

Emotional T2 Counteracting Attentional Blink: A Window for Understanding Preferential Processing of Emotion

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Abstract

Attentional blink refers to the phenomenon where identifying the first target (T1) interferes with the identification of the second target (T2) that appears within 200-500 ms when recognizing two targets from a series of distractor stimuli, reflecting the limitations of conscious processing in the temporal dimension. However, research has found that emotional T2 can counteract attentional blink to a certain extent compared to neutral T2. This provides an observational window and research tool for understanding humans' prioritized conscious processing of emotional stimuli. The counteraction of attentional blink by emotional T2 is influenced by factors such as T1 task difficulty, T2 task type, and emotional expectation. The brain regions involved in this process mainly include the amygdala, anterior cingulate cortex, and orbitofrontal cortex. In terms of temporal course, emotional T2 exhibits enhanced effects compared to neutral T2 in both early and late stages of cognitive processing. The cognitive neural mechanisms underlying emotional counteraction of attentional blink can be explained by the attentional enhancement and consolidation competition hypothesis, which posits that early attentional capture of emotional information mediated by the amygdala is the key to emotional counteraction of attentional blink, while the late consolidation process is influenced by top-down factors such as task demands.

Full Text

Preamble

Emotional T2 Attenuates Attentional Blink: A Window into Understanding the Preferential Processing of Emotion

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Abstract

Attentional blink (AB) refers to the phenomenon where identifying a second target (T2) is impaired when it appears 200–500 ms after a first target (T1) within a series of distractors, reflecting limitations in temporal conscious processing. However, research has found that emotional T2 can attenuate AB compared to neutral T2, providing an observational window and research tool for understanding humans’ preferential conscious processing of emotional stimuli. Emotional T2 attenuation of AB is influenced by factors such as T1 task difficulty, T2 task type, and emotional expectancy. The brain regions primarily involved include the amygdala, anterior cingulate cortex, and orbitofrontal cortex. Temporally, emotional T2 exhibits enhanced effects during both early and late stages of cognitive processing compared to neutral T2. The cognitive neural mechanism can be explained by the Attentional Enhancement and Consolidation Competition Hypothesis: early attentional capture mediated by the amygdala is key to emotional attenuation of AB, while the late consolidation process is modulated by top-down factors such as task demands.

Keywords: emotion, attentional blink, rapid serial visual presentation

Introduction

Timely detection of survival-relevant information from our rapidly changing world is crucial for avoiding danger and generating appropriate behavioral responses. However, due to attentional resource bottlenecks, humans often struggle to identify multiple targets from continuously and rapidly presented visual stimuli, a phenomenon well-documented in laboratory studies. In experiments using the Rapid Serial Visual Presentation (RSVP) paradigm, identifying the first target (T1) typically impairs recognition of a second target (T2) appearing 200–500 ms later—a phenomenon known as attentional blink (Raymond et al., 1992). More intriguingly, when emotional stimuli serve as T2, they are better recognized than neutral targets, demonstrating an attenuation of attentional blink (Anderson, 2005; Anderson & Phelps, 2001; Bach et al., 2014; Maratos et al., 2008; Mishra et al., 2017; Ray et al., 2020; Sun, Jia, et al., 2022; Sun et al., 2021). This raises a critical question: How does emotion attenuate attentional blink?

Over the past two decades, researchers have employed various stimulus materials

and methodologies to investigate the relationship between emotional processing and attentional blink. These studies can be categorized into three main types. The first type presents emotional stimuli as critical distractors before the target, finding that task-irrelevant emotional stimuli can induce a phenomenon similar to attentional blink, termed emotion-induced blink (Keefe et al., 2019; Kennedy et al., 2014; McHugo et al., 2013; Santacroce et al., 2021). The second type uses emotional stimuli as T1 in RSVP tasks, finding that emotional T1 enhances attentional blink, known as emotional attentional blink (Kan et al., 2021; Pecchinenda et al., 2020; Saxton et al., 2020). The third type, which is the focus of this paper, employs emotional stimuli as T2 in RSVP tasks, finding that emotional T2 reduces attentional blink—what we term emotional attenuation of attentional blink (Anderson, 2005; Anderson & Phelps, 2001; Bach et al., 2014; Maratos et al., 2008; Ray et al., 2020; Sun, Jia, et al., 2022). Previous reviews have summarized how emotional stimuli affect attentional blink when presented as T1 or as critical distractors (Chen et al., 2014; McHugo et al., 2013). The present article focuses specifically on the impact of emotional stimuli when presented as T2.

We address this question for two primary reasons. First, attentional blink serves as an important window into the limitations of conscious processing, and summarizing how emotion attenuates AB helps us understand the mechanisms underlying preferential conscious processing of emotional information. Second, for humans, rapid identification of emotions and their changes is of great significance. Understanding the mechanisms and individual differences in emotional attenuation of AB may help us identify more sensitive behavioral markers for early detection of emotional disorders. This article first defines the concept of emotional attenuation of AB, then summarizes factors influencing this phenomenon. Subsequently, we review the brain mechanisms and temporal dynamics involved. Finally, we propose an Attentional Enhancement and Consolidation Competition model to explain the cognitive neural mechanisms of emotional attenuation of AB.

2.1 What is Emotional Attenuation of Attentional Blink?

In RSVP tasks, visual stimuli are typically presented at a rate of 10 Hz at the same spatial location, requiring participants to identify two targets among a series of distractors. In this paradigm, T2 identification accuracy follows a U-shaped trend as T1-T2 interval increases, first decreasing then increasing (Chun & Potter, 1995; Dux & Marois, 2009; Zhang & Wang, 2009). Compared to neutral T2, emotional T2 appearing within the attentional blink interval is more likely to be consciously reported. We refer to this processing advantage for emotional stimuli within the blink interval as emotional attenuation of attentional blink (Anderson, 2005; Anderson & Phelps, 2001; Bach et al., 2014; Maratos et al., 2008; Milders et al., 2006; Mishra et al., 2017; Ray et al., 2020; Sun, Jia, et al., 2022; Sun et al., 2021). This definition implies that the advantage is specific to the 200–500 ms attentional blink interval following T1. After this interval,

as bottleneck constraints are lifted or attentional selection mechanisms recover, emotional and neutral targets can be identified equally well, eliminating the relative advantage for emotional processing.

