Eye Movement Study of Attentional Bias to Threat Stimuli in Individuals with Post-traumatic Stress Disorder

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Abstract

Attentional bias toward threat stimuli is a characteristic manifestation in individuals with post-traumatic stress disorder (PTSD). In recent years, researchers have utilized eye-tracking technology to investigate the processing characteristics and underlying mechanisms of attentional bias. Although research findings regarding the existence of attentional orienting acceleration, difficulty in attentional disengagement, or attentional avoidance are inconsistent, they all attempt to provide eye-tracking evidence for validating models such as the vigilance-avoidance model and the attentional maintenance model. In future research, when recording gaze patterns of individuals with PTSD, it is essential not only to construct and integrate eye-tracking models of PTSD individuals from multiple dimensions, but also to combine multiple techniques to jointly investigate the mechanisms of threat information attentional bias in PTSD individuals from a multimodal perspective.

Full Text

The Eye Movement Study of Attentional Bias Towards Threat in Posttraumatic Stress Disorder

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Abstract: Attentional bias toward threat is a common phenomenon in individuals with Posttraumatic Stress Disorder (PTSD). In recent years, researchers have employed eye-tracking technology to investigate the processing characteristics and underlying mechanisms of this attentional bias. Although findings regarding the existence of facilitated attentional orienting, difficulty in attentional disengagement, or attentional avoidance remain inconsistent, these studies collectively aim to provide ocular evidence for theoretical models such as the vigilance-avoidance model and attentional maintenance model. Future research examining the gaze patterns of PTSD individuals should not only construct and integrate eye movement models from multiple dimensions but also combine multiple technologies to investigate the threat information attention bias mechanism from a multimodal perspective.

Keywords: Posttraumatic Stress Disorder, attentional bias, eye movement

Posttraumatic Stress Disorder (PTSD) is a common and debilitating psychiatric condition, with involuntary and uncontrollable intrusive memories of traumatic events being one of its most prominent symptoms (American Psychiatric Association, APA, 2013). Despite the development of corresponding pharmacological treatments, the prognosis remains concerning, with recovery rates of only 20%–30% (Krystal et al., 2017). Cognitive models of PTSD posit that increased attentional bias toward traumatic events or threat information represents a typical cognitive deficit in PTSD patients (Aupperle et al., 2012).

The majority of studies examining attentional bias toward threat in PTSD individuals have primarily employed reaction time tasks, which infer the presence of attentional bias by examining participants' task performance under different threatening stimulus conditions. Examples include the emotional Stroop task (Herzog et al., 2017; Williams et al., 1996) and the dot-probe paradigm (MacLeod et al., 1986; Swick & Ashley, 2017). However, these reaction time-based studies have yielded inconsistent conclusions. For instance, some researchers using the emotional Stroop task found that PTSD individuals allocated more attentional resources to threat stimuli (Gindt et al., 2017), whereas Yuval et al. (2016) argued that this population does not exhibit significant attentional bias toward threat information. Other studies using the dot-probe paradigm have revealed that attentional bias in PTSD individuals is not a unitary component but rather fluctuates between threat bias and threat avoidance (Iacoviello et al., 2014; Naim et al., 2015). These inconsistent findings may stem from the indirect nature of such tasks, which cannot directly examine the temporal course of attentional processing before and after key presses (Lazarov et al., 2016; Lazarov et al., 2017; Price et al., 2016). Consequently, to accurately differentiate various aspects of attentional bias processing, some researchers have begun adopting eye-tracking technology to record the real-time ocular behavior of PTSD individuals during attentional processing, aiming to reveal the characteristics of their attentional patterns through analysis of various eye movement indices. This paper summarizes relevant studies that have used eye-tracking technology to investigate threat attention bias in PTSD and builds upon these

findings.

2 Components and Measurement Indices of Attentional Bias

Attentional bias refers to the persistent allocation of greater attentional resources to real or experimentally induced threat stimuli during attentional processing (Joyal et al., 2019). Attentional bias primarily comprises three components (Sheppes et al., 2013): facilitated attentional orienting (or vigilance), difficulty in attentional disengagement, and attentional avoidance. Facilitated attentional orienting or vigilance refers to PTSD individuals' tendency to prioritize attention toward threat stimuli, accelerating threat detection speed. Difficulty in attentional disengagement indicates that once PTSD individuals detect threat stimuli, they struggle to terminate attentional processing of them. Attentional avoidance describes PTSD individuals' tendency to allocate attention away from threat stimuli and toward non-threatening stimuli. Although these components appear mutually exclusive, they may coexist at different stages of information processing (Weierich et al., 2008). Research has found that facilitated attentional orienting occurs during early automatic processing stages, whereas difficulty in disengagement emerges during later stages (Bishop, 2009). However, the rapid occurrence of the former may influence the latter, while the latter may also occur independently of the former (Sheppes et al., 2013).

To reveal differences among these components of attentional bias, researchers have utilized eye-tracking technology to examine the attentional bias processing trajectory. In-Albon and Schneider (2010) argued that over time, individuals' attention allocation to visual stimuli shows high consistency with gaze position and movement direction, confirming the validity of using eye-tracking methodology to investigate attentional bias. Typically, researchers require participants to freely view stimulus arrays (free-viewing paradigm) and subsequently analyze various collected eye movement indices to infer attentional processing patterns. Based on existing research, common eye movement indices for attentional bias can be categorized into temporal dimension indices and spatial dimension indices. Temporal dimension indices, which relate to when the eyes move, specifically refer to the time spent encoding specific content in the visual field, such as first fixation duration and total fixation duration, reflecting individuals' attentional maintenance of visual information. Spatial dimension indices concern gaze movement location, such as fixation order and saccade position, enabling real-time understanding of attention allocation patterns or amounts through analysis of fixation position changes. Additionally, pupillometry measures, including pupil size and reactivity (dilation or constriction), allow continuous measurement of involuntary physiological responses closely related to emotion (Cascardi et al., 2015).

3 Mechanisms of Attentional Bias in PTSD Individuals

3.1 Facilitated Attentional Orienting in PTSD Individuals

3.1.1 Eye Movement Research on Facilitated Attentional Orienting in PTSD Facilitated attentional orienting or vigilance reflects the speed at which early attention is captured by threat stimuli. In eye-tracking research, first fixation and pupil change indices are commonly used to reflect facilitated attentional orienting or vigilance. When threat and non-threat stimuli are presented simultaneously, if PTSD individuals' first fixations land more frequently on threat stimuli, or if pupil dilation is greater when first looking at threat stimuli, this indicates they rapidly prioritize attentional resource allocation to threat stimuli, demonstrating facilitated attentional orienting or vigilance. Pupil diameter changes are influenced by both bottom-up and top-down factors: the former are triggered by physical changes in external stimuli such as brightness, while the latter result from psychological changes induced by stimuli, such as attention and emotional motivation (Yang et al., 2020). Therefore, researchers using pupil indices uniformly control for material grayscale and separately control for word frequency and length in verbal stimuli, as well as overall complexity in pictorial stimuli, to ensure exclusion of non-experimental factors.

Some studies using threat words as materials have provided evidence for the facilitated orienting component of attentional bias (Bryant et al., 1995; Felmingham et al., 2011). Bryant et al. (1995) employed a free-viewing paradigm, presenting PTSD individuals who had experienced motor vehicle accidents with simultaneous displays of one motor vehicle accident-related threat word (or neutral word) and three filler words. Results showed that when stimuli contained threat words, PTSD individuals exhibited a greater proportion of first fixations on them; conversely, healthy control participants showed no significant difference in first fixation proportions between word types. This finding indicates that PTSD individuals more rapidly direct attention toward threat stimuli, confirming the existence of facilitated attentional orienting. Felmingham et al. (2011) replicated these findings using physical assault words instead of threat words with a similar experimental design. However, other studies using pictorial threat stimuli have found no evidence of facilitated attentional orienting (Lee & Lee, 2012; Lee & Lee, 2014). Lee and Lee (2012) presented participants with four types of pictures simultaneously (trauma-related violent images, dysphoric, positive, and neutral images) and required free viewing for 10 seconds, but found no significant differences among PTSD, trauma-exposed non-PTSD, and healthy control groups in the location of first fixations. They suggested that participants might have difficulty evaluating four different visual stimuli simultaneously. To further clarify the attentional mechanisms in PTSD, Lee and Lee (2014) presented only two stimuli per trial and found no significant group differences in trials pairing emotional (anger, fear, happiness) with neutral stimuli or negative (anger, fear) with positive (happiness) stimuli, indicating equal probability across groups for first selecting each emotional stimulus. Armstrong et al. (2013), using veterans as participants, also found no evidence of facilitated

orienting to threat stimuli. Kimble et al. (2010) used threat pictures and found only a trend toward faster orientation to threat images (particularly Iraq war images) in high-symptom PTSD veterans. When using first fixation latency as an index, consistent with first fixation location results, no significant differences were found between PTSD and non-PTSD groups in time to orient to threat stimuli (Bryant et al., 1995; Felmingham et al., 2011; Kimble et al., 2010). However, when researchers used pupil response as an index, heterogeneous results emerged. PTSD individuals with physical abuse histories showed no significant pupil dilation when viewing threat words, indicating no heightened vigilance toward threat stimuli (Felmingham et al., 2011). In contrast, PTSD veterans exhibited larger average pupil values when viewing threat pictures (Kimble et al., 2010), demonstrating vigilance.

On one hand, these non-homogeneous pupil index results may be influenced by threat stimulus presentation format, suggesting that vigilance is more easily exhibited when viewing threat pictures compared to words. On the other hand, even when selecting individuals with identical trauma histories (PTSD veterans) and presenting the same threat stimulus type (pictures), Armstrong et al. (2013) found no facilitated orienting using the proportion of first fixations on threat stimuli as an index, whereas Kimble et al. (2010) concluded that "PTSD individuals exhibit facilitated attentional orienting" when analyzing pupil values as the dependent variable. This discrepancy may indicate differential impacts of various eye movement indices on findings. The proportion of first fixations constitutes a spatial dimension index related to gaze movement location, which depends on saccades—movements requiring time for planning and execution (Yan et al., 2013). This suggests that by the time gaze lands on the first fixation location, temporal accumulation has occurred, whereas attentional vigilance is an instantaneous phenomenon. Therefore, pupil indices, which do not rely on temporal accumulation, may be more suitable for examining this component. Additionally, inconsistent attentional vigilance between individuals with PTSD resulting from physical abuse versus war may reflect different roles of trauma event types in attentional bias. During human-caused and natural disaster trauma events, the sources of emotions experienced by individuals are not identical. Although both include self-experienced negative emotions such as "fear," the former also uniquely includes other-directed negative emotions such as "anger" (the perpetrator' s emotion). Hindash et al. (2019) found that PTSD individuals show greater attentional bias toward threat emotions from their own traumatic experiences (fear) compared to perpetrator threat emotions (anger). Since a key pathological mechanism in PTSD development relates to emotional memories formed during trauma events (Wang & Zhu, 2016), this difference in emotional sources may contribute to trauma-specific effects on attentional bias.

3.1.2 Influencing Factors of Facilitated Attentional Orienting in PTSD Individuals Current findings on whether PTSD individuals exhibit facilitated orienting to threat stimuli remain inconsistent. The selection of eye movement indices and threat stimulus presentation format appear to interactively influence

threat orienting: when examining rapid detection through first fixation location, PTSD individuals prioritize attention toward verbal threat stimuli; when analyzing first fixation latency, PTSD individuals show no vigilance effects; and when measuring pupil responses, only pictorial threat stimuli elicit exaggerated reactions in PTSD individuals. This interaction may reflect the interplay between stimulus material complexity and eye movement indices. Compared to pictorial stimuli, individuals can parafoveally preview verbal information, leading to more rapid lexical processing and thus enabling the manifestation of threat orienting.

Armstrong et al. (2013) suggested that pictures lack the specificity to activate traumatic memories from parafoveal vision, preventing PTSD individuals from exhibiting threat orienting. Additionally, pictures belong to an ideographic symbol system, with processing described as "picture → semantics," whereas English word recognition involves phonological extraction, following the pathway "word → phonology → semantics" (Han & Yang, 2003), resulting in faster fixation times for pictures than English words. However, Han and Yang (2003) used only line drawings without backgrounds, which contained minimal irrelevant information and low complexity. Unlike these studies, trauma-related pictures (e.g., war-related images) and facial images (e.g., angry faces) used in other research contain substantial irrelevant background information and high complexity. Therefore, when threat stimuli are presented as pictures, irrelevant perceptual information beyond threat signals may interfere with threat perception, ultimately leading to inconsistent attentional orienting results between stimulus types. Regarding presentation format, Felmingham et al. (2011) presented stimuli at a visual angle of $4\$\times 2°, smaller than that used for picture presentation (11.33×8.48°, 5.64×8.64°, 11.5×\$14°)$. A smaller visual angle indicates greater proximity to the fovea, requiring shorter saccade distances to acquire information and enabling faster information retrieval. This may explain why facilitated attentional orienting was only observed with verbal stimulus materials.

