Emotion

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Working Memory Regulates Trait Anxiety-Related Threat Processing Biases

Robert W. Booth
MEF University

Bundy Mackintosh
University of Essex

Dinkar Sharma
University of Kent

High trait anxious individuals tend to show biased processing of threat. Correlational evidence suggests that executive control could be used to regulate such threat-processing. On this basis, we hypothesized that trait anxiety-related cognitive biases regarding threat should be exaggerated when executive control is experimentally impaired by loading working memory. In Study 1, 68 undergraduates read ambiguous vignettes under high and low working memory load; later, their interpretations of these vignettes were assessed via a recognition test. Trait anxiety predicted biased interpretation of social threat vignettes under high working memory load, but not under low working memory load. In Study 2, 53 undergraduates completed a dot probe task with fear-conditioned Japanese characters serving as threat stimuli. Trait anxiety predicted attentional bias to the threat stimuli but, again, this only occurred under high working memory load. Interestingly however, actual eye movements toward the threat stimuli were only associated with state anxiety, and this was not moderated by working memory load, suggesting that executive control regulates biased threat-processing downstream of initial input processes such as orienting. These results suggest that cognitive loads can exacerbate trait anxiety-related cognitive biases, and therefore represent a useful tool for assessing cognitive biases in future research. More importantly, since biased threat-processing has been implicated in the etiology and maintenance of anxiety, poor executive control may be a risk factor for anxiety disorders.

Keywords: Interpretive bias, attentional bias, anxiety, executive control, working memory

There are two major cognitive features of trait anxiety. First, trait anxious individuals show cognitive biases regarding potential threats (see, e.g., Mathews & MacLeod, 2005, for a review). For example, they show an *attentional bias* toward threat-related stimuli (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007), and an *interpretive bias* so that ambiguous stimuli and situations are understood in a threatening way (Mathews & Mackintosh, 2000; Mathews & MacLeod, 2005). Second, they show deficits in executive cognitive control and working memory (WM; Berggren & Derakshan, 2013; Eysenck, Derakshan, Santos, & Calvo, 2007). As both features are reliably found in trait anxious individuals, it is reasonable to ask whether there is some link between them.

One theoretical approach that has addressed this issue is attentional control theory (Derakshan & Eysenck, 2009; Eysenck et al., 2007). This theory focuses on executive control and performance deficits in both state anxious and trait anxious individuals, but also discusses cognitive bias. The theory assumes that anxious individuals display a weakness in top-down attentional control (relative to bottom-up, more reflexive control), and weaknesses in the inhibition and shifting functions of the central executive component of WM (see Miyake et al., 2000, for a taxonomy of executive functions). Importantly for the present discussion, the theory also states that anxious individuals' inhibition should be especially impaired in the presence of threat stimuli. Cognitive biases are attributed to a failure to inhibit bottom-up orienting toward salient, threatening stimuli; they are a failure of attentional control (see also Bishop, Jenkins, & Lawrence, 2007). If this is correct, then anxiety-related cognitive biases should be even more apparent when executive control ability is impaired.

A similar position is advanced by Mathews and MacLeod (2005, see also Mathews & Mackintosh, 1998). They suggest trait anxious individuals' attention might be biased toward goal-irrelevant threat stimuli, while executive attentional control works to keep attention focused on task-relevant stimuli (Derryberry & Reed, 2002). Congruently, Ouimet, Gawronski, and Dozois (2009) suggested that interpretive bias in trait anxiety is the result of relatively associative (i.e., relatively uncontrolled) valence judgments: interpretation does not necessarily require many cognitive resources (Chun,

Robert W. Booth, Department of Psychology, MEF University; Bundy Mackintosh, Department of Psychology, University of Essex; Dinkar Sharma, Centre for Cognitive Neuroscience and Cognitive Systems, School of Psychology, University of Kent.

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Correspondence concerning this article should be addressed to Robert W. Booth, Psikoloji Bölümü, MEF Üniversitesi, Ayazağa Caddesi No. 4, 34396, Maslak – Sarıyer, İstanbul, Turkey. E-mail: rob.booth.psych@gmail.com

Spiegel, & Kruglanski, 2002, Study 1). It is therefore the responsibility of executive control processes to rein in inappropriate interpretations. These formulations are consistent with emotion regulation theories (see Koole, van Dillen, & Sheppes, 2011) suggesting that executive control is used to regulate associative emotional processing when such processing is undesirable (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008; Ochsner, Bunge, Gross, & Gabrieli, 2002; see also Wegner, Erber, & Zanakos, 1993).