Emotional attenuation of AB is based on accuracy analyses rather than reaction time measures. Reaction time primarily reflects processing speed differences. For instance, dot-probe tasks using RT measures show faster responses to targets appearing at the same location as emotional stimuli (Carlson & Reinke, 2014; Pourtois et al., 2004). In visual search paradigms, emotional targets facilitate responses while emotional distractors interfere with them (Huang et al., 2011; Öhman, Flykt, et al., 2001; Öhman, Lundqvist, et al., 2001; Pinkham et al., 2010). These RT-based findings indicate that emotional stimuli can capture attention more quickly and receive prioritized processing. Emotional attenuation of AB, however, emphasizes conscious processing at the perceptual level—whether participants are aware of T2's occurrence or its specific content—rather than processing speed. Accuracy provides a simpler and more direct measure of conscious processing (Mishra et al., 2017).

Two key issues in AB research concern target detection and identification (Chun & Potter, 1995). Detection requires participants to judge whether a specific target is present, whereas identification demands discrimination of target content, representing a higher level of processing. Correspondingly, studies on emotional attenuation of AB include both detection-based measures (Milders et al., 2006; Stein et al., 2010; Ye et al., 2011) and discrimination-based measures (Bach et al., 2014; Engen et al., 2017; W. Luo et al., 2010; Maratos et al., 2008; Ray et al., 2020; Sklenar & Mienaltowski, 2019; Sun et al., 2021; Tian et al., 2018; Van Dam et al., 2012; Zhang et al., 2013; Zhu et al., 2015). We discuss each approach below.

2.2 Emotional Attenuation of AB Based on Detection or Discrimination Measures

In RSVP tasks using detection-based measures, task demands are relatively simple, requiring only that participants report whether a predefined target appeared—for example, detecting intact upright faces among scrambled or inverted faces (Milders et al., 2006; Stein et al., 2010; Ye et al., 2011), or detecting real words among pseudowords (Kihara & Osaka, 2007; Mack et al., 2002; Ogawa & Suzuki, 2004; Zhao et al., 2018). In Milders et al. (2006), for instance, researchers presented scrambled face images as distractors and intact faces as targets. The first target was a green intact face, after which a gray intact face (fearful or neutral expression) might appear. Participants reported the gender of the green face (T1) and whether an intact face (T2) appeared subsequently. Results showed higher detection rates for fearful than neutral faces at short intervals (SOA = 160, 240, and 400 ms), but no difference at long intervals (SOA = 560 ms). Such studies consistently demonstrate an emotional target detection advantage: emotional targets as T2 are more easily detected from rapidly presented distractor sequences, suggesting that early emotional

information processing has automatic characteristics and is less constrained by currently available attentional resources (Anderson et al., 2003; Mendez-Bertolo et al., 2016; Öhman, 2005). However, these studies typically calculate only T2 hit rates as detection measures, neglecting to include T2-absent trials or compute discrimination indices (d') and response criteria. Another limitation of detection measures is their inability to determine whether participants base their judgments on salient emotional features or conscious awareness of emotional content.

Unlike detection tasks, discrimination tasks require participants to report target content, partially addressing the limitation of detection tasks in assessing conscious awareness. In discrimination studies, researchers commonly use emotional words, faces, and scene pictures as T2 stimuli, requiring participants to report facial expressions or the valence of emotional words and scenes (explicit emotional T2 tasks) (de Jong et al., 2009; Engen et al., 2017; W. Luo et al., 2010; Maratos et al., 2008; Ray et al., 2020; Sklenar & Mienaltowski, 2019; Sun et al., 2021; Tian et al., 2018; Van Dam et al., 2012; Zhang et al., 2013; Zhu et al., 2015). Other studies require participants to report non-emotional information about T2 (implicit emotional T2 tasks). For example, when using emotional words as T2, participants might report the word itself (Anderson, 2005; Anderson & Phelps, 2001; Keil & Ihssen, 2004; Schwabe & Wolf, 2010; Strauss et al., 2013) or select the target from a list of alternatives (Langley et al., 2008; Schwabe et al., 2011). When using emotional faces as T2, participants might report identity or gender 等非情绪性信息 (Bach et al., 2014; De Martino et al., 2009; Engen et al., 2017; Sigurjonsdottir et al., 2015; Sun et al., 2021). Discrimination task studies show that participants can effectively process content information of emotional stimuli appearing within the attentional blink interval, including target valence or task-relevant non-emotional information. However, researchers often omit T2-absent trials or include only a low proportion of them, leading participants to expect that targets will always appear. Such expectations facilitate perceptual processing of targets (Meijs et al., 2018; Trauer et al., 2019; Zivony & Eimer, 2022), thereby affecting discrimination performance. Future research should therefore pay greater attention to the inclusion of T2-absent trials and how this factor influences emotional attenuation of AB.

2.3 Lag1 Sparing and the Influence of Emotional T2

In addition to inducing attentional blink within the 200–500 ms window after T1, RSVP tasks also produce Lag1 sparing when T2 appears in the first position after T1 (Lag1), where the AB phenomenon is significantly reduced or even eliminated (Chun & Potter, 1995; Raymond et al., 1992; Wu & Zhang, 2011). Consequently, T2 identification accuracy follows a U-shaped trend as T1-T2 interval increases. Lag1 sparing typically includes two features: first, although the content of two adjacent targets can be reported, their order is often confused; second, when targets are presented consecutively, Lag1 sparing can extend to

three or more targets (Dux et al., 2014). Generally, T2 accuracy at Lag1 is about 5% higher than in the attentional blink interval (Lag2–Lag4), providing a quantitative index for studying Lag1 sparing (Visser et al., 1999).

This paper defines emotional attenuation of AB as the processing advantage for emotional T2 over neutral T2 within the attentional blink interval (Lag2–Lag5). However, when T2 appears at Lag1, immediately adjacent to T1, does emotional T2 still show a processing advantage that might affect Lag1 sparing? Lag1 sparing and attentional blink are two phenomena occurring under different conditions within the same experimental task, and the information processing mechanisms underlying task performance should be the common psychological mechanism producing both phenomena. Therefore, when constructing a theoretical explanation for emotional attenuation of AB, we must also briefly introduce how emotional T2 affects Lag1 sparing. It should be noted that no study has directly examined how emotional T2 influences Lag1 sparing, though some studies investigating emotional T2 attenuation of AB have included conditions where emotional T2 appeared at Lag1 (Mishra et al., 2017). Summarizing these studies, we can understand the mechanisms through which emotional T2 affects Lag1 sparing in two ways: first, whether emotional stimuli as targets at Lag1 produce Lag1 sparing; second, whether recognition differs among different emotional targets at Lag1.

