The influence of visual working memory representations on attention bias to threat in individuals with high trait anxiety

Nisha Yao
Institute of Psychology, Chinese Academy of Sciences, China; University of Chinese Academy of Sciences, China; Peking University, China

Marcus A. Rodriguez
Boston Child Study Center, USA; Pitzer College, USA

Mengyao He
School of Psychological and Cognitive Sciences, School of Psychological and Cognitive Sciences, Peking University, China

Mingyi Qian
School of Psychological and Cognitive Sciences/Beijing Key Laboratory of Behavior and Mental Health, Peking University, China

Abstract
Experimental studies have yielded discrepant results regarding the relationship between anxiety and attention bias to threat. Cognitive factors modulating the presence of threat-related attention bias in anxiety have drawn growing attention. Previous research demonstrated that visual working memory (WM) representations can guide attention allocation in a top-down manner. Whether threat-related WM representations affected the presence of attention bias in anxiety awaits examination. Combining a memory task and a dot-probe task, this study investigated how WM representations of faces with neutral or negative expressions modulated the attention bias to threat among highly anxious individuals versus controls. Results showed that highly anxious individuals developed more pronounced attention bias to threat when maintaining WM representations of negative faces as compared to the control group. There were no significant between-group effects when the WM representations were neutral. These results suggested that highly anxious individuals were more susceptible to the influence of mental representations with negative valence on attention deployment.

Keywords
Attention bias, emotion, memory-driven attention, trait anxiety, visual working memory

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Corresponding author:
Mingyi Qian, School of Psychological and Cognitive Sciences, Peking University, Haidian District, Beijing 100871, China.
Email: qmy@pku.edu.cn

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Introduction

It has been assumed that attention bias to threat plays a crucial role in the etiology and maintenance of anxiety. However, experimental studies have yielded discrepant results regarding the relationship between anxiety and attention bias to threat (Cisler & Koster, 2010). For instance, high levels of anxiety were observed to be associated with facilitated attention, engagement to threat, difficulty in attention disengagement from threat, or attention avoidance of threat, while some researchers reported similar patterns of attention bias to threat between high and low anxiety individuals (Van Bockstaele et al., 2014). Meanwhile, modifying attention bias to threat did not necessarily result in anxiety amelioration (Mogg & Bradley, 2016). Given that the interaction between anxiety and attention bias to threat is nuanced, the boundary conditions for the presence of the anxiety-related attention bias shall be clarified, among which the cognitive factors modulating the presence or absence of the threat-related attention bias in anxiety have gained prominence in recent research (Mogg & Bradley, 2016).

Cognitive models of anxiety posited that both top-down (i.e., goal-directed) and bottom-up (stimulus-driven) processes contribute to the development and maintenance of threat-related attention bias in anxiety (Berggren & Derakshan, 2013; Derakshan & Eysenck, 2009; Eysenck, Derakshan, Santos, & Calvo, 2007; Mogg & Bradley, 2016). It was proposed that highly anxious individuals had dysfunction in threat evaluation and thus perceived more intense threat in mildly threatening or ambiguous situations than low anxiety individuals did, which led to attention bias to potential threat in anxiety (Mogg & Bradley, 2016). Subsequently, Eysenck, Derakshan, Santos, and Calvo (2007) proposed an attention control theory and suggested that anxiety disrupted the balance between the goal-directed and stimulus-driven systems. Namely, anxiety impaired the goal-directed process, so highly anxious individuals would be more easily distracted by goal-irrelevant distractors, especially when the distractors were threat-related (Derakshan & Eysenck, 2009; Eysenck et al., 2007). Bishop, Jenkins, and Lawrence (2007) provided evidence supporting impairment in top-down control system in trait anxiety. In their research, participants were required to indicate whether a string of six letters contained an “X” or an “N”; the letter string always contained a target and was superimposed on a face expressing negative or neutral emotion. It was observed that trait anxiety was associated with reduced prefrontal response to negative facial distractors, supporting impaired top-down control in regulating process of threatening yet task-irrelevant stimuli (Bishop et al., 2007; Bishop, 2007).

Among research on anxiety-related top-down processes, working memory (WM) has been regarded as an important top-down mechanism moderating the manifestations of attention bias in anxiety (Kiyonaga & Egner, 2013; Peschard & Philippot, 2016). Theoretically, the capacity of WM storage was presumed as an indicator of available cognitive resources necessary for supporting ongoing mental processes (Baddeley, 2003). By manipulating WM load, how availability of WM resources affected the pattern of attention bias in anxiety was examined. For instance, Judah, Grant, Lechner, and Mills (2013) combined a dot-probe task with 1,500-ms presentation times of facial cues and a concurrent n-back task consuming WM resources. For the dot-probe task, on each trial, a pair of negative and neutral faces were presented and a probe appeared in the location of one of the faces immediately after their disappearance. Faster reaction times (RT) to the probe following the negative face indicated difficulty in attention disengagement from threat, while faster RT to the probe following the neutral face indicated attention avoidance of threat. For the n-back task, participants were required to report the letter which appeared n trials back. Results revealed that participants with high social anxiety exhibited difficulty in attention disengagement from faces expressing disgust emotion under high WM load (n = 2); when performing a dot-probe task without a WM load, highly anxious individuals showed attention avoidance of negative information (Judah, Grant, Lechner, & Mills, 2013). Moreover, subsequent studies revealed that, under high WM load, highly anxious individuals were more easily distracted by task-irrelevant stimuli (Qi et al., 2014; Soares, Rocha, Neiva, Rodrigues, & Silva, 2015). Thus, it is reasonable to suggest that, when WM load was high and WM capacity impoverished, reduced top-down control in regulating attention allocation toward goal-relevant tasks may be a critical reason for the threat-related attention bias in anxiety.

Apart from WM load, the contents of WM exerted influence on attention selection (Chun, Golomb, & Turk-Browne, 2011; Kiyonaga & Egner, 2013). Chun, Golomb, and Turk-Browne (2011) suggested that the interaction between WM and attention is bidirectional...
threat (e.g., threat schemas) work as filters, filtering cognitive representations of the schema model of anxiety disorders (Beck, Emery, & Greenberg, 1985), cognitive representations of anxiety disorders (Beck, Emery, & Greenberg, 1985). For instance, according to the schema model of anxiety disorders (Beck, Emery, & Greenberg, 1985), cognitive representations of threat (e.g., threat schemas) work as filters, filtering out nonthreatening information and biasing attention toward external stimuli that forecast threat. It has been suggested that personal learning history and memory contribute to the formation of threat schemas; idiosyncratic threat schemas further result in maladaptive attention allocation toward schema-related threatening information in anxiety (Beck, 2011). Indeed, previous research observed more pronounced attention bias to disorder-congruent threatening information as compared to disorder-incongruent information in anxiety (e.g., greater attention bias to socially threatening cues than nonsocial negative cues in social anxiety disorder), suggesting that specific threatening cues in accordance with the threat schemas triggered greater attention bias (Pergamin-Hight, Naim, Bakermans-Kranenburg, van IJzendoorn, & Bar-Haim, 2015). Nevertheless, research on content specificity of attention bias to threat in anxiety provided indirect evidence supporting the influence of internal mental representations on attention selection. As been mentioned above, WM representations have been regarded as a measurable form of mental representations, and examining the role of WM contents in modulating attention bias may provide direct evidence supporting the interaction between internal representations and external attention selection in anxiety (Soto et al., 2005).

Hence, the current research aims to investigate how WM representations of threat affected the magnitude of attention bias in anxiety. Based on the previous research, enhanced attention bias in the presence of disorder-specific threatening cues could be attributed to the activated disorder-related idiosyncratic representations of threat (Pergamin-Hight et al., 2015). Furthermore, cognitive models of anxiety emphasized the role of mental representations of threat in guiding attention selection (Beck, 2011). Thus, it is reasonable to suggest that congruence between a mental representation of threat and an external threatening cue may more significantly facilitate attention toward the threatening cue among the high versus low anxiety individuals. Further, this congruency effect shall not be solely attributed to greater influence of matching low-level physical features between WM representations and external cues on attention selection in high anxiety group as compared to low anxiety group.

Altogether, the present study investigated whether and how WM representations in negative or neutral valence modulated the pattern of attention bias in the presence of threat among highly anxious individuals versus controls. We combined a WM task and a...
dot-probe task (Downing, 2000). The former task served to manipulate the WM content, while the latter task was a classical task for measuring attention bias associated with anxiety (MacLeod, Mathews, & Tata, 1986). In the present study, on each trial, participants first memorized a negative (i.e., angry) or neutral (i.e., calm) face, then performed a dot-probe task, and finally received a memory test. The dot-probe task consisted of 500-ms presentation of a pair of negative and neutral faces (one of which was either identical to or had the same valence as the memorized face), followed by a probe in one of the locations previously occupied by the two faces. Furthermore, to preclude the possibility that all observed effects were attributable to high anxiety individuals’ greater tendency to allocate attention based on matching low-level physical features between WM representations and external cues, participants performed another dual task. This task examined, when the two dot-probe facial cues had the same valence yet different physical features, how matching features between the WM representation and one of the dot-probe facial cues moderated attention allocation in high versus low anxiety groups.

Based on research on WM-driven attention allocation (Downing, 2000; Liu et al., 2016; Soto et al., 2005), we hypothesized that when performing the dot-probe task, attention would be shifted to the face whose valence and/or identity matched with the memorized face maintained in WM. Moreover, based on the research of content-specific attention bias to threat in anxiety and cognitive models of anxiety, we hypothesized that when performing the dot-probe task, the magnitude of attention bias toward negative faces would be larger in the high trait anxiety (HTA) group than in the control group when the WM representations were negative. This effect would be specific to negative valence, and similar pattern of results would not be observed when WM representations of neutral faces were held. Further, highly anxious individuals would not show more enhanced attention bias toward external cues having matching low-level physical features as the WM representations in comparing to the control group.

**Method**

**Participants**

Based on the Chinese norm of the State-Trait Anxiety Inventory—Trait (STAI-T; male: 41.11 ± 7.74; female: 41.31 ± 7.54; Wang, Wang, & Ma, 1999), individuals who scored one standard deviation above the norm mean (i.e., STAI-T > 48) were designated in the HTA group, while individuals who scored below the norm mean (i.e., STAI-T < 40) were designated in the low-to-medium anxiety control group. We did not include individuals with a STAI-T score of 40 in the current research to increase the between-group difference on anxiety levels. An advertisement of the current research as well as another different research was posted online via a campus bulletin board system. Participants could sign up for either research and should complete a web survey examining levels of trait anxiety and depression using the STAI-T and Beck Depression Inventory (BDI; Wang et al., 1999). It was informed that there was no compensation for completing the web survey; the experimenters would give feedback on the levels of anxiety and depression to all participants and invite those with specific scores in the STAI-T and BDI to perform the experimental tasks based on a predefined criterion.