All of these similar theoretical positions yield the hypothesis that reduced executive control should exaggerate the influences of trait anxiety on cognitive bias. For example, reducing executive control resources might make individual differences in interpretation more apparent (Salemink & Wiers, 2012). Where a stimulus's threat value is irrelevant, associative processes may activate a threatening or benign interpretation of the stimulus depending on the individual's trait anxiety level, but either interpretation would be regulated by executive control in all individuals (cf. Gawronski, Geschke, & Banse, 2003). Similarly, because trait anxious individuals' attentional bias is not typically adaptive, executive control would be used to regulate or override it. Impaired executive control should make the bias more apparent.

Several studies have tested this hypothesis using an individual-differences approach. Most have assessed attentional control using self-report measures: Derryberry and Reed (2002) found that only high trait anxiety, low attentional control participants showed attentional bias to threat; Helzer, Connor-Smith, and Reed (2009) and Susa, Benga, Pitică, and Miclea (2014) found that fearful temperament only predicted attentional bias to threat in participants scoring low on attentional control; Lonigan and Vasey (2009) found that only schoolchildren high in negative affectivity and low in control showed attentional bias to threat. Bardeen and Orcutt (2011) found that low attentional control predicted bias in participants with higher posttraumatic stress symptoms. On the other hand, Schoorl, Putman, van der Werff, and van der Does (2014) found that posttraumatic stress disorder (PTSD) symptoms were associated with attentional bias *away* from threat in patients with low attentional control. Turning to interpretive bias, Muris, Meesters, and Rompelberg (2007, footnote 2) found no interaction between attentional control and neuroticism on children's interpretive bias.

Other studies have assessed control more directly, using a behavioral measure. Reinholdt-Dunne, Mogg, and Bradley (2009) assessed executive control using the attentional network task, and found that only participants low in control and high in trait anxiety showed emotional Stroop interference from threat faces. Salemink and Wiers (2012) used Stroop interference as a measure of executive control: adolescents with low control but high state anxiety showed the most interpretive bias. On the other hand, Salemink, Friese, Drake, Mackintosh, and Hoppitt (2013) assessed working memory (WM) capacity, a strong correlate of attentional control, and found that social anxiety only predicted interpretive bias in participants with larger WM capacity.

All these studies took a correlational approach, assessing how individual differences in control moderate the relationship between trait anxiety and cognitive bias. A better test of the hypothesis that executive control regulates cognitive bias requires within-participants manipulation of executive control (Derakshan & Eysenck, 1998). The key prediction is that, in a single group of participants, trait anxiety's relationship with interpretive or attentional bias should be clearer when executive control is experimentally impaired. One reliable technique for impairing executive attentional control is to impose a WM load, requiring participants to retain task-irrelevant information as a secondary task (see Lavie, Hirst, de Fockert, & Viding, 2004). A recent study by MacNamara and Proudfit (2014) found that WM load exaggerated the differences in distraction by negative images between anxiety patients and healthy controls, which is consistent with our hypotheses; however, this study did not assess biased processing, where threatening and neutral stimuli are present at the same time.

We therefore conducted two studies to test the hypothesis that WM load moderates trait anxiety's influence on the two most-studied cognitive biases. In Study 1, we measured negative interpretive bias, using ambiguous vignettes; in Study 2, we measured attentional bias to fear-conditioned stimuli. In both cases, we used the WM load manipulation developed for impairing cognitive control by Lavie et al. (2004); this manipulation has been previously successful in our laboratory (Booth, Mackintosh, Mobini, Oztop, & Nunn, 2014).

Study 1

Study 1 tested the hypothesis that WM load would moderate trait anxiety's effect on a classic measure of interpretive bias (Mathews & Mackintosh, 2000). We focused on trait rather than state anxiety in this study, since cognitive bias has been more associated with trait anxiety in the literature. Participants were given a *reading comprehension test* that required them to read a series of ambiguous vignettes, which could be interpreted either as depicting some threat to the central character, or as depicting a benign situation. WM load was manipulated during this task. Later, participants were given a *memory test*: they were presented with both the benign and the threat interpretations (positive and negative targets) alongside positive and negative foil interpretations (which presented information not included in the original vignette), and asked which most accurately summarized the vignette. A negative interpretive bias is present if the participant is more likely to choose the negative target interpretations over the positive target interpretations, without being more likely to choose the negative foil over the positive foil. This last condition is crucial for discriminating between true interpretive bias, where the participants tend to understand the vignettes negatively at encoding, and response bias, where participants simply tend to choose more negative summaries at recall (see Method).