Most studies find that Lag1 sparing does not occur for emotional stimuli as T2 (Anderson, 2005; Kihara & Osaka, 2007; Mack et al., 2002; Miyazawa & Iwasaki, 2010; Ray et al., 2020; Sklenar & Mienaltowski, 2019). Other studies find that whether emotional T2 shows Lag1 sparing is modulated by several factors. For instance, Anderson (2005) found that Lag1 sparing for low-arousal and neutral words as T2 was observed only when T1 and T2 shared the same target features, whereas high-arousal words showed no Lag1 sparing. Once T1 features (color, target type) mismatched T2 features, Lag1 sparing disappeared for all target types. Additionally, valence plays an important role in how emotional T2 affects Lag1 sparing. One study found Lag1 sparing for both positive and neutral words as T2, but not for negative words (Ogawa & Suzuki, 2004). Anxiety and emotional disorders may also affect Lag1 sparing for emotional targets. For example, using angry, happy, and neutral faces as T2 appearing at Lag1, Lag3, Lag5, and Lag7 after T1, researchers found Lag1 sparing for all face types only in high social anxiety groups, with no emotional differences in the magnitude of Lag1 sparing (de Jong et al., 2009). Given that T2 accuracy shows a U-shaped trend with increasing T1-T2 interval, the absence of Lag1 sparing for emotional T2 in most studies may reflect the same emotional processing advantage as emotional attenuation of AB: the advantage for emotional T2 within the attentional blink interval results in no accuracy differences at short intervals, preventing observation of Lag1 sparing. In this case, we must consider whether the reduction or elimination of Lag1 sparing is specific to emotional targets. In some studies, Lag1 sparing is absent not only for emotional targets but also for neutral targets (Kihara & Osaka, 2007; Langley et al., 2008; Mack et al., 2002; Miyazawa & Iwasaki, 2010; Sklenar & Mienaltowski, 2019).

Therefore, only when the reduction or elimination of Lag1 sparing is specific to emotional targets can we conclude that emotional processing affects the Lag1 sparing phenomenon.

Another issue related to Lag1 sparing concerns differences in recognition rates among emotional targets of different valences at Lag1. Some studies have found significant emotional effects at Lag1, with higher accuracy for emotional than neutral T2 (Kihara & Osaka, 2007; Mack et al., 2002; Miyazawa & Iwasaki, 2010; Ogawa & Suzuki, 2004), and this emotional advantage is unaffected by anxiety (de Jong et al., 2009). These results indicate that emotional processing also has certain advantages when T1 and T2 appear adjacent to each other. Some studies find that the emotional processing advantage at Lag1 is affected by age. In one study, young and older adults identified red and green target words among black distractor words, with T1 always neutral and T2 either positive or negative. When stimulus duration was 116 ms, older adults showed an emotional processing advantage at Lag1, but young adults did not. In young adults, when stimulus duration was reduced to 84 ms, they showed better identification of positive than neutral words at Lag1, but worse identification of negative than neutral words (Langley et al., 2008). Additionally, the identification disadvantage for negative relative to neutral targets at Lag1 has been observed in schizophrenia patients with high negative symptoms (Strauss et al., 2013). It should be noted that a few studies have not found significant emotional effects at Lag1 (Bach et al., 2014; Sklenar & Mienaltowski, 2019).

Overall, existing research indicates that emotional T2 shows processing advantages when appearing at Lag1. Moreover, most studies find that emotional targets as T2 are less likely to show Lag1 sparing across time. These findings consistently demonstrate that emotional T2 has a competitive advantage when appearing during the early stage of T1 processing. Some studies also find that this advantage, while facilitating T2 recognition, may interfere with T1 processing. For example, when surprised and happy expressions appear sequentially, prioritized processing of happy expressions (T2) interferes with processing of surprised expressions (T1), producing a reverse blink phenomenon (Ray et al., 2020). However, since these studies focus on examining the processing advantage for emotional T2 within the attentional blink interval, they do not analyze whether emotional T2 at Lag1 affects not only T2 identification but also the sequential representation of T1 and T2. Future research should examine emotional T2 processing at Lag1, its impact on the sequential representation of the two targets, and how emotion influences Lag1 sparing when extended to multiple targets.

3.1 T1 Task Difficulty

Currently, controversy exists regarding whether emotional attenuation of AB is affected by available attentional resources. Attentional blink is often considered to result from T1 processing occupying limited attentional resources, preventing effective T2 processing (Chun & Potter, 1995). Therefore, the processing ad-

vantage for emotional targets in AB tasks might suggest that emotional processing requires only minimal attentional resources or even proceeds automatically (Vuilleumier et al., 2001). However, this view has been challenged. In RSVP tasks, researchers have reduced attentional resources available for T2 by increasing T1 task difficulty, finding that prioritized emotional processing during AB is constrained by currently available attentional resources (Stein et al., 2010; Sun, Jia, et al., 2022; Ye et al., 2011). For example, Ye et al. (2011) manipulated T1 task difficulty using a Flanker task. In the low-difficulty condition, Flanker arrows were congruent; in the high-difficulty condition, they were incongruent. Participants first judged the direction of the central arrow in T1, then reported whether a complete face (fearful vs. neutral) appeared after T1. Results showed that in the low-difficulty condition, fearful faces showed a detection advantage over neutral faces within the AB interval, indicating attenuation of AB by fear. However, this advantage disappeared in the high-difficulty condition. Similarly, another study using fearful and happy faces as T2 found that increasing T1 task difficulty eliminated the attenuation effect for fearful over happy faces (Stein et al., 2010).

These findings suggest that emotional attenuation of AB may depend on whether currently available attentional resources can still meet the demands of emotional information processing. Once attentional resources fall below a critical threshold, the processing advantage for emotional information may be suppressed (Holmes et al., 2003; Pessoa et al., 2002; Pessoa et al., 2005).

However, this speculation has not been fully confirmed by recent research. Some researchers have used multi-level T1 difficulty manipulations (letter search tasks and letter working memory tasks) to examine how T1 difficulty affects emotional attenuation of AB across different T2 task types. Results showed that in face detection T2 tasks and emotion classification T2 tasks, emotional attenuation of AB was unaffected by T1 difficulty; only in gender classification T2 tasks did the attenuation effect for fearful faces disappear under high T1 difficulty (Sun, Jia, et al., 2022; Sun et al., 2022). In other words, even when using more difficult T1 tasks to reduce available attentional resources, emotional information can still receive prioritized processing in certain tasks, again suggesting that emotional processing may be unaffected by currently available attentional resources (Anderson et al., 2003; Öhman et al., 2007; Vuilleumier et al., 2001). These inconsistent results may relate to different types of attentional resources consumed by different T1 tasks. For example, high-difficulty conditions in Flanker tasks involve identification and resolution of conflicting information, whereas high-difficulty conditions in letter search tasks require longer search times for target letters. Compared to letter search tasks, Flanker tasks may occupy more cognitive control-related resources. Therefore, whether emotional attenuation of AB is suppressed may depend on the type of attentional resources occupied by the T1 task.

In summary, increasing T1 task difficulty can suppress emotional T2 processing to some extent, thereby reducing emotional attenuation of AB. However, simply

manipulating T1 task difficulty does not necessarily constrain prioritized processing of emotional T2. When T2 tasks are relatively simple (face detection) or emotion-related (emotion tasks), emotional targets can still obtain certain attentional resources.

3.2 Valence and Arousal of Emotional T2

Dimensional theories of emotion propose that emotions can be characterized by two dimensions: valence (whether the emotion is positive or negative) and arousal (the intensity of the emotional state) (Yiend, 2010). Previous studies comparing different valences in emotional attenuation of AB have employed several approaches. Some researchers use neutral T2 as a control condition, examining how positive or negative T2 alone affects AB compared to neutral information (Anderson & Phelps, 2001; De Martino et al., 2009; Sun et al., 2021; Sun, Shang, et al., 2022). Since emotional stimuli differ from neutral stimuli on both valence and arousal dimensions, this approach cannot clarify whether valence or arousal plays the primary role. Other researchers control stimulus arousal levels, directly comparing positive versus negative T2 to isolate the effect of valence on emotional attenuation of AB and assess the relative advantage of negative versus positive information in attenuating AB (Milders et al., 2016; Milders et al., 2006; Ray et al., 2020; Stein et al., 2010). Additionally, most studies on emotional attenuation of AB include positive, negative, and neutral materials simultaneously, allowing differentiation of valence and arousal effects (Bach et al., 2014; W. Luo et al., 2010; Luo & Qi, 2022; Sklenar & Mienaltowski, 2019; Tian et al., 2018; Zhang et al., 2014).

So, which factor—arousal or valence—plays the primary role in emotional attenuation of AB? Substantial evidence suggests that the arousal hypothesis has greater explanatory power than the valence hypothesis. The arousal hypothesis posits that emotional T2 attenuates AB regardless of valence; emotional stimuli with sufficient arousal levels receive better recognition within the AB interval (Anderson, 2005; Keil & Ihssen, 2004). Evidence supporting the arousal hypothesis includes similar AB attenuation effects for both positive and negative stimuli compared to neutral stimuli (de Jong et al., 2009; de Oca et al., 2012; Li et al., 2022; Tian et al., 2018; Van Dam et al., 2012; Zhao et al., 2018). Within the arousal hypothesis framework, high-arousal stimuli can capture attentional engagement through their emotional salience in a bottom-up manner, while also increasing overall brain activation during the task, placing individuals in a higher state of alertness to identify more targets.

The valence hypothesis proposes that different valences produce different emotional attenuation effects, 主要包括威胁优先加工和快乐优先加工两种观点. For example, threat-related negative information as T2 may be processed and identified more preferentially than positive information, representing a threat-processing advantage (Bach et al., 2014; De Martino et al., 2009; Engen et al., 2017; Maratos et al., 2008; Milders et al., 2006; Zhu et al., 2015). This threat-processing advantage may reflect evolutionarily developed prioritization of threat informa-

tion (Anderson et al., 2003). Conversely, some studies find that positive stimuli as T2 show greater attenuation of AB than negative stimuli, representing a happiness advantage (Miyazawa & Iwasaki, 2010; Ray et al., 2020). This happiness advantage may stem from positive emotions broadening attentional scope and increasing temporal flexibility in attentional allocation (Mishra et al., 2017; Ray et al., 2020). Clearly, these studies yield contradictory results, and future research will likely continue to support either threat or happiness prioritization. However, we note that although emotional materials in these studies are rated and matched on valence and arousal, individual differences in stimulus evaluation and emotional arousal remain—that is, different individuals evaluate and respond emotionally to the same stimuli differently. A reasonable solution is to conduct post-experiment individual-level ratings of stimulus valence and arousal, using individual data to build multilevel linear regression models to separate the effects of valence and arousal. It should be noted that some studies have found no differences between positive and negative stimuli in AB attenuation effects (de Oca et al., 2012; Maratos et al., 2008; Ogawa & Suzuki, 2004; Stein et al., 2010). Due to lack of strict control over arousal differences across valence conditions, these conflicting results may still be caused by arousal differences. Therefore, no clear conclusion currently exists regarding the role of valence in emotional attenuation of AB (Mishra et al., 2017).

Overall, emotional target stimuli containing emotional content can reliably attenuate AB compared to neutral stimuli, suggesting that increased arousal from emotional processing may be the primary cause. However, whether threat prioritization or happiness prioritization exists in emotional attenuation of AB remains controversial. Future research should manipulate emotional valence while controlling for arousal effects to separate their distinct influences.

3.3 T2 Task Type

In studies of emotional attenuation of AB, different T2 task types essentially establish different attentional templates, with participants determining processing depth for emotional T2 based on task goals. For example, in face detection tasks, participants can rely on local features like eyes or teeth to infer target presence, whereas in facial expression or gender discrimination tasks, deeper processing is required to extract task-relevant information. The core question for detection and discrimination tasks is whether emotional information can facilitate target detection and whether objects containing emotional information can be effectively processed.

Research finds that in both detection and expression discrimination tasks, emotional stimuli as T2 are more easily detected than neutral stimuli, and target emotional information is more likely to receive conscious processing within the AB interval (de Jong et al., 2009; W. Luo et al., 2010; Maratos et al., 2008; Milders et al., 2006; Ogawa & Suzuki, 2004; Tian et al., 2018; Zhao et al., 2018; Zhu et al., 2015). Moreover, even when tasks require judgment of non-emotional information, task-relevant information from emotional targets within the AB in-

terval is more easily extracted. For example, when using emotional faces as T2, facial expressions can facilitate extraction of non-emotional information like identity or gender (Bach et al., 2014; De Martino et al., 2009; Engen et al., 2017). Overall, emotional attenuation of AB appears independent of T2 task type—emotional information within the AB interval receives prioritized processing in both detection and discrimination tasks. We therefore speculate that emotional information participates in attenuating AB during both detection and discrimination stages: first, emotional information in targets facilitates detection; second, this detection advantage translates into subsequent discrimination advantages, promoting conscious processing of task-relevant information.

A subsequent question concerns the extent to which detection advantages can be converted into discrimination advantages. This requires integrating detection and discrimination tasks, which can be achieved by adding T2-absent trials to discrimination tasks. For example, in facial expression discrimination tasks, researchers could add an option for whether a face was seen, allowing simultaneous calculation of detection rates and discrimination accuracy. Recent research has found dissociations between detection and discrimination measures in emotional attenuation of AB: facilitation effects for facial expressions in detection do not necessarily translate into identification advantages for other dimensions, or even for expression identification itself (Sun et al., 2021). Sun et al. (2021) manipulated T2 task type in RSVP tasks, adding T2-absent trials to both expression discrimination (expression classification) and implicit emotion tasks (gender classification), calculating both face detection rates and discrimination accuracy. Behavioral results showed that in gender classification tasks, facial expression facilitated face detection but did not affect gender classification performance. In emotion-relevant tasks, expression facilitated face detection, but fearful expression identification was actually worse. These results indicate that expression-based prioritization in detection is unaffected by T2 task type, while T2 task type modulates expression identification—specifically, facial expressions within the AB interval are not effectively processed in expression discrimination tasks. ERP results also show that late processing of expressions is modulated by task emotion relevance. Analysis of ERPs for correctly identified fearful versus neutral faces revealed that early processing advantages for facial expressions were unaffected by T2 task type: fearful faces evoked enhanced P100 components compared to neutral faces in both tasks, reflecting rapid attentional capture by emotional information (W. Luo et al., 2010). However, late processing of facial expressions was modulated by task emotion relevance: fearful faces evoked larger P300 amplitudes than neutral faces in expression classification tasks, but not in gender classification tasks. Previous research suggests P300 reflects fine processing of threat information, and its modulation by task type indicates that emotional information in gender classification tasks may be suppressed due to competition with task-relevant information, preventing consolidation into working memory for fine processing (Eimer & Holmes, 2007; Schupp et al., 2007).

Unlike explicit emotion classification tasks that require attention to emotional features, emotion processing in detection and implicit emotion tasks occurs pri-

marily implicitly, reflecting bottom-up characteristics. Previous research suggests that automatic and controlled emotion processing have temporal selectivity: early emotion processing is a bottom-up, stimulus-driven automatic process unaffected by task demands, while late emotion processing is a top-down, goal-driven controlled process modulated by task requirements (Q. Luo et al., 2010). Therefore, in emotional attenuation of AB, emotional information can automatically capture attention rapidly during early processing, promoting attentional selection and candidate target identification. However, during late processing, whether this emotional information can be consolidated into working memory depends on task demands.

3.4 Anxiety Influences Emotional Attenuation of AB

Individuals with high trait anxiety scores are prone to developing anxiety disorders (Mineka & Oehlberg, 2008). Both high trait anxiety individuals and clinical anxiety patients show heightened sensitivity to emotional stimuli, overestimating the likelihood and negative impact of future negative events (Aue & Okon-Singer, 2015; Clarke et al., 2013; Grupe & Nitschke, 2013). Attentional control theory posits that anxiety relates to both bottom-up attentional bias toward negative information and impaired top-down attentional control (Eysenck et al., 2007). High trait anxious individuals exhibit both reduced goal-directed attention and increased stimulus-driven attention, creating an imbalanced attentional system that produces hypervigilance and overreaction to threat stimuli. Previous research finds that trait anxious individuals identify fearful and angry faces faster than non-anxious individuals (Cooper et al., 2008; Surcinelli et al., 2006; Sussman et al., 2016). Moreover, temporal prioritization of facial expressions relates to trait anxiety: high trait anxious individuals more easily identify negative emotional faces among sequentially presented distractors. For example, using fearful and happy faces as T2 in RSVP tasks, researchers found that while both face types were subject to AB, the impact was smaller for fearful than happy faces in high trait anxiety groups (Fox et al., 2005), suggesting that trait anxiety may lead to selective sensitivity to threat-related stimuli.

Compared to trait anxious individuals, specific phobia patients often show severe anxiety responses to particular objects. For example, spider phobia patients exhibit stronger emotional responses to spider-related stimuli than normal individuals. When such specific stimuli appear in distractor sequences, can spider phobia patients process them preferentially? Research finds that both spider phobia patients and control individuals can identify more emotional targets in stimulus sequences, but phobia patients show selective sensitivity to spider-related pictures (Reinecke et al., 2008; Trippe et al., 2007; Weierich & Treat, 2015). Although socially anxious individuals are sensitive to others' facial expressions, research finds that attenuation of AB for angry and happy faces is unrelated to social anxiety levels (de Jong et al., 2009; de Jong & Martens, 2007), suggesting that social anxiety does not seem to affect efficiency of processing facial emotion information. One possible explanation is that social anxiety sensitivity to facial

expressions may manifest only in implicit processing of emotional information, with explicit emotion tasks failing to differentiate high versus low social anxiety individuals. Future research could use detection or implicit emotion tasks to reveal implicit processing biases for emotional information in socially anxious individuals.

Overall, anxious individuals more easily notice threat information in their environment, and this lower threshold for detecting emotional stimuli enables them to detect and identify emotional targets in distractor sequences more readily. However, future research should also consider effects of different anxiety subgroups (generalized anxiety patients) or anxiety contexts (test anxiety, social anxiety) on emotional attenuation of AB.

3.5 Expectancy Factors

As an important adaptive function, the brain excels at rapidly identifying statistical regularities in the environment to generate expectations about upcoming events (Friston, 2010). Expectations about future events not only influence perceptual processing when those events occur (Kok et al., 2012; Trauer et al., 2019) but also promote prioritized conscious processing (Alilovic et al., 2021; Meijs et al., 2019; Meijs et al., 2018). In laboratory conditions, participants also form expectations about upcoming targets based on statistical regularities learned from previous trials, including target timing, location, and features. Crucially, such expectations can improve task performance to some extent (Tang et al., 2014; Visser et al., 2014). In previous studies, emotional faces of different valences always appeared as T2 with equal probability after T1. Although participants were unaware of this information beforehand and experimental procedures contained no explicit cues about T2 facial emotion, participants could implicitly learn statistical regularities about the task during practice and formal experiments, including T1-T2 interval information and emotional features of T2 faces (Meijs et al., 2018; Tang et al., 2014). How then do expectations about emotional stimuli in RSVP tasks influence emotional attenuation of AB?

In implicit emotion tasks, emotional information is task-irrelevant. However, research finds that target emotional content can facilitate conscious processing of task-relevant information under AB conditions (Bach et al., 2014; De Martino et al., 2009; Engen et al., 2017; Sigurjonsdottir et al., 2015; Sun et al., 2021). For example, when requiring gender judgments for faces, researchers found better gender discrimination performance for threat faces than neutral faces within the AB interval (Engen et al., 2017; Sigurjonsdottir et al., 2015). That is, although facial expression is task-irrelevant, expression information can facilitate processing of other facial dimensions under limited attentional resources (Milders et al., 2006). In implicit emotion tasks, when participants can expect target emotional valence, does this emotional expectancy further increase emotional attenuation of AB by enhancing detection likelihood, or does it reduce the effect by suppressing task-irrelevant emotional processing? Sun, Shang, et al. (2022) manipulated emotional expectancy by setting the proportion of fear-

ful and neutral faces as T2 within blocks in a gender classification T2 task. Behavioral results showed that expectancy based on emotional T2 probability suppressed the fear processing advantage, with only low-probability fearful faces attenuating AB. ERP results further revealed that fearful faces evoked larger P300 amplitudes than neutral faces only in low-probability fearful conditions, with no difference in high-probability conditions, indicating that emotional expectancy suppressed late processing of emotional information. In AB tasks, the P300 component is thought to reflect consolidation of identified T2 targets, meaning the target is encoded into working memory (Dell'Acqua et al., 2015; McArthur et al., 1999; Zivony & Lamy, 2022). Thus, these results suggest that in implicit emotion tasks, emotional expectancy suppresses late working memory encoding of emotional information.

It should be noted that the above study used a gender classification T2 task to examine expectancy effects, where expectancy suppressed representation of task-irrelevant information (Sun, Shang, et al., 2022). Conversely, in explicit emotion tasks, where expectancy content aligns with task goals, emotional expectancy might increase emotional attenuation of AB by facilitating detection or representation of emotional targets. Future research should further investigate this issue.

4.1 Brain Mechanisms Related to Emotional Attenuation of AB

Due to the low temporal resolution of functional magnetic resonance imaging (fMRI) and the fact that T1-T2 intervals inducing AB are typically under 1 second, this technology often cannot capture brain activation during emotional attenuation of AB. Scientists have adopted an approach that ignores temporal characteristics and instead compares brain activation differences between trials where emotional attenuation of AB occurs (emotional stimuli correctly reported) versus trials where it does not occur (emotional stimuli missed or incorrectly reported) (De Martino et al., 2009; Schwabe et al., 2011). One fMRI study examined brain activation involved in emotional attenuation of AB (De Martino et al., 2009). Participants identified a building (T1) and a face (T2) among scrambled images, with T2 faces including fearful and neutral expressions. Behavioral results showed better identification for fearful than neutral faces within the AB interval, demonstrating attenuation of AB. Imaging results revealed that correctly identified T2 faces evoked enhanced fusiform gyrus activity related to face processing, while the behavioral benefit for fearful over neutral faces primarily related to enhanced activation in the anterior rostral cingulate cortex. Previous research indicates that the anterior rostral cingulate cortex is closely related to emotional processing, participating in selective attention to emotional information (Lane, Fink, et al., 1997; Elliott et al., 2000) and evaluation of emotional intensity (Taylor et al., 2003). Therefore, the anterior rostral cingulate cortex may participate in early attentional selection of emotional information during emotional attenuation of AB.

Schwabe et al. (2011) simultaneously manipulated emotional valence of both

T1 and T2 in an RSVP task. Results showed that emotional T2 attenuated AB while emotional T1 enhanced AB. Critically, emotional T2 attenuation of AB under neutral T1 conditions related to amygdala activation, whereas the enhancing effect of emotional T1 on AB related to enhanced activation in anterior cingulate cortex, insula, and orbitofrontal cortex. Previous research suggests amygdala activation relates to early emotional responses, while anterior cingulate cortex, insula, and orbitofrontal cortex relate to fine processing of emotional information (Garfinkel & Critchley, 2014; Garvert et al., 2014; Troiani & Schultz, 2013). These results thus suggest that the enhancing effect of emotional T1 on AB primarily involves brain regions related to fine emotional processing, while emotional T2 attenuation of AB involves regions related to reactive emotional processing.

Another approach to studying brain mechanisms of emotional attenuation of AB involves recruiting brain lesion patients (Anderson & Phelps, 2001; Piech et al., 2011). Brain lesion and fMRI studies suggest that enhanced early perceptual processing of emotional information in AB may involve emotion-related brain regions such as the amygdala, anterior cingulate cortex, and insula (Anderson & Phelps, 2001; De Martino et al., 2009; Piech et al., 2011; Schwabe et al., 2011). In healthy participants, emotional stimuli as T2 show processing advantages over neutral stimuli and are more likely to be consciously reported. However, this advantage is not observed in patients with left amygdala damage, indicating that the left amygdala plays an important role in promoting prioritized processing of emotional information (Anderson & Phelps, 2001).

Overall, because attentional resources are limited within the AB window in RSVP tasks, prioritized processing of emotional information primarily relies on the amygdala-mediated subcortical rapid emotional processing pathway. Intracranial EEG or magnetoencephalography (MEG) methods, which combine high spatial and temporal resolution, should be used more frequently in future research to further clarify the brain structures and temporal distribution characteristics involved in emotional attenuation of AB.

4.2 Temporal Characteristics of Emotional Attenuation of AB

Event-related potential (ERP) methods in EEG research offer extremely high temporal resolution with millisecond precision, providing valuable insights into the time course of cognitive and emotional processing. Therefore, some studies have used ERP to examine cognitive mechanisms of emotional T2 attenuation of AB (Keil et al., 2006; W. Luo et al., 2010; Luo & Qi, 2022; Qiu et al., 2022; Sun et al., 2021; Sun, Shang, et al., 2022; Trippe et al., 2007; Zhu et al., 2015). These studies find processing advantages for emotional over neutral information at multiple processing stages. Keil et al. (2006) found that at Lag2, both positive and negative words showed better task accuracy than neutral words, and compared to neutral words, they evoked enhanced EEG activity over posterior brain regions between 120–270 ms after T2 onset. This suggests that the facilitative effect of emotional information on T2 identification within

the AB interval primarily relates to enhanced early perceptual processing of emotional information. That is, emotional stimuli produce stronger perceptual representations than neutral stimuli during early processing stages, preserving more information after experiencing the same attentional resource limitations and distractor masking, thereby demonstrating attenuation of AB.

Emotional information shows enhanced effects not only during early processing stages but also during subsequent multiple processing stages (W. Luo et al., 2010; Zhang et al., 2014). For example, W. Luo et al. (2010) proposed a three-stage model for facial expression processing under AB conditions. In this model, facial expressions have different processing characteristics at different stages. Specifically, the first stage is automatic processing of fear information, manifested as fearful faces evoking enhanced N100 and P100 components compared to happy and neutral faces, indicating rapid detection of threat information. The second stage involves separation of emotional and non-emotional information, shown as emotional faces (fearful and happy) evoking enhanced N170 and VPP components compared to neutral faces. The third stage involves separation of different emotional information, where N300 and P300 components evoked by fearful, happy, and neutral faces become completely dissociated (W. Luo et al., 2010). Although this model was proposed for facial expression processing, it shows that emotional faces demonstrate processing advantages over neutral faces at least in the second and third stages. Therefore, under AB conditions, emotional information processing affects multiple cognitive processes including T2 detection and discrimination.

Overall, ERP research indicates that emotional information in T2 targets affects multiple stages of cognitive processing, and early processing of emotional information is key to emotional T2 attenuation of AB. This is crucial for understanding whether AB arises from impairment in early processing stages, late stages, or multiple stages (Zivony & Lamy, 2022). Additionally, recent findings show that early processing of emotional faces under AB conditions has automatic characteristics, while late fine processing is modulated by top-down factors such as task type and emotional expectancy (Sun et al., 2021; Sun, Shang, et al., 2022). Future research should continue exploring how top-down factors like expectancy participate in the cognitive mechanisms of emotional attenuation of AB.

5 Early Attention Enhancement and Late Consolidation Competition Hypothesis

Previous theories of AB suggest that T2 fails to be consciously reported because T1 consolidation inhibits, temporarily disrupts, or delays T2 selection, preventing T2 from being identified as a candidate target during the target selection stage (Di Lollo et al., 2005; Nieuwenstein, 2006; Nieuwenstein et al., 2005; Taatgen et al., 2009; Vul et al., 2008). Alternatively, some theories propose a working memory consolidation bottleneck allowing only one item to be consolidated at a time, with T1 consolidation preventing T2 consolidation within the subsequent

200–500 ms window (Chun & Potter, 1995; Lagroix et al., 2012; Raymond et al., 1992; Wyble et al., 2009). Both theories emphasize that interference from T1 consolidation with T2 attentional selection or consolidation is the key cause of AB. However, a series of experimental results show that T2 emotional characteristics affect both early attentional selection and late consolidation (W. Luo et al., 2010; Sun et al., 2021; Sun, Shang, et al., 2022; Zhang et al., 2013). This suggests that AB theories cannot ignore how T2 properties affect AB, and implies that AB is not influenced by a single process of attentional selection or consolidation bottleneck, but by both stages (Zivony & Lamy, 2021). Therefore, the two-stage model of AB has attracted our attention.

The two-stage model of AB proposes that information processing in RSVP can be divided into perceptual processing and working memory consolidation stages (Chun & Potter, 1995). In the first stage, all information is represented and rapidly categorized, during which target-relevant stimuli are selected. However, these early processes are not sufficiently complete for conscious report and require initiation of an attentional engagement stage for selected candidate targets. In the second stage, early stimulus representations can be transformed into stable, consciously reportable forms. The two-stage model suggests that AB occurs because T1 consolidation in the second stage occupies limited short-term memory capacity, leaving T2 stranded in stage one without effective consolidation.

The two-stage model provides a good framework for analyzing AB effects, but faces difficulties in explaining emotional attenuation of AB. In emotional attenuation research, emotional information processing advantages appear in both perceptual processing and memory consolidation stages, but the two-stage model cannot explain why top-down factors like task demands affect emotional attenuation of AB in the second stage. Based on the two-stage model, we propose the “Attentional Enhancement and Consolidation Competition” hypothesis (see Figure 1 [Figure 1: see original paper]) to explain emotional attenuation effects. This hypothesis similarly posits that target processing 主要包括探测和巩固两个阶段, 探测阶段的主要功能是确定候选目标, 巩固阶段的主要功能是将任务相关信息加工到可意识报告的水平. According to the Attentional Enhancement and Consolidation Competition hypothesis, the detection advantage for emotional T2 stems from its emotional salience, but whether this detection advantage translates into a discrimination advantage is influenced by top-down factors such as task demands and emotional expectancy. When task demands focus on emotional content, representation of emotional information is enhanced during consolidation; when task demands focus on non-emotional content, consolidation of emotional information must compete with processing of task-relevant information and is suppressed. Therefore, emotional attenuation of AB reflects both the facilitative effect of emotional processing on attentional selection during target detection and the competition between emotional and other information during consolidation.

[Figure 1: see original paper]

Figure 1. The Early Attention Enhancement and Late Consolidation Competition hypothesis of emotional T2 attenuating attentional blink. T1 and T2 refer to the first and second targets, D1, D2, D3... refer to distractor items. Blue arrows indicate effects of T1 consolidation on T2 detection and consolidation processes. Red arrows indicate effects of T2 emotional salience and other factors on detection and consolidation processes.

First, we propose that in stage one, target emotional salience enables emotional stimuli to be rapidly detected and confirmed as candidate targets. At the behavioral level, this manifests as emotional stimuli being more easily detected than neutral stimuli. At the neural level, emotional T2 evokes enhanced early EEG components compared to neutral T2, with these components emerging as early as 120 ms after T2 onset (Keil et al., 2006; W. Luo et al., 2010; Trippe et al., 2007; Zhang et al., 2014; Zhang et al., 2013). The amygdala-centered subcortical emotional processing pathway may be the key brain structure for emotional attenuation of AB during detection. Previous research suggests the amygdala is responsible for rapid detection and response to threat-related stimuli (Anderson et al., 2003; Öhman, 2005; Vuilleumier et al., 2001). Emotional T2 attenuation of AB is observed in healthy participants but not in patients with amygdala damage, indicating the amygdala plays an important role in detecting emotional information (Anderson & Phelps, 2001). However, this evidence does not support the emotional automaticity hypothesis of emotional attenuation of AB (Maratos et al., 2008), which posits that emotional processing does not consume attentional resources and therefore should not be limited by currently available attentional resources in RSVP tasks, thus showing attenuation of AB. Nevertheless, increasing T1 task difficulty to reduce available attentional resources for T2 can suppress the emotional target processing advantage (Stein et al., 2010; Sun, Jia, et al., 2022; Ye et al., 2011). In other words, emotional attenuation of AB may occur because T1 tasks are too simple, leaving residual attentional resources after T1 consolidation that can still meet the demands of prioritized emotional processing (Lavie, 2010; Pessoa et al., 2002; Sebastian et al., 2017).

Second, discrimination advantages for emotional targets are influenced by emotional expectancy and task goals, and detection advantages do not necessarily translate into discrimination advantages. A series of studies finds that regardless of whether RSVP tasks require reporting T2 emotional information, task-relevant content of emotional targets is more likely to be consciously reported than that of neutral targets under AB conditions (Bach et al., 2014; de Jong et al., 2009; De Martino et al., 2009; Engen et al., 2017; W. Luo et al., 2010; Ray et al., 2020; Zhang et al., 2013). This suggests that after rapid attentional capture of emotional targets during detection, task-relevant content also receives conscious processing during discrimination. However, recent research finds that detection advantages for emotional targets do not necessarily translate into discrimination advantages, especially in implicit emotion tasks (Sun, Jia, et al., 2022; Sun et al., 2021). One study found that in gender classification tasks, the facilitative effect of T2 facial expression on gender processing was suppressed by

T1 task difficulty and emotional expectancy (Sun, Jia, et al., 2022; Sun, Shang, et al., 2022). Another study found that although expression facilitated face detection, facial expression did not affect task performance in gender classification tasks, and fearful face identification accuracy was actually lower than neutral faces in emotion classification tasks (Sun et al., 2021). These findings indicate that in both implicit and explicit emotion tasks, facial expressions within the AB interval facilitate target detection, but their emotional content is not necessarily processed effectively. We speculate this may be due to limited attentional resources during working memory consolidation, where consolidation of emotion-related information must compete with T1 and other distractors. When task goals focus on non-emotional information, late processing of emotional information is suppressed by factors such as T1 task difficulty, task demands, and emotional expectancy, causing emotional attenuation of AB to disappear (Sun, Jia, et al., 2022; Sun et al., 2021; Sun, Shang, et al., 2022).

In summary, according to our Attentional Enhancement and Consolidation Competition hypothesis, facial expression information's emotional salience enables the face to rapidly capture attention and receive enhanced processing during early stages, allowing detection of more emotional targets. Second, stimuli receiving attentional enhancement during detection suffer less interference from masking stimuli during T1 consolidation and more easily enter the consolidation stage. When objects containing emotional information enter consolidation, whether task-relevant information can be consciously discriminated depends on whether task demands focus on emotional features. When tasks require attention to non-emotional features, fine representation of facial emotional information is suppressed, especially under high emotional expectancy conditions. When tasks require attention to emotional features, facial emotional information receives consolidation advantages.

6 Conclusions and Outlook

Emotional attenuation of AB reflects prioritized processing of emotional information under attentional resource constraints. Application of techniques such as EEG and fMRI has helped reveal the mechanisms underlying this phenomenon. Emotional attenuation of AB involves both components of automatic emotional processing and top-down cognitive control driven by goals. The emotional salience of emotional T2 itself facilitates early attentional selection processes for targets within the blink interval, primarily driven by subcortical regions like the amygdala. Consolidation of emotional T2 is influenced by factors such as task type and is primarily mediated by cognitive control-related brain regions like the prefrontal cortex.

It should be noted that current studies always require participants to report both targets and always require T1 to be reported before T2, which may introduce differences in importance between T1 and T2. The reporting order actually implies priority of T1 and T2 during retrieval, and emotional attenuation of AB could also be considered as emotional T2 being more easily retrieved than

neutral T2. Therefore, future research could manipulate retrieval priority by changing the reporting order of T1 and T2 to further examine whether retrieval competition exists in emotional attenuation of AB. Additionally, when emotion serves as T2, especially in implicit emotion tasks, there is a lack of emotional probe trials to assess the degree of emotional stimulus processing during the experiment, and a lack of post-task evaluations requiring participants to rate their perception of emotions during the task (Bach et al., 2014; De Martino et al., 2009; Nakamura et al., 2017; Sun et al., 2021; Zhao et al., 2018). Future research needs to control for these factors in experimental design.

Emotional attenuation of AB could potentially serve as a behavioral index reflecting individual differences in emotional processing. Some studies have examined emotional attenuation of AB in anxiety, autism, and PTSD populations (Schonenberg & Abdelrahman, 2013; Trippe et al., 2007; Van Dam et al., 2012; Weierich & Treat, 2015; Yerys et al., 2013). Future research could consider using this index to screen clinical emotional disorder patients and provide guidance for emotion regulation training and psychological/behavioral correction therapies. Emotional T2 attenuation of AB manifests across multiple stages of emotional processing and reflects interactive influences between emotional processing and attentional control. Regarding neural mechanisms, future research should examine how brain regions such as the amygdala, anterior rostral cingulate cortex, and prefrontal cortex coordinately participate in emotional attenuation of AB, and whether the roles of these regions differ between implicit and explicit emotion tasks.

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