Future research should examine whether changes in visual angle affect threat attention bias mechanisms. On the other hand, verbal stimuli elicit lower arousal levels, whereas pictorial stimuli that induce high arousal hinder the bias toward threat stimulus detection, resulting in facilitated orienting only for verbal stimuli. Some researchers argue that the visual salience and complexity of pictures increase the likelihood of automatic attentional capture, diminishing the role of threat significance and reducing PTSD individuals' ability to detect threat stimuli (Thomas et al., 2013). These differences may be more apparent in first fixation location indices. However, when using pupil change indices, the increased physical size and complexity of pictures may more strongly impact pupil responses, causing pictorial threat stimuli to elicit more pronounced pupil reactions in PTSD individuals. Furthermore, covert eye movements may occur without overt movement (Lee & Lee, 2012), while first fixation latency is recorded based on individuals' overt eye movement behavior. Consequently, rapid vigilance may manifest as covert movement, preventing comprehensive

examination through this index. Future research should effectively investigate the nature of facilitated attentional orienting or vigilance while considering the specific aspects of ocular behavior captured by different eye movement indices to avoid index selection biases affecting results.

3.1.3 Summary When verbal stimuli serve as threat information, spatial indices dependent on temporal accumulation are more suitable for examining facilitated attentional orienting. Pictures function as direct ideographic symbol systems, but irrelevant information contained within pictorial stimuli may interfere with "picture → semantics" processing. Conversely, English words access semantics indirectly, and this indirect pathway may provide time for overt eye movements, enabling rapid reflection of threat word information capture of attention in PTSD individuals. When threat stimuli are presented as pictures, pupil indices appear more sensitive to measuring vigilance, influenced by picture stimulus properties (complexity and salience). Regarding first fixation latency, this index specifically refers to the time required for participants to saccade from the initial fixation point to a specific stimulus type (Kimble et al., 2010), similar to saccade time, indicating the actual time needed for eye movement between two fixation points (Yan et al., 2013). Therefore, regardless of threat information presentation format, latency may not be highly sensitive for examining facilitated attentional orienting due to its inability to accurately measure covert movements. However, this does not mean that a particular stimulus format is only suitable for one type of index when analyzing attentional vigilance; researchers should comprehensively employ multiple eye movement indices to conduct detailed analyses from different dimensions.

3.2 Attentional Disengagement Difficulty in PTSD Individuals

3.2.1 Eye Movement Research on Attentional Disengagement Difficulty in PTSD Attentional disengagement difficulty reflects the degree to which individuals maintain attention on threat stimuli. In eye movement research, total fixation duration is commonly used to index attentional disengagement difficulty. If PTSD individuals show significantly longer total fixation times on threat stimuli compared to non-PTSD individuals, this indicates they have difficulty shifting attention to non-threat stimuli. Researchers have found that PTSD individuals exhibit attentional disengagement difficulty from threat stimuli (Armstrong et al., 2013; Kimble et al., 2010; Lee & Lee, 2012, 2014). Kimble et al. (2010) categorized threat pictures into trauma event-related images (Iraq war pictures) and general negative threat images (motor vehicle accident pictures), requiring Iraqi war veterans to freely view paired neutral and threat stimuli. Results showed that high-symptom individuals exhibited longer total fixation times on both types of threat pictures compared to low-symptom individuals, with this effect remaining stable within 10 seconds, indicating sustained attention to both trauma-related and general negative threat stimuli in PTSD individuals. Armstrong et al. (2013), also examining veteran populations using emotional faces (disgust, fear, and happy) paired with neutral faces, found

that PTSD veterans showed longer fixation times on disgust and fear faces compared to healthy controls, confirming attentional disengagement difficulty from general negative threat stimuli. Lee and Lee suggested that PTSD individuals' attentional disengagement difficulty from angry faces (2012) and violent stimuli and dysphoric images (2014), compared to healthy controls, may occur because viewing stimuli that can trigger traumatic memories induces genuine emotional arousal, leading to greater attentional resource allocation. Additionally, intrusive and ruminative thoughts in PTSD individuals may drive attentional maintenance, causing involuntary over-allocation of attention to such stimuli. Thomas et al. (2013), using university students as participants, also found that PTSD individuals exhibited sustained attention to trauma-related threat pictures. Conversely, Felmingham et al. (2011) presented participants with one physical assault word and three neutral words simultaneously and found no significant differences in average first fixation duration between trauma-exposed healthy individuals and PTSD individuals. They argued that between-group differences are necessary to demonstrate attentional disengagement difficulty in PTSD, thus denying the association between PTSD attentional bias and disengagement difficulty. These results indicate that fixation duration indices can reflect PTSD individuals' attentional disengagement mechanisms. However, some researchers have examined attentional disengagement using spatial indices such as fixation count (Yan et al., 2016) or other indices like sustained pupil changes (Wirz & Schwabe, 2020). Therefore, future research should employ multiple eye movement indices to investigate PTSD attentional disengagement from multiple dimensions.

3.2.2 Influencing Factors of Attentional Disengagement Difficulty in PTSD Individuals While inconsistent conclusions exist regarding whether PTSD individuals exhibit attentional disengagement difficulty from threat stimuli, most studies (using pictures as stimuli) affirm the presence of this phenomenon, and neither stimulus presentation duration nor trauma event type affects its stability. Eye movement studies of other disorders have also found that anxiety and depression populations show longer fixation times on threat stimuli (Lazarov et al., 2016). Brain imaging research further suggests that threat stimuli, serving as cues for recalling traumatic events, can activate fear-related brain regions such as the amygdala (Hayes et al., 2012; Sergerie et al., 2008) or brain regions related to attentional control (Fani et al., 2012; Hayes et al., 2012), thereby increasing fixation times on threat stimuli in PTSD individuals (Lee & Lee, 2014). From the perspective of threat stimulus characteristics, the appearance of threat signals indicates emergency situations for PTSD individuals, who may consequently over-monitor threat stimuli to prevent self-harm (Armstrong & Olatunji, 2012). From an attentional control perspective, PTSD individuals exhibit weaker control abilities and tend to ignore other distractors (Sarapas et al., 2017). Research has found that attentional control in high-symptom PTSD individuals positively correlates with the ability to disengage attention from threat stimuli and voluntarily shift it away (Bardeen et al., 2016).

However, when stimuli are replaced with words, parafoveal preview can accelerate lexical processing, but after attentional orienting captures the word, the low information density of words lacks the capacity for sustained attentional capture. Consequently, individuals can easily shift attention away from threat words, resulting in no disengagement difficulty. This suggests that the inherent properties of words and pictures lead to differential processing, which further separates the manifestation of attentional disengagement difficulty.

3.2.3 Summary PTSD individuals are generally considered to exhibit attentional disengagement difficulty when they maintain attention on threat stimuli for longer durations, showing significant differences from neutral stimulus fixation times. However, threat information contained in verbal stimuli can be acquired and processed more rapidly (Lazarov et al., 2018), and contains no additional information thereafter. This lower information density may reduce the degree to which "threat signals" sustain attentional capture in PTSD individuals. The latter may also result from unconscious binding of "static—word," causing static threat words to less readily exhibit attentional disengagement difficulty. Future research could embed words within background information to examine whether information density changes attentional disengagement difficulty for threat words in PTSD individuals, thereby testing this hypothesis. Additionally, a potential phenomenon exists: in daily life, individuals typically encounter verbal information through reading, a static presentation mode, whereas pictorial stimuli are more ecological, often presented dynamically while approximating real-life experiences. This frequent implicit exposure may create unconscious binding of "word—static" and "picture—dynamic," leading to dynamic perception of pictures and static perception of words in experimental settings. Research has found that dynamic gaze cues produce stronger cueing effects (Zhang et al., 2015), making dynamic presentation modes more likely to sustain attention than static ones. Therefore, PTSD individuals are more likely to exhibit attentional disengagement difficulty toward threat pictures. Future studies could use implicit association paradigms to examine whether individuals unconsciously bind words with static and pictures with dynamic properties, and further investigate whether dynamic presentation of words (e.g., "flashing" words) affects attentional bias in PTSD individuals. In summary, researchers should attend to the properties and presentation modes of threat stimuli used in experiments and examine PTSD attentional disengagement difficulty from different perspectives.

3.3 Attentional Avoidance in PTSD Individuals

3.3.1 Eye Movement Research on Attentional Avoidance in PTSD Attentional avoidance reflects PTSD individuals' ability to rapidly shift attention from threat information to other information. In eye movement research, temporal course analysis and second fixation indices are commonly used to reflect attentional avoidance. When PTSD individuals' fixation times on threat stimuli do not significantly decrease over time, or when first fixation duration (or first

fixation count proportion) is significantly longer (greater) than second fixation duration (or second fixation count proportion), this indicates voluntary termination of sustained attention to threat information. Numerous studies have investigated this mechanism in PTSD individuals but have not found evidence of threat avoidance (Armstrong et al., 2013; Felmingham et al., 2011; Kimble et al., 2010; Lee & Lee, 2012, 2014; Thomas et al., 2013). Armstrong et al. (2013) divided stimulus presentation time into six 500ms intervals and found no time interval effects, indicating that differences in fixation times on threat stimuli (disgust and fear faces) between PTSD and the other two groups (trauma-exposed and healthy controls) remained relatively stable within 3 seconds. Thomas et al. (2013) presented stimulus sequences containing trauma-related threat pictures and found that PTSD individuals showed significantly increased fixation time proportions on threat stimuli compared to healthy controls during both 0–2s and 4–6s post-stimulus intervals, with no avoidance phenomenon observed. Lee and Lee (2012, 2014) divided the 10-second presentation time into five 2-second intervals and similarly found that PTSD individuals' increased fixation on threat stimuli (violent images) remained relatively stable. Furthermore, Felmingham et al. (2011) used threat words as regions of interest and analyzed second fixation locations following the first fixation. They hypothesized that PTSD individuals would show fewer second fixations on threat words compared to trauma-exposed healthy individuals after initially fixating on threat words. However, between-group differences were not significant, failing to support this hypothesis. Kimble et al. (2010) examined attentional avoidance and found that high-symptom PTSD individuals did not show significantly reduced second fixation times on threat pictures. Therefore, they concluded that PTSD individuals do not exhibit attentional avoidance.

3.3.2 Influencing Factors of Attentional Avoidance in PTSD Individuals Attentional avoidance can be understood not only as a component of attentional bias but also as a short-term adaptive coping strategy for PTSD individuals to avoid continuous harm from painful memories triggered by threat stimuli (Williams et al., 1997). However, from a long-term developmental perspective, the existence of attentional avoidance may exacerbate PTSD symptoms, as habitually disengaging attention from threat stimuli and shifting to neutral stimuli may represent a maladaptive avoidance strategy (Bardeen & Daniel, 2017), reflecting PTSD individuals' inability to properly process threat stimuli. Therefore, compared to short-term harm, the absence of attentional bias may represent a more effective long-term self-protection mechanism. Additionally, re-experiencing constitutes a primary characteristic of this disorder (APA, 2013), manifesting as involuntary intrusive memories, and PTSD individuals exhibit impaired executive control functions that prevent autonomous disengagement from threat stimuli (Leskin & White, 2007). The combined effect of these two factors may cause them to more readily exhibit attentional disengagement difficulty rather than attentional avoidance.

3.3.3 Summary In summary, altering analysis methods (temporal course analysis, second fixation index analysis), stimulus types (words, faces, or pictures), or stimulus presentation durations has not revealed attentional threat avoidance in PTSD individuals. Furthermore, when researchers employ temporal course analysis, differences in time intervals do not affect results. However, variability may exist in the attentional bias processing trajectory of PTSD individuals. Thomas et al. (2013) found a trend toward attentional avoidance in PTSD individuals during intermediate presentation times (neither early nor late): during 0–2s, PTSD individuals showed greater total fixation time proportions on trauma threat pictures compared to healthy controls; after 2 seconds (2–4s), their attention to threat pictures decreased to levels comparable to healthy controls; but during subsequent 4–6s intervals, their attention to threat pictures increased again to levels significantly different from the healthy control group. This pattern indicates substantial attentional fluctuation between threat vigilance and threat avoidance in PTSD individuals (Naim et al., 2015).

In conclusion, when using eye-tracking technology to examine attentional bias toward threat stimuli in PTSD individuals, the influencing factors differ across the three components. First, threat stimulus type and eye movement index selection may interactively influence facilitated attentional orienting. PTSD individuals' heightened vigilance to verbal stimuli relates not only to differential interference during recognition processes for pictures versus words but also to differences in arousal, salience, and complexity between the two stimulus types. Additionally, the smaller presentation visual angles used in research may accelerate attentional capture of threat verbal information, promoting attentional vigilance to threat words. Conversely, inconsistent selection of eye movement indices may produce divergent results regarding facilitated orienting, potentially due to inherent index characteristics: first fixation latency is insensitive to this component due to its inability to measure covert eye movements, spatial indices are more suitable for examining attentional orienting to threat words, and pupil indices better reflect attentional orienting to threat pictures. Second, the absence of attentional disengagement difficulty from threat words in PTSD individuals may relate to parafoveal preview, information density, and unconscious binding. Parafoveal preview accelerates word processing, but low information density reduces the capacity for sustained attentional capture. The unconscious binding of "static–word" makes static threat words less likely to exhibit attentional disengagement difficulty. Third, the absence of attentional avoidance toward threat information may represent a long-term self-protection strategy in PTSD individuals, unaffected by analysis methods, word types, or presentation durations. Therefore, understanding PTSD individuals' attentional bias toward threat information from a temporal perspective more likely reflects a "facilitated orienting–disengagement difficulty" mechanism. That is, PTSD individuals can rapidly detect threat stimuli and subsequently struggle to disengage from further processing of them.

4 Theoretical Models of Attentional Bias in PTSD

Component theories of attention posit that attentional bias is not a single-stage phenomenon but exists within specific attentional components such as facilitated orienting, disengagement difficulty, and avoidance. However, which attentional component accurately expresses attentional bias, or at which attentional stage attentional bias occurs, remains debated. To address this issue, researchers have proposed different stage theories of attentional bias.

4.1 Vigilance-Avoidance Model

The vigilance-avoidance model was proposed to explain threat attention bias in anxiety disorders (Williams et al., 1997). This model suggests that attentional bias in anxious individuals manifests in two aspects: attentional vigilance in early stages and attentional avoidance in later stages. When confronted with stimulus streams containing threat stimuli, early vigilance in anxious individuals promotes automatic stimulus detection, making threat stimuli easier to identify. However, after threat stimuli capture visual attention, anxious individuals adopt strategies to avoid them, resulting in avoidance phenomena during later strategic processing. Since both PTSD and anxiety individuals belong to the category of affective disorders, this theory also serves as theoretical support for PTSD attentional bias. In other words, according to the vigilance-avoidance model, PTSD individuals can detect threat stimuli more quickly and accurately, but once identified, they engage in avoidance behaviors that prevent further processing.

Based on the aforementioned eye movement research on PTSD threat attention bias, these individuals do not exhibit avoidance during later threat processing stages, while the existence of early vigilance is subject to interactive effects of stimulus materials and eye movement indices. First, verbal and pictorial stimuli have revealed early attentional vigilance across different eye movement indices (first fixation location and pupil response), supporting the early-stage perspective of the vigilance-avoidance model. However, from a stimulus perspective, the aforementioned analyses suggest that stimulus properties such as complexity and arousal influence vigilance phenomena. This may alert researchers to refine the theory further, proposing that attentional vigilance may have limiting conditions, with attentional orienting potentially showing dissociation for threat information of varying complexity or arousal levels. Moreover, none of the above studies found attentional avoidance phenomena, which may represent a long-term self-protection strategy in PTSD individuals.

4.2 Attentional Maintenance Hypothesis

The attentional maintenance hypothesis (Fox et al., 2001) posits that PTSD individuals' attentional bias primarily manifests in processing stages following threat detection. This model differs from the vigilance-avoidance model in two ways. First, the vigilance-avoidance model suggests attentional bias occurs in

both early and late stages, with early-stage vigilance enabling rapid threat detection. In contrast, the attentional maintenance hypothesis argues that PTSD individuals' early detection of threat information does not differ from normal individuals. Second, the vigilance-avoidance model suggests late-stage attentional bias manifests as avoidance, whereas this model predicts that when PTSD individuals detect environmental threat information, they do not exhibit avoidance but rather struggle to disengage attention from threat stimuli. It is this bias occurring during the attentional disengagement stage that leads to threat attention bias in later stages. In summary, this model proposes that PTSD individuals' weakened ability to disengage attention from threat stimuli results in attentional bias manifested as increased fixation times on these stimuli.

The aforementioned eye movement research on PTSD threat attention bias indicates that studies using pictures as threat stimuli support the attentional maintenance hypothesis, whereas studies using words do not yield consistent conclusions. Based on previous analyses, this discrepancy may result from different stimulus properties. The rapid processing, low information density, and potential unconscious binding of "word–static"may collectively reduce the capacity of threat information to sustain attention after capture in PTSD individuals.

Compared to behavioral reaction time studies, the advantage of eye-tracking technology lies in its ability to monitor the temporal course of PTSD individuals' threat stimulus processing in real time, enabling deeper understanding of attentional characteristics triggered by different trauma event types and validation of stage theories such as the vigilance-avoidance model. The progression from phenomenological investigation to theoretical construction has indeed provided more comprehensive examination of attentional bias mechanisms in this affective disorder. However, whether researchers can maximize the advantages of eye-tracking technology to construct unique attentional bias eye movement patterns and corresponding models for PTSD individuals from multiple dimensions remains worth exploring. For instance, from a developmental perspective, the prevalence of PTSD among American children and adolescents with similar experiences is higher than among American adults (Pang et al., 2017), and PTSD children exhibit more hypervigilance and recurrent intrusive trauma memories compared to PTSD adults (Thienkrna et al., 2006). Additionally, the immaturity of the oculomotor physiological system in children and adolescents may lead to greater limitations or inconsistent eye movement behaviors. The 叠加 of these two differences may generate heterogeneity in attentional bias eye movement patterns across different PTSD populations. Therefore, researchers should construct corresponding attentional bias eye movement patterns and theoretical models from developmental perspectives and subsequently integrate eye movement patterns and theoretical models constructed across multiple dimensions. This approach would not only provide a novel perspective for understanding PTSD threat attention bias mechanisms but also expand and supplement existing PTSD attentional bias models.

While fully utilizing eye-tracking technology to investigate PTSD attentional

bias, some researchers have questioned the reliability of eye movement indices. Sears et al. (2019) used a free-viewing paradigm with fixation duration and fixation count on threatening, sad, and happy faces as indices and found good internal consistency. However, when using a 6-month retest interval and dividing 8-second presentation times into four 2-second intervals, they found low reliability (Cronbach' s α and split-half reliability) for fixation times on all face types during the 0–2s interval. Skinner et al. (2018) also found low reliability for early attentional bias indices. Therefore, Sears et al. (2019) suggested that caution should be exercised when interpreting data from early time intervals when using eye movement indices to assess attentional bias. This indirectly reflects the limitations of using single methods to investigate problems.

To overcome this dilemma, integrating results from multiple types of indices has become a reliable and necessary approach, such as incorporating physiological and electroencephalographic measures. Felmingham et al. (2011) simultaneously used eye-tracking technology and skin conductance as dependent variables, finding that PTSD groups showed greater skin conductance increases than trauma control groups when first viewing trauma threat stimuli, indicating that autonomic reactivity co-occurs with PTSD attentional bias and confirming the association between threat attention bias and autonomic arousal. Moreover, combining eye-tracking and EEG technologies can investigate the temporal course of attentional bias from both behavioral and electrophysiological perspectives, with complementary indices better revealing the mechanism's progression. Additionally, brain region structure plays an important role in posttraumatic stress reactions and related disorders, such as the prefrontal cortex, amygdala, and hippocampus (Wang et al., 2015). Integrating functional magnetic resonance imaging with high spatial resolution and eye-tracking technology enables in-depth investigation of PTSD attentional bias from spatiotemporal dimensions, linking eye movement phenomena to brain region activation. In summary, combining multiple indices and technologies not only allows exploration of PTSD attentional bias mechanisms from more comprehensive perspectives but also represents a future research trend.

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