A further advantage of Mathews and Mackintosh's (2000) interpretive bias measure is that it presents vignettes depicting both social threats (e.g., shunning, mockery) and physical threats (e.g., attack, robbery). This is important because previous research has sometimes found that anxious individuals only show cognitive biases regarding certain types of threat (Mogg, Mathews, & Weinman, 1989). In particular, social threats may elicit more reliable effects than do physical threats (e.g., Helzer et al., 2009; Mathews & MacLeod, 1985); this may be because for student samples, which are typically young and relatively affluent, social misfortune or loss of reputation are more realistic everyday dangers than are violence or illness. This may be particularly true for the current study, which was conducted at a private university (i.e., one charging significant tuition fees) in Istanbul. For these reasons, we calculated separate bias scores for social and physical threat vignettes, so threat type could be included as an independent variable in our analyses.

Method

Participants. Sixty-eight native Turkish-speaking undergraduates (59 females, mean age = 21.37) participated for course credit. The distribution of trait anxiety scores was typical for undergraduate samples (see Table 1, cf. Spielberger, Gorsuch, & Lushene, 1970).

Eleven further participants were dismissed following computer errors, and one gave no correct answers to the WM probes in one condition, and so yielded incomplete data (see Results for data exclusion).

Design. A mixed quasi-experimental design was used. WM load (high or low) and threat type (physical or social) were manipulated within participants, and trait anxiety was measured as a continuous predictor. The dependent variables were interpretive bias and response bias.

Materials. The study was conducted using E-Prime.

State–Trait Anxiety Inventory—Trait subscale. The State–Trait Anxiety Inventory—Trait subscale (Spielberger et al., 1970) was used in its Turkish translation (Öner & LeCompte, 1985), and consists of 20 items (e.g., "I worry about unimportant things"). Participants respond on a 4-point scale from *almost never* to *almost always*. Only the trait anxiety scale was used in Study 1. Cronbach's alpha = .87 in this sample.

Interpretive bias assessment. This was adapted from Mathews and Mackintosh (2000, Experiment 1), translated into Turkish, and took the form of an incidental memory test. In the study phase, participants read 20 vignettes, which could be interpreted as either benign or threatening. Half the vignettes portrayed physical threats and half social threats. Each vignette had a unique title, which was visible throughout that vignette's presentation. One word in the last sentence was presented as a fragment, which participants had to complete. This was followed by a simple comprehension question. The fragment-completion and comprehension questions were included to ensure participants attended to the vignettes, and to blind participants to the fact they would later be asked to recall the vignettes. An English example is presented below: the fragment's solution is *laugh,* and the question's correct answer is *yes.*

> The Wedding Reception
>
> A friend asks you to give a speech at her wedding reception. You prepare some remarks and, when the time comes, get to your feet. As you start to speak, you notice that some people in the audience start to l—gh.
>
> Did you stand up to speak? (Yes/No)

In the test phase, participants were given each vignette's title along with four alternative summaries, and were asked to indicate which summary was most accurate. One summary was a positive target, presenting the vignette's benign interpretation (e.g., "As you speak, people in the audience laugh appreciatively"); one was a negative target, presenting the threatening interpretation (e.g., "As you speak, people in the audience find your efforts laughable"); one was a positive foil ("As you speak, people in the audience applaud your comments"); and one was a negative foil (e.g., "As you speak, some people in the audience start to yawn"). The foil sentences were included to help differentiate between true interpretive bias (toward negative targets) and response bias; that is, a general tendency to select more negatively valenced summaries. Such a response bias would lead participants to select negative targets more than positive targets, and also to select negative foils more than positive foils. True interpretive bias would lead participants to select negative targets more than positive targets, but would not lead them to show any difference in their selection rates of negative and positive foils.

Filler task. For the filler task, participants were presented with a 2-min movie of nature scenes assembled from neutral clips 5004, 5007, and 5008 from the Emotional Movie Database (Carvalho, Leite, Galdo-Álvarez, & Gonçalves, 2012).

Procedure. Participants were tested alone, with instructions to contact the experimenter if they had any questions.