Among the 173 individuals completing the web survey (age: $M = 21.97, SD = 2.97$; gender: 61.85% female; STAI-T: $M = 42.55, SD = 9.46$; BDI: $M = 11.33, SD = 7.30$), there were 77 individuals who signed up for the current research (age: $M = 22.30, SD = 2.92$; gender: 64.94% female; STAI-T: $M = 42.81, SD = 10.22$; BDI: $M = 11.38, SD = 6.32$). Twenty-nine individuals were included in the HTA group and 30 in the control group and performed the experimental tasks, while the remaining individuals were thanked for their interest in our research. Participants were compensated for 40 RMB (approximately 6 USD) for the current research. Normal or corrected-to-normal vision was required. The two groups were comparable in age and gender and differed significantly in STAI-T and BDI (Wang et al., 1999) scores (see Table 1). A post hoc power analysis using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that the current sample allowed examination of a $2 \times 2$ interaction with a power>$ .95$ for detecting small- to medium-sized effects ($F$ test, effect size = .25, $\alpha = .05$).

**Materials**

Forty-four photographs of calm faces (50% males; Yang, Xu, Du, Shi, & Fang, 2011) were adopted as templates. These faces were Asian faces and were initially developed for and used in Yang, Xu, Du, Shi, and Fang (2011) research. Each of these template faces was converted to a front-view calm face stimulus and a
Table 1. Characteristics of the participants in each group.

|          | Control (n = 30) | HTA (n = 29) | Test statistics |
|----------|-----------------|--------------|----------------|
| Age      | 22.33 (2.44)    | 22.55 (3.39) | t(57) = −0.29, p = .78 |
| Female (%) | 76.67       | 65.52       | χ²(1, N = 57) = 0.89, p = .34 |
| STAI-T   | 32.00 (4.05)   | 53.48 (4.24) | t(57) = −19.90, p < .01 |
| BDI      | 6.27 (3.76)    | 16.86 (4.45) | t(57) = −9.90, p < .01 |

Note. HTA = high trait anxiety. STAI-T = State-Trait Anxiety Inventory–Trait; BDI = Beck Depression Inventory.

Front-view angry face stimulus with FaceGen Modeller Core 3.13 (Singular Inversions Inc., Toronto, Canada 2016). This process resulted in 44 pairs of calm and angry faces (i.e., 44 facial identities × 2 emotions). Twelve adults who majored in psychology rated these faces on a 9-point scale (1 = very angry, 5 = calm, 9 = very happy) for emotionality. These adults did not perform the current experiments. Twenty-four calm faces which scored closest to 5 and their paired angry faces were used as neutral and negative expressions, respectively (i.e., 24 facial identities × 2 emotions). Rating scores of the selected calm faces (M = 5.01, SD = 0.17, range = 4.58–5.25) were significantly higher than those of the paired angry faces (M = 2.40, SD = 0.32, range = 1.58–2.83), t(34.85) = 34.96, p < .001. The remaining 40 faces (i.e., 20 facial identities × 2 emotions) were used in practice trials. Angry expressions were used as negative cues because they directed hostility toward the beholders and were thus anxiety-provoking (Staugaard, 2010). Accordingly, angry faces were widely used in research on attention bias in anxiety (Cisler & Koster, 2010; Pergamin-Hight et al., 2015).

All faces were converted to gray scale and processed to have equal overall luminance and contrast. An oval contour was applied to each face to remove non-expression features (i.e., ear and neck). Each face image subtended 80 × 104 pixels (visual angle: 2.3° × 3.0°). Stimuli were presented against a black background on a 27-inch LCD monitor (resolution: 1920 × 1080 pixels; refresh rate: 60 Hz) at a viewing distance of approximately 55 cm. The stimulus presentation was not synchronized to the refresh rate of the monitor. A QWERT keyboard was used as the response device. A chin rest was used to fix the viewing distance. Stimuli and tasks were administered using MATLAB R2014b (MathWorks, Natick, Massachusetts, USA).

Measures

The STAI-T scale (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) measures stable and dispositional properties of anxiety. The BDI (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) measures depressive symptoms in adults. The Chinese versions of STAI-T and BDI have adequate psychometric properties (Wang et al., 1999). The internal consistency of the STAI-T and BDI was .92 and .85 in the current sample.

Procedures

All participants performed a practice block (10 dot-probe and 20 dual task trials) in the beginning. Participants could ask the experimenters for clarification if they could not understand the task requirements. Faces used in the practice block were different from those used in the experimental tasks, and only neutral faces were used for practice. After the practice block, a baseline dot-probe task and three different dual tasks measuring the influence of memory contents on attention deployment were conducted. Participants received feedback only during practice. The current study was approved by the local ethical committee.

Baseline attention bias. The baseline attention bias was measured by a dot-probe task (MacLeod et al., 1986). On each trial, after a 1,000-ms fixation presentation, a horizontally aligned negative–neutral face pair was displayed for 500 ms with each face’s center being 60 pixels (visual angle: 1.7°) away from the fixation. A Landolt-C-like stimulus was used as the probe stimulus (Perlato, Santandrea, Della Libera, & Chelazzi, 2014; Thoern, Grueschow, Ehler, Ruff, & Kleim, 2016), as it was frequently used in research on WM-driven attention selection (Hollingworth & Beck, 2016; Reinhart, McClenahan, & Woodman, 2016; Woodman & Luck, 2007). That is, a gray circle contour with a gap at the top or bottom (line width: 3 pixels; gap width: 3 pixels; visual angle: 0.08°) appeared upon the disappearance of the faces. Participants were instructed to report the gap location by pressing the “|” or “|” button of the keyboard as quickly and accurately as possible. The probe disappeared upon response or 3,000 ms after the stimulus onset. The baseline dot-probe task contained 48 trials, with the location of the negative faces (face appeared
in the left or right), the probe location (the Landolt C stimulus appeared in the left or right), and the probe type (gap at the top or bottom of the Landolt C stimulus) counterbalanced. The probe appeared in the location previously occupied by the negative faces in 50% of the trials, thereby introducing no contingency. The facial pictures used in the dot-probe task were randomly sampled from the 48 facial images (24 facial identities × 2 expressions) for each participant (see Materials). On each trial, the negative and neutral faces were of different identities and same gender. Faces with different identities were used in every two consecutive trials. Half of the 48 trials displayed female faces and half male faces. Attention bias score was calculated for each participant by subtracting the mean RT to the probes appearing at the same location as the negative faces from the mean RT to the probes appearing at the same location as the neutral faces. A positive attention bias score indicated attention toward negative faces.

**Attention bias when negative information was memorized.** A dual task combining a memory task and a dot-probe task was formed to measure WM-attention interaction (see Figure 1). There were two congruency conditions: (1) the memory targets and one of the dot-probe faces were of the same valence and identity (i.e., identical condition) and (2) the memory targets and one of the dot-probe faces were of the same valence yet different identities (i.e., valence-matching condition). The congruency conditions were treated as two blocks and counterbalanced between participants, with 48 trials per block for both the HTA and control groups. Specifically, on each trial, one to-be-remembered face displaying negative emotion (i.e., angry) was presented for 1,500 ms, followed by a 1,000-ms interval. Subsequently, a dot-probe task identical to the baseline task was performed, during which a negative–neutral face pair was presented. The negative face in the dot-probe task either had the same valence and identity (identical, 50% of the trials) or had the same valence but different identities (valence-matching, 50% of the trials) as the to-be-remembered face, while the neutral face was always different from the to-be-remembered face in both identity and valence. Following the dot-probe task, a test face appeared at the screen center for a memory recognition task after a 1,000-ms interval. The expression of this test face was always the same as the to-be-remembered face (i.e., angry expression), but the identity (i.e., the person in the image) of the test face was different from the to-be-remembered face in 50% of the trials. Participants were instructed to indicate whether or not the test face was exactly the same (50% of trials) as the to-be-remembered face. Participants responded by pressing the “↑” (same) or “↓” (different) button on the keyboard within 5,000 ms. Both speed and accuracy were emphasized for the dot-probe task; only accuracy was emphasized for the memory task.

Similarly, the faces used in this task were randomly sampled from the 48 facial images (24 facial identities × 2 expressions; see Materials) for each participant. On each trial, the faces were of the same gender; the neutral face used in the dot-probe task differed in identity from the negative dot-probe facial cue, the memorized face, and the memory-test face. Faces with different identities were used in every two consecutive trials. For each block, half of the 48 trials displayed female faces and the other half male faces.

**Attention bias when neutral information was memorized.** This dual task was the same as the above-mentioned dual task (i.e., Attention bias when negative information was memorized), except that the to-be-remembered faces were always neutral faces. Accordingly, the neutral face in dot-probe task was either identical (i.e., with the same valence and identity, 50%) or valence-matching (with the same valence but different identities, 50%) to the to-be-remembered face. We included this dual task as a control task to attest that the influence of memory contents on attention allocation in the HTA group was valence-specific.

**Attention allocation when low-level features of faces were controlled.** Finally, participants performed the last dual task, which was included to examine whether and how similarity of the low-level physical features between the memorized faces and the dot-probe facial cues modifies the attention selection. Still, participants performed a dot-probe task while holding a WM representation of a face. There were three conditions: (1) participants memorized an angry face and both of the dot-probe facial cues displayed angry expressions (i.e., Negative–Negative condition; the first term refers to the valence of the memorized faces and the second term refers to the valence of the dot-probe facial cues; the same applied to the following conditions), (2) participants memorized an angry face and both of the dot-probe faces displayed calm expressions (i.e., Negative–Neutral condition), and
Figure 1. Dual task trials when the working memory representations were negative. (a) The identical condition: The memorized face was identical to one of the two faces presented in the dot-probe task. (b) The valence-matching condition: One face in the dot-probe task only had the same valence as the memorized face.
(3) participants memorized a calm face and both of the dot-probe faces displayed calm expressions (i.e., Neutral–Neutral condition). For all three conditions, one of the dot-probe facial cues had the same identity as the memorized face, whereas the other face had a different identity as the memorized face. These conditions were blocked and counterbalanced with 32 trials/block for both the HTA group and the control group. Different from the first two dual tasks, the matching low-level physical features between WM representations and external cues were the main drive for facilitated attention selection. Thus, we could investigate how matching low-level features affected WM-driven attention selection in the HTA and control groups.

**Results**

**Baseline attention bias to negative faces**

Response latencies less than 200 ms were considered outliers and excluded. Inaccurate responses were also excluded (0.64% of the trials). The pattern of results did not change without data reduction. This data reduction procedure applied to the following dual tasks. Attention bias scores were calculated using the remaining trials (see Table 2). A univariate analysis of variance (ANOVA) revealed no significant between-group difference in baseline attention bias, $F(1, 57) = 0.34, p = .56, \eta^2_p = .01$. One-sample $t$-tests indicated no preexistent attention bias in the HTA group, $t(28) = -1.01, p = .32$, or the control group, $t(29) = -0.33, p = .74$, consistent with a recent review indicating that there were discrepant results regarding the presence or absence of attention bias in anxiety (Van Bockstaele et al., 2014). Attention bias scores of the baseline dot-probe task and the dual tasks as well as effect sizes of the between-group difference in threat-related attention bias under each condition are presented in Table 2.

**Attention bias when maintaining negative information**

For the first dual task, RT outliers (0.07% of trials) and response errors (0.81% of the remaining trials) were excluded. Attention bias scores were then computed (see Table 2). A $2 \times 2$ (Congruency × Group [HTA, control]) repeated-measures ANOVA was performed on the attention bias scores. A significant main effect of congruency was found, $F(1, 57) = 15.83, p < .01, \eta^2_p = .22$. Pairwise comparisons revealed that, when negative information was maintained in WM, the magnitude of attention bias toward negative faces was greater in the identical condition than in the valence-matching condition, $p < .001$. Importantly, there was a main effect of group reaching significance, $F(1, 57) = 4.73, p = .03, \eta^2_p = .08$. Pairwise comparisons indicated more enhanced attention toward negative faces in the HTA group as compared to the control group when negative information was actively memorized (see Table 2). No interaction effect between congruency and group, $F(1, 57) = 0.01, p = .93, \eta^2_p < .01$, was observed.

As levels of depression differed between groups, depression severity was added as a covariate in the $2 \times 2$ repeated-measures ANOVA. The main effect of congruency, $F(1, 56) = 2.69, p = .11, \eta^2_p = .05$, and the interaction effect, $F(1, 56) = 0.12, p = .74, \eta^2_p < .01$, were not significant. Similarly, individuals in the HTA group exhibited greater attention bias toward negative faces as compared to the controls when memorizing negative information, $F(1, 56) = 5.09, p = .03, \eta^2_p = .08$.

**Attention bias when maintaining neutral information**

For the second dual task investigating the influence of memory representations with neutral valence on attention selection, RT outliers (0.16% of trials) and response errors (0.65% of the remaining trials) were excluded. Attention bias scores were computed (see Table 2). Similarly, we performed a $2 \times 2$ (Congruency × Group) repeated-measures ANOVA on the attention bias scores. There was a significant main effect of congruency, $F(1, 57) = 20.84, p < .01, \eta^2_p = .27$, indicating greater attention toward the neutral faces when performing the dot-probe task in the identical condition as compared to the valence-matching condition. However, the main effect of group, $F(1, 57) = 0.07, p = .79, \eta^2_p < .01$, as well as the interaction effect, $F(1, 57) < 0.01, p = .95, \eta^2_p < .01$, was not significant (see Table 2). When depression severity was added as a covariate in the $2 \times 2$ repeated-measures ANOVA, the pattern of results was generally the same. The two groups did not differ significantly in attention bias, $F(1, 56) = 0.03, p = .87, \eta^2_p < .01$. The main effect of congruency, $F(1, 56) = 0.94, p = .34, \eta^2_p = .02$, and the
interaction effect, $F(1, 56) = 0.24, p = .63, \eta^2_p < .01$, were not significant.

**Attention allocation when low-level features of faces were controlled**

For the last dual task examining how similarity of low-level physical features between memory representation and dot-probe facial cues affected attention selection, RT outliers (0.07% of trials) and response errors (0.88% of the remaining trials) were excluded. As being mentioned earlier, the dot-probe task contained pairs of faces with the same valence yet different identities; for each pair, one of the faces had the same identity as the memorized face. To quantify the effects of memory contents on attention, attention bias scores were calculated by subtracting the mean RT to the probes following the dot-probe faces identical to the memorized faces from the mean RT to the probes following the dot-probe faces different from the memorized faces. A positive score suggested increased attention toward the memory-matching dot-probe facial cues in the dot-probe task (see Table 2).

A $3 \times 2$ (Condition [both the memorized faces and the dot-probe faces were negative (Negative–Negative; the first term refers to the valence of the memorized faces and the second term refers to the valence of the dot-probe facial cues; the same applied to the following conditions), the memorized faces were negative and the dot-probe faces were neutral (Negative–Neutral), both the memorized faces and the dot-probe faces were neutral (Neutral–Neutral)] × Group) repeated-measures ANOVA was performed on the attention bias scores. We observed increased attention toward the memory-matching dot-probe facial cues in both groups across the three conditions. Data analysis revealed a significant main effect of condition, $F(2, 114) = 5.79, p < .01, \eta^2_p = .09$. Pairwise comparisons revealed that the magnitude of the attention bias in the Negative–Negative condition was significantly larger than that in the Negative–Neutral condition, $p = .01$, while there was a trend toward greater attention bias in the Neutral–Neutral condition than in the Negative–Neutral condition, $p = .07$. No other between-condition difference reached significance. Yet, the main effect of group, $F(1, 57) = 0.32, p = .58, \eta^2_p = .01$, and the interaction effect, $F(2, 114) = 1.89, p = .16, \eta^2_p = .03$, were not significant. When depression severity was added as a covariate in the above-mentioned analysis, a similar pattern of results was revealed. The main effect of memory-matching condition, $F(2, 112) = 0.84, p = .44, \eta^2_p = .02$, the main effect of group, $F(1, 56) = 0.93, p = .34, \eta^2_p = .02$, and the interaction effect between condition and group, $F(2, 112) = 0.91, p = .41, \eta^2_p = .02$, were not significant.

**WM test**

Memory recognition performance of each dual task was examined. Responses with an RT less than 200 ms were excluded (0.04%, 0%, and 0.05% of trials for each dual task, respectively). Accuracy of the memory test was computed for each task and each

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**Table 2. Attention bias scores of the baseline dot-probe task and the dual tasks and effect sizes of the between-group difference.**

| Condition | Control ($n = 30$) | HTA ($n = 29$) | Between-group difference |
|-----------|--------------------|----------------|-------------------------|
|           | Mean | SE | Mean | SE | Cohen’s $d$ |
| Baseline  |      |    |      |    |             |
| Dual task 1 |        |    |        |    |             |
| Identical | 23.46 | 7.48 | 39.86 | 8.09 | .39         |
| Valence   | 20.23 | 8.15 | 32.82 | 7.22 | .30         |
| Dual task 2 |        |    |        |    |             |
| Identical | 35.83 | 7.87 | 37.18 | 9.37 | .03         |
| Valence   | 25.73 | 7.77 | 37.24 | 7.41 | .28         |
| Dual task 3 |        |    |        |    |             |
| Neg-Neg   | 14.35 | 7.83 | 2.29  | 7.91 | .28         |
| Neg-Neu   | 20.23 | 8.15 | 32.82 | 7.22 | .30         |

Note. HTA = high trait anxiety; Baseline = baseline dot-probe task; Dual task 1 measured attention bias when negative information was memorized; Dual task 2 measured attention bias when neutral information was memorized; Dual task 3 examined how similar low-level features affected attention bias; Identical = identical condition; Valence = valence-matching condition; Neg-Neg, Neg-Neu, Neu-Neu: Neg = Negative, Neu = Neutral (the first abbreviation indicate the valence of the memorized faces and the second abbreviation indicate the valence of the dot-probe facial cues); SE = standard error. Positive mean values indicated attention bias to negative information.
participant (see Table 3). For the first dual task examining the influence of WM representations with negative valence on attention selection, a $2 \times 2$ (Congruency $\times$ Group) repeated-measures ANOVA was performed. No significant main effect of congruency, $F(1, 57) = 2.02, p = .16, \eta^2_p = .03$, or group, $F(1, 57) = 0.2, p = .66, \eta^2_p < .01$, was observed. Nor did the interaction effect reached significance, $F(1, 57) = 0.08, p = .78, \eta^2_p < .01$.

Similarly, a $2 \times 2$ (Congruency $\times$ Group) repeated-measures ANOVA was performed for the second dual task, which investigated the influence of memory representations with neutral valence on attention selection. Results revealed a main effect of congruency, $F(1, 57) = 6.25, p = .02, \eta^2_p = .10$. Pairwise comparisons indicated higher accuracy in the identical condition than in the valence-matching condition across groups, $p = .02$. The main effect of group, $F(1, 57) = 0.01, p = .94, \eta^2_p < .01$, and the interaction effect, $F(1, 57) = 0.33, p = .57, \eta^2_p = .01$, were not significant.

For the last dual task investigating how similarity of low-level features between memory representations and dot-probe cues affected attention selection, a $3 \times 2$ (Condition $\times$ Group) repeated-measures ANOVA was performed. Results demonstrated a main effect of condition, $F(2, 114) = 12.42, p < .01, \eta^2_p = .18$. Pairwise comparisons indicated that the accuracy in the Neutral–Neutral condition was higher than that in the Negative–Negative condition and that in the Negative–Neutral condition, $ps < .01$, while the accuracy in the Negative–Neutral condition did not differ from that in the Negative–Negative condition. Neither the main effect of group, $F(1, 57) = 0.14, p = .71, \eta^2_p < .01$, nor the interaction effect, $F(2, 114) = 1.70, p = .19, \eta^2_p = .03$, reached significance. Importantly, accuracy in the memory test was generally high and did not differ between groups.

Given that the same up and down arrow keys were used for responses in the dot-probe and memory tasks, it was possible that the memory accuracy would be higher when congruent responses (i.e., up or down arrow keys for both tests) were required for the dot-probe and memory tests rather than when incongruent responses were required (i.e., up arrow key for the dot-probe test and down arrow key for the memory test or vice versa). Therefore, we further compared the accuracy rate when congruent versus incongruent responses were required in each task for each group using separate paired sample $t$-tests. Results revealed no significant difference between the congruent and incongruent responses conditions for the HTA and control groups (HTA group: $ps = .06–.82$; control group: $ps = .16–.71$).

### Discussion

The current study investigated how WM representations with negative or neutral valence modulated the presence of attention bias to threat among individuals with HTA when compared to controls. We observed that, when the representations stored in WM were negative, the HTA group showed a larger magnitude of attention bias to threat relative to the control group. Meanwhile, the magnitude of attention bias to neutral dot-probe facial cues was comparable between groups when the WM representations were neutral.

| Dual task | Identical | Mean (%) | SE  | Identical | Mean (%) | SE  | Between-group difference |
|-----------|-----------|----------|-----|-----------|----------|-----|-------------------------|
| Dual task 1 | Neg-Neg | 86.35 | 1.61 | 89.09 | 1.51 | .32 |
| Dual task 2 | Neg-Neg | 87.60 | 1.60 | 87.46 | 1.19 | .02 |
| Dual task 3 | Neg-Neg | 92.29 | 1.56 | 91.59 | 1.13 | .09 |

Note. HTA = high trait anxiety; Dual task 1 measured attention bias when negative information was memorized; Dual task 2 measured attention bias when neutral information was memorized; Dual task 3 examined how similar low-level features affected attention bias; Identical = identical condition; Valence = valence-matching condition; Neg-Neg, Neg-Neu, Neu-Neu: Neg = Negative, Neu = Neutral (the first abbreviation indicate the valence of the memorized faces and the second abbreviation indicate the valence of the dot-probe facial cues); SE = standard error.
Regarding the group difference in the threat-related attention bias when WM representations were negative, it is possible that highly anxious individuals were more likely to attend to the memory-matching faces to refresh their memory and improve the face recognition performance than the controls. Nevertheless, the accuracy of the WM task did not differ between the identical and valence-matching conditions when negative faces were memorized. Further examination of the effect sizes of the between-group difference in the magnitude of threat-related attention bias in each condition demonstrated small-to-medium effect in the identical condition and medium effect in the valence-matching condition, both suggesting greater increase in the threat-related attention bias in the HTA group than the control group. Thus, it is not likely that the strategical viewing tendency to refresh memory was the sole drive for the current pattern of results when WM representations of negative faces were maintained.

The current pattern of results suggested that the anxiety-related memory-driven attention allocation was specific to WM representations with negative valence. When examining the pattern of attention bias influenced by memory representations of neutral faces, we observed no significant group difference. Furthermore, participants in both the HTA and control groups exhibited greater attention bias toward neutral dot-probe faces in the identical condition, whereas no such effect was observed in the valence-matching condition. Examination of the performance for the WM task when neutral faces were memorized revealed higher accuracy in the identical condition than in the valence-matching condition. It is likely that participants in both groups strategically attended to the memory-matching faces to consolidate memory in the identical condition, while no significant memory-driven attention bias to neutral faces in the valence-matching condition was observed. This pattern of results is consistent with the previous research demonstrating the specific effect of WM representations with negative valence for facilitating the emotional processing of negative faces suppressed by the CFS, which would not happen if stimuli with neutral valence were involved (Liu et al., 2016).

Given that emotional faces contained both emotional valence and low-level features, we further examined the effect of the similarity in low-level features between mental representations and dot-probe cues on attention allocation. In the third dual task, we observed that when both the valence and the identity were the same between the memory representations and the dot-probe facial cues (similar to the identical condition), participants across the HTA and control groups showed increased attention toward the memory-matching faces in the dot-probe task, which is consistent with previous research (Downing, 2000). However, when the memorized faces and the dot-probe facial cues had the same identity yet different valence, no pronounced attention bias to the memory-matching faces in the dot-probe task was observed. This may suggest that when memory-driven attention allocation was based on the matching low-level features between the memory representations and the external visual cues, a more precise matching was required to have a significant effect of memory-guidance of attention (Hout & Goldinger, 2015).

Findings of the current study suggested that threat-related WM representations could modulate the manifestations of attention bias to threat in anxiety. This pattern of results is consistent with the prediction of content-specific attention bias to threat, suggesting that mental representations of threat interact with selective attention in an involuntary manner and bias attention toward disorder-specific negative information (e.g., Beck, 2011; Pergamin-Hight et al., 2015). More importantly, the current research took into consideration of the advances in cognitive neuroscience examining WM guidance of attention and provided an avenue for investigating how internal representations affect external attention allocation in anxiety. Accordingly, the current findings were in alignment with the predictions of the schema model of anxiety (Beck, 2011). Based on our findings, when there were internal representations of threat and these representations were currently activated, highly anxious individuals were more susceptible to the influence of threat-related internal representations and thus allocated greater attention resources toward external threatening cues. Considering the bidirectional influence between WM contents and attention (Chun et al., 2011; Kiyonaga & Egner, 2013), it is reasonable to suggest that enhanced attention toward external threatening cues would, in turn, strengthen the internal WM representations of threat, thereby generating and maintaining attention bias to potential threat in anxiety.

A stronger tendency to allocate attention toward threatening cues when holding threat-related representations in WM among individuals with HTA as compared to controls could be attributable to impaired top-down control in anxiety (Bishop, 2007; Peschard...
& Philippot, 2016). In the current research, participants were required to maintain an emotional face in WM on each trial. As trait anxiety was associated with low WM capacity (Yao, Chen, & Qian, 2018), the current WM task no doubt consumed available WM resources and impaired cognitive control in HTA individuals. Thus, highly anxious individuals were pronouncedly distracted by memory-matching threatening cues. Furthermore, when WM representations were of neutral valence, no significant group difference was observed. Consistently, the previous research suggested that, when WM load was high, highly anxious individuals exhibited difficulty in attention disengagement from disgust faces rather than happy faces (Judah et al., 2013). Thus, there is a possibility that, despite of the impaired top-down control, threatening information is more salient to HTA individuals and thus captures greater internal and external attention resources (Kiyonaga & Egner, 2013). Future research is awaited to elucidate how goal-directed and stimulus-driven processes contribute to the threat-related WM guidance of attention in anxiety using neuroimaging techniques.

The current research has implications. We contributed to the literature on threat-related attention bias in anxiety by taking into consideration of the interaction between internal mental representations and external attention allocation. Thus, the current study provided evidence supporting the top-down influence of WM content and its valence on the development of attention bias to threat in HTA individuals as compared to controls. Accordingly, given the bidirectional interaction between attention and WM contents (Chun et al., 2011; Kiyonaga & Egner, 2013), it is possible that the reciprocal influence between threat-related WM contents and external attention toward threatening cues may serve to maintain attention selection of threatening information and thus maintain anxiety. Furthermore, we combined the research on WM guidance of attention (e.g., Olivers et al., 2011) and anxiety studies (Van Bockstaele et al., 2014), thereby suggesting an avenue for assessing top-down influence of mental representations on attention bias in anxiety. Finally, the current findings suggested that the dot-probe task could be modified to create a more sensitive measure of anxiety-related cognitive bias. Previous research pointed out that the magnitude of attention bias measured by the dot-probe task was not consistently associated with levels of anxiety, thereby questioning the validity of the dot-probe task (Kappenman, Farrens, Luck, & Proudfit, 2014). Thus, more research is encouraged to identify potential moderating factors that could help enhance the measurement of attention bias in dot-probe task (Caudek, Ceccarini, & Sica, 2017).

Nevertheless, the current research has several limitations that should be treated with caution. First, the order between tasks were not counterbalanced. As we observed group difference in the first task yet not in the second and third tasks, it is possible that the differences on the task level were attributable to the practice effect and/or the habituation of facial stimuli. We examined the influence of threat-related WM contents on selective attention first, considering that this task was most pertinent to the predictions derived from the cognitive models of anxiety (Beck, 2011; Mogg & Bradley, 2016). Further, the previous research examining how valence of WM contents affected processing of emotional stimuli suggested a congruency effect specific to negative valence instead of neutral valence (i.e., facilitated processing of negative stimuli when negative information was maintained in WM; Liu et al., 2016). Hence, we intended to examine the change in the pattern of attention bias when there was a WM representation of threat directly after the baseline assessment of attention bias, without introducing non-task-specific confounding factors. Given the potential effects of habituation, we randomly sampled the stimuli used on each trial from the current stimuli pool to introduce greater variability in stimulus-presentation sequence between tasks. Still, we could not exclude the possibility that practice and habituation mitigated the between-group differences in the second and third dual tasks, when WM representations with neutral valence were maintained or matching low-level physical features were manipulated. If so, the current findings may be attributable to increased WM load caused by the memory task and impaired cognitive control in anxiety (Bishop, 2007; Yao et al., 2018). That is, when WM load was high, highly anxious individuals exhibited dysfunction in top-down control processes and were more easily distracted by task-irrelevant stimuli which had matching features as the concurrently maintained WM representations (Moriya & Sugiura, 2012). Thus, replication is required before we can come to a firm conclusion that, beyond the effects of WM load, the influence of WM contents with negative valence contributed to the current pattern of results. Future research may benefit from recruiting a larger sample and counterbalancing the order of tasks, which would
also allow examination of the potential effects of task order.

Second, the current task included 48 trials in the baseline assessment of attention bias. The number of trials may be too few to provide a reliable estimate of attention bias. Nevertheless, although the previous research adopted more trials when assessing attention bias, more conditions were examined and thus each condition had fewer trials (Chapman, Devue, & Grimshaw, 2019). Thus, we adopted low number of trials in the baseline task, as the current baseline assessment contained a single condition. Still, future research using dot-probe task is encouraged to have more trials per condition to increase the reliability of the attention bias scores. Third, affective priming may play a role in directing attention toward valence–congruent information. However, an inhibited or reversed priming effect was observed in highly anxious individuals (Haas, Amso, & Fox, 2017; Helfinstein, White, Barr-Haim, & Fox, 2008). Namely, individuals with high versus low anxiety showed reduced attention bias to threat when primed by stimuli in negative valence (Maier, Berner, & Pekrun, 2003). Thus, it is unlikely that affective priming shaped the current observations. Nevertheless, future replication and extension of the current research taking into consideration of the above-mentioned limitations are warranted.

In sum, the current study contributed to the growing body of literature on attention bias to threat in anxiety disorders. The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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ORCID iD
Nisha Yao  https://orcid.org/0000-0002-6117-5694

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**Author biographies**

**Nisha Yao** is a postdoctoral fellow at the Institute of Psychology, Chinese Academy of Sciences, Beijing, China. Her research interests include cognitive bias related to and cognitive training for anxiety.

**Marcus A. Rodriguez** is an assistant Professor of Psychology at Pitzer College. His research interests include mindfulness, mobile technologies, suicide prevention and global mental health.

**Mengyao He** is a doctoral candidate at School of Psychological and Cognitive Sciences, Peking University, Beijing, China.

**Mingyi Qian** is a professor at School of Psychological and Cognitive Sciences, Peking University, Beijing, China. Her research interests include cognitive bias related to anxiety and depression, and (online) treatment of anxiety.