noted that there are multiple methods for measuring source identification, and different researchers may employ varying measurement techniques, which could potentially impact the final experimental results. Therefore, future research can utilize alternative methods such as the multinomial processing tree model of source monitoring (MPT) (Bayen & Murnane, 1996) or the d' form bivariate SDT model (see e.g., DeCarlo, 2003) to further validate ABE in source memory.

Thirdly, we observed differential effects of emotional valence on the ABE in item memory and source memory. Specifically, the ABE for emotional materials, particularly negative ones, was notably stronger than that of neutral materials in item memory, but no discernible effect was observed in source memory. According to an early model, processing emotional stimuli includes two continuous stages: a pre-attentive stage, where participants rapidly orient towards emotional features, and a post-stimulus stage, involving the controlled processing of the semantic information of emotional stimuli (Christianson, 1992). In our study, where words served as background stimuli, their emotionality stemmed from their semantic content. Research indicates that semantic processing demands more attention and resources compared to general perceptual information processing and is more susceptible to the influence of target detection (Bireta & Mazzei, 2015). Participants, focusing on item memory based on familiarity processes, allocated surplus cognitive resources to process semantic information, thus showing the influence of emotional valence. However, in source memory (based on recollection processes), for emotional information to be processed, participants not only needed to consciously process the source features but also had to allocate additional attention to the words themselves and engage in semantic processing. Due to limited attention resources and encoding time constraints, the post-stimulus stage for emotional stimuli was incompletely executed, resulting in a failure to modulate ABE in source memory based on emotionality. Nevertheless, given that this study did not utilize the "remember/know" (R/K) paradigm, an effective approach to investigate familiarity- versus recollection-based processes (Tulving, 1985; Ingram et al., 2012), it remains unclear how items and source features undergo distinct processing in target detection tasks. Future research could employ the R/K paradigm to further investigate the processing mechanism of the ABE in source memory.

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Declarations

Competing interests The authors declare no competing interests.

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