Participants first completed the trait anxiety scale, then the interpretive bias assessment's study phase, which was presented as a reading comprehension test. The vignette's title was displayed at the top of the screen, with the first line below. Participants revealed the second line by pressing the down arrow key, and so on until the entire vignette was displayed onscreen. One word in the final line was presented as a fragment: participants pressed the down key when they understood what the complete word was, then typed the first missing letter. If they responded incorrectly, the

Table 1
Intercorrelations and Descriptive Statistics for Interpretive and Response Bias Scores, Study 1

Variable	2	3	4	5	6	7	8	9	*M*	*SD*
1. Trait anxiety	−.089	.331**	.184	−.011	.041	.147	−.152	.122	42.96	8.99
2. Interpretive bias, high load, physical threat		.039	.199	.250*	.095	.090	.091	.093	−.16	.54
3. Interpretive bias, high load, social threat			.147	.117	.190	.088	.040	.158	−.12	.49
4. Interpretive bias, low load, physical threat				.121	.240*	.073	.197	.110	−.08	.44
5. Interpretive bias, low load, social threat					.272*	.007	.350**	.167	−.09	.42
6. Response bias, high load, physical threat						.170	.155	−.009	.02	.28
7. Response bias, high load, social threat							−.014	.155	−.04	.26
8. Response bias, low load, physical threat								.313**	−.04	.22
9. Response bias, low load, social threat									−.08	.23

Note. $N = 68$. Interpretive bias is the difference between endorsement rates for negative and positive target summaries; response bias is the difference in endorsement rates between negative and positive foil summaries. A more positive score indicates a more negative bias.
* $p < .05$. ** $p < .01$.

computer showed the word "Wrong!" and presented the fragment again; this procedure repeated until the participant responded correctly. The comprehension question was then presented, to which participants responded "Yes" or "No" via a key-press. Again, the question repeated until participants responded correctly.

The study phase consisted of two blocks. One randomly determined block was the high WM load block. Participants were presented with six digits for 2 s before each vignette; following the comprehension question, participants were presented with a single digit and were asked to indicate with a key-press whether they saw this digit before the vignette (new foil digits were presented on 50% of trials, see Lavie et al., 2004). The low WM load block was identical except that only one digit was presented before each vignette. Ten physical and 10 social threat vignettes were randomly selected for each block and were presented in a random order. An additional four practice vignettes were presented to participants, without WM load, before they began the study phase.

Next, participants completed the filler task. They were asked to watch the movie carefully, as they would be asked about it later (they were not). The filler task took 2 min.

Finally, participants completed the test phase of the interpretive bias assessment. Each vignette's title was again presented, along with the four summaries described above. These were presented in a random order, and were numbered 1 to 4. Participants pressed the number key corresponding to the most accurate summary of the vignette they had read.

Participants were then thanked and debriefed.

Results

For each participant, their probability of selecting each type of summary (i.e., positive target, negative target, positive foil, or negative foil) was calculated, within each cell of the design. Trials where participants answered the WM probe incorrectly (17%) were excluded. Interpretive bias scores were calculated for each cell by subtracting the participant's probability of selecting the positive target from their probability of selecting the negative target. Response bias scores were calculated by subtracting their probability of selecting the positive foil from their probability of selecting the negative foil. When the interpretive bias index is positive, and the response bias index is zero, this indicates a negative interpretive bias. If however participants simply chose more negative summaries during the test phase, then both the interpretive bias and response biases indices would be positive. Descriptive statistics and bivariate correlations are presented in Table 1.

Bias scores were analyzed with a general linear model, with WM load (high or low) and threat type (physical or social) as repeated-measures factors, and trait anxiety as a continuous predictor.[1] We first analyzed the response bias scores, calculated from foil responses, to ensure that response bias would not contaminate our key interpretive bias analyses. There was a marginal effect of threat type, $F(1, 66) = 3.49$, $\eta_p^2 = .05$, $p = .07$, indicating that participants selected the negative foil more often for social threat items (M bias $= -.06$) than for physical threat items (M bias $= -.01$); no other effects approached significance, F values < 2.30, p values $> .13$. The fact that response bias was unaffected by trait anxiety or WM load suggests that any effects of these variables on interpretive bias (calculated from participants' choices of positive or negative targets) are not contaminated by response bias.

To test our key predictions, we then subjected interpretive bias scores to the same analysis. There was an interaction between WM load and threat type, $F(1, 66) = 6.61$, $\eta_p^2 = .09$, $p = .01$; importantly, this was subsumed within a significant three-way interaction, $F(1, 66) = 7.44$, $\eta_p^2 = .10$, $p = .008$. This interaction resulted from trait anxiety only predicting bias in the high load-social threat cell, unstandardized $B = .02$, 95% CI [.005, .03], $p = .006$; it did not predict bias in the low load-social threat cell, $B = -.001$, 95% CI [−.01, .01], $p = .93$, nor in either physical threat cell, $B = -.01$, 95% CI [−.02, .01], $p = .47$ for high load and $B = .01$, 95% CI [−.003, .02], $p = .13$ for low load. No other effects were significant, F values < 1.96, p values $> .16$.

Separate WM load × Trait anxiety models for the two threat types confirmed that WM load significantly moderated trait anxiety's relationship with interpretive bias for social threat items, $F(1, 66) = 5.49$, $\eta_p^2 = .08$, $p = .02$ (see Figure 1), but not for physical threat items, $F(1, 66) = 2.92$, $\eta_p^2 = .04$, $p = .09$.

Anxious individuals have an executive control deficit, which sometimes manifests as a reduced WM capacity (e.g., Ashcraft & Kirk, 2001). The high WM load condition may therefore have depleted the executive control resources of more anxious participants more than it did those of less anxious participants, leading to differential effects of load on high versus low anxious participants. To investigate this alternative account, we subjected WM task accuracy to the same general linear model we used to analyze bias scores above. There was the expected main effect of WM load, $F(1, 66) = 5.31$, $\eta_p^2 = .07$, $p = .02$, but the main effect of trait anxiety was not significant, $F(1, 66) = 2.73$, $\eta_p^2 = .04$, $p = .10$, and importantly, neither was any interaction effect involving either variable, F values < 1.10, p values $> .30$. Analyses of performance in the word fragment and comprehension tasks yielded no significant results, F values < 2.18, p values $> .14$. These null results suggest WM load had equivalent effects on executive control resources for all participants.

Detection theory and choice theory analyses. With memory-based variables such as these, it is common to conduct analyses with detection theory-based measures of sensitivity, such as d'. However, d' is unsuitable in this case because it is designed to work with simple detection tasks (e.g., single-stimulus recognition), whereas we have used a four-alternative forced-choice task. In these tasks, the simple probability of choosing the correct answer is already an unbiased measure of sensitivity (and bias is not estimable; Stanislaw & Todorov, 1999), so the above analyses are appropriate according to detection theory. However, Macmillan and Creelman (2005) recommend choice theory (Luce, 1959) for analyzing multialternative forced choice data, and present formulae for calculating relative bias, that is, participants' tendency to select one response alternative over one other response alternative. This relative bias is clearly appropriate for assessing interpretive and response biases in our study. We calculated interpretive bias as participants' preference for the negative target over

[1] Analyzing such unusual designs is actually trivial in Statistical Package for the Social Sciences (SPSS)'s general linear model dialog, or SAS's Proc GLM. See http://core.ecu.edu/psyc/wuenschk/MV/RM-ANOVA/MixedANOVAwContinuousPredictor.doc

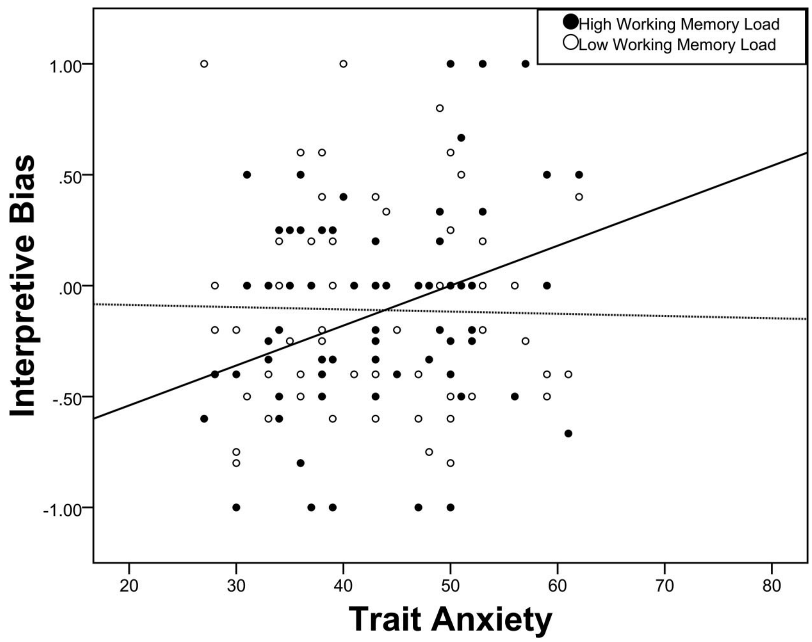

Figure 1. Relationship between trait anxiety and interpretive bias under high (solid line) and low (broken line) working memory load, for social threat items only. A more positive interpretive bias score indicates a greater tendency toward threatening interpretations.

the positive target, and response bias as their preference for the negative foil over the positive foil, using Macmillan and Creelman's (2005) formulae. We subjected these bias scores to the same analyses reported above, and results were consistent with those based on raw response probabilities. Specifically, the three-way interaction on interpretive bias was still significant, $F(1, 66) = 6.33$, $\eta_p^2 = .09$, $p = .01$, and the same interaction on response bias was still not significant, $F(1, 66) = 0.47$, $\eta_p^2 = .007$, $p = .49$.

Discussion

In an unselected sample of undergraduates, trait anxiety was related to interpretive bias, but only under high WM load. This builds on the work of Salemink and Wiers (2012) by showing that a within-participants experimental manipulation of executive control capacity (WM load) moderates trait anxiety's effects on interpretive bias, and supports the hypothesis that latent emotion-related biases influence cognition more when available executive control resources are scarce (Hofmann et al., 2008; Salemink & Wiers, 2012), consistent with Eysenck et al.'s (2007) characterization of cognitive biases as failures of executive control. These results are also consistent with Ouimet et al.'s (2009) assertion that interpretive bias is a product of associative processing systems, which are regulated by executive control.

It is not necessarily surprising that interpretive bias effects were only found with social threat items. The participants were students at a small private university; their age and socioeconomic status may make social threats more of an everyday concern than the threat of violence or illness (see Helzer et al., 2009; Mathews & MacLeod, 1985). Since we completed the study, informal questioning of some of these students has confirmed that most are much more concerned about "social death" than they are about actual death, perhaps due to their relatively privileged status in Istanbul society. Concern-specific cognitive biases are not an uncommon finding in the anxiety literature (e.g., Mogg et al., 1989); in the future, if this study were replicated with a measure of social anxiety, stronger effects may be found. In Study 2, we were able to alleviate this problem by using fear-conditioned Japanese characters as our threat stimuli, therefore ensuring equivalent relevance of the threat stimuli for all participants.

One criticism of some interpretive bias measures is that they are vulnerable to response bias (see Mathews, Richards, & Eysenck, 1989). In our task, participants might simply select negative summaries during the test phase, regardless of their initial understanding of the vignettes, and regardless of their memories of those vignettes. These effects are unlikely in the current experiment since the key effects involve the WM load factor, which was manipulated at encoding, rather than at the response stage. Similarly, high WM load may have impeded participants' encoding of the stories, forcing them to use more guesswork in the test phase, and trait anxiety may have biased this guesswork rather than the original interpretation. However, the fact that our analysis of foil responses (response bias scores) yielded such different results from our analysis of target responses (interpretive bias scores) weakens this account. An ideal assessment of response bias would require the presentation of completely new vignettes in the test phase, without telling participants the vignettes are new, to see if they still choose more negative summaries. The fact we did not do this represents a weakness of this study. Future research must include such foil vignettes to fully discount response bias effects.

Two important issues remained outstanding following Study 1. First, there was the possibility that WM load exaggerated trait anxiety's effects on bias because participants found the more difficult WM load anxiogenic, that is, that WM load was confounded with state anxiety. It was important to rule out this alternative account. Second, the results did not clarify which aspects of affective processing are under executive control. Trait anxiety may potentially bias both early reflexive input processes, such as alerting or orienting, or later more cognitive processes, such as appraisal, and either could be under the control of WM (Mathews & MacLeod, 2005). Note that input processes could account for interpretive bias, as they could bias the participant's attention toward the more negative aspects of the vignettes (Mathews & Mackintosh, 1998). Ouimet et al. (2009) suggest that interpretations are a product of both conscious processing and implicit associations, that is, they occur later than the input stage. We attempted to resolve these issues in Study 2.

Study 2

Study 2 aimed to replicate and extend the results of Study 1, using a different bias measure: attentional bias to threat (Bar-Haim et al., 2007; Cisler & Koster, 2010). This was measured using the dot probe task (MacLeod, Mathews, & Tata, 1986), in which one threat and one neutral stimulus are briefly presented on a computer screen, before one stimulus is replaced by a small probe. Attentional bias is indicated where participants respond faster to probes replacing the threat stimulus.

In Study 1, we only found interpretive bias effects with social threat vignettes, and we argue above that this is because social threat was more relevant to our participant group. To remedy this problem, in Study 2 we employed fear-conditioned neutral stimuli, to ensure the threat was equally relevant for all participants. We used Japanese kanji characters as our conditioned threat stimuli; these have the advantage of being novel for Turkish participants, and because different characters are conditioned for each participant, threat value is not confounded with visual features of the stimulus (Booth & Sharma, 2014; van Damme, Crombez, Hermans, Koster, & Eccleston, 2006).

In Study 1, we were unable to assess whether the WM load itself was experienced as stressful by participants. To address this issue, we recorded skin conductance and eyeblink muscle activity during the dot probe task: if participants feel more stressed under high load, they should show more skin conductance responses and greater eyeblink activity. In particular, we were then able to use these physiological variables as covariates in our analyses: if WM load's moderation of the relationship between anxiety and bias is a result of the load's stressful nature rather than the load's impairment of executive control, controlling for skin conductance or eyeblink muscle activity should nullify the WM load × Anxiety interaction.

Study 2 also sought to clarify the results of Study 1 by recording eye movements during the dot probe task. Eye movements can provide useful extra information about attention-allocation, and may provide a more pure measure of early input processes such as alerting and orienting (Armstrong & Olatunji, 2009).

Finally, in Study 2 we assessed both trait and state anxiety. Although cognitive biases are more commonly associated with trait anxiety, state anxiety has sometimes been found to moderate this relationship (Waechter & Stolz, 2015). Therefore, we included state anxiety to check for such moderation of our hypothesized Trait anxiety × WM load interaction.

Method

Participants. Fifty-three native Turkish-speaking undergraduates (33 females, *M* age = 21.51) participated for course credit or payment. The distribution of trait anxiety scores was similar to that for Study 1 (see Table 2). An additional three participants' data were excluded due to failures of the physiological equipment, and one additional participant's data were excluded due to high influence on the analyses.

Design. A mixed quasi-experimental design was used. WM load (high or low) was manipulated within participants, and state and trait anxiety were measured as continuous predictors. The dependent variables were attentional bias, which was assessed both by using traditional response times (RTs) and via eye movements (see Eye tracking below). Eyeblink startle electromyogram (EMG) and skin conductance were also recorded, to assess the efficacy of conditioning, and for use as covariates in our analyses.

Materials and measures. The study was conducted using SR Research's Experiment Builder software. Participants responded using a Microsoft Sidewinder gamepad. An SR Research chin and forehead rest was placed 65 cm from a 40 cm CRT monitor, which was running at 75 Hz.

State–Trait Anxiety Inventory. In Study 2, both the state and trait subscales were used. Cronbach's alpha = .83 for the state scale, and .80 for the trait scale.

Conditioning phases. Conditioned stimuli (CSs) were 16 Japanese kanji characters, taken from the KanjiLearn website (http://www2.gol.com/users/jpc/Japan/Kanji/KanjiLearn/). Characters were written in black on a square white background. For each of the two conditioning phases, four characters were randomly selected to serve as conditioned CS1s, and four to serve as nonconditioned

Table 2
Intercorrelations and Descriptive Statistics for Attentional Bias as Assesssed with Response Times and Eye Movements, Study 2

Variable	2	3	4	5	6	*M*	*SD*
1. Trait anxiety	.426**	.389**	.020	.205	.113	39.74	7.06
2. State anxiety		−.010	−.122	.289*	.337*	38.62	7.04
3. Attentional bias (RTs), high load			−.048	−.025	.032	2.38	28.83
4. Attentional bias (RTs), low load				.134	−.021	8.83	21.92
5. Attentional bias (eye movements), high load					.442**	.19	.16
6. Attentional bias (eye movements), low load						.16	.15

Note. $N = 53$. A more positive attentional bias indicates greater attention towards the threat stimulus.
* $p < .05$. ** $p < .01$.

CS2s. These CS1s and CS2s then served as threat and nonthreat stimuli in the next dot probe phase.

In each conditioning phase, participants passively watched the screen. Eight characters were presented for 2,000 ms each. Half the characters were randomly selected as CS1s, and these characters were followed by an unconditioned stimulus (US), which was a 9,100 Hz tone, presented at 92 dBA for 1,000 ms. The others were designated as CS2s, and no US was presented following these characters. All characters were followed by a blank screen for 4,500 ms.

Dot probe phases. During the dot probe phases, participants completed dot probe and WM tasks simultaneously. Each trial began with the WM study phase: in the high load condition, six randomly determined digits were presented for 2,000 ms, then masked for 2,500 ms. In the low load condition, one digit was presented for 500 ms, then masked for 750 ms. Presentation times were varied to equate encoding difficulty, based on Lavie et al. (2004). Digits were presented in white, on a black background. Following this, a central fixation was presented for 1,000 ms. One threat CS1 and one nonthreat CS2 character were then presented either side of the screen for 100 ms. Each conditional stimulus (CS) occupied a square with sides of 2.73°, centered 6.58° from the center of the screen. The CSs and their locations were randomly determined for each trial. A gray double-arrow probe (≪) 0.91° long was then presented, pointing up or down, in one of the CS's locations. The direction and location of the probe was randomized for each trial. Participants indicated the probe's direction, as quickly as possible, via a button-press with their right thumb. The probe remained onscreen until the participant responded. The trial ended with the WM test phase: a single digit was presented, and participants were asked whether this digit had been presented in the WM study phase. Participants responded via the gamepad. A new, foil digit was presented on 50% of trials.

In each dot probe phase, participants completed 64 trials. Of these 64 trials, the first 20 were designated as practice trials, and were excluded from analyses.

Physiological measures. Physiological measures were collected using a BIOPAC MP36, sampling at 500 Hz. Eyeblink startle EMG and skin conductance responses were recorded and analyzed in accordance with Society for Psychophysiological Research guidelines (Blumenthal et al., 2005; Fowles et al., 1981). EMG was conducted using 11 mm Ag/AgCl electrodes, treated with a 7% chloride salt gel and mounted in a 35-mm adhesive collar. Two electrodes were attached over the orbicularis oculi muscle under the right eye, and an isolated ground electrode was placed in the center of the forehead. Skin conductance was measured using 11 mm Ag/AgCl electrodes treated with 0.5% chloride salt gel, mounted in a 27 × 36 mm adhesive patch. These were placed on the distal phalanges of the fourth and fifth fingers of the nondominant hand.

Eye tracking. Gaze fixation of the dominant eye (determined by Miles test) was recorded at 1,000 Hz during the dot probe phases, using an Eyelink 1000 eye tracker. Only the horizontal location of gaze was tracked. A three-point calibration was conducted before each dot probe phase, calibrations were accepted if the error was less than 0.5°. Before each trial began, a single central fixation point was presented to check drift: calibration was repeated if tracking error exceeded 0.5°.

Procedure. Participants were briefed, and electrodes were applied. During a 10-min habituation period, participants completed the anxiety questionnaires, and received instructions regarding the dot probe task. They then completed a conditioning phase and a dot probe phase, followed by another conditioning phase and dot probe phase. They completed one dot probe phase under high WM load, and the other under low WM load. The order of load conditions was randomized.

Efficacy of US. EMG waveforms were high-pass FIR-filtered at 28 Hz to remove noise, then rectified. The waveform's area was calculated for the 4,500-ms period following each CS's offset. Participants showed more startle blink activity when a US was presented (M = 0.062mV · s; SD = 0.16mV · s) than when a US was not presented (M = 0.056mV · s, SD = 0.16mV · s), mean difference = 0.006, 95% CI [0.001, 0.011], $t(52) = 2.46$, $p = .02$.

Skin conductance waveforms were low-pass FIR-filtered at 1 Hz to remove noise, then high-pass IIR-filtered at 0.05 Hz to remove baseline drift. A skin conductance response was recorded wherever the resultant waveform peaked at more than 0.05 μS. Participants were more likely to make a response when a US was presented (M probability = .62, SD = .28) than when a US was not presented (M = .45, SD = .25), mean difference = .16, 95% CI [.09, .24], $t(52) = 4.61$, $p < .001$.

Together, these results indicate that the US was effective.

Results

RTs less than 1,000 ms were retained (Baert, De Raedt, Schacht, & Koster, 2010) if participants responded correctly to both the probe and the WM task; using alternative outlier criteria did not greatly alter the results. Separate attentional bias scores for the high and low WM load conditions were calculated by subtracting the participants' mean reaction time on trials where the probe appeared in the threat CS1's location from that for trials where the probe appeared in the nonthreat CS2's location. The resulting index, where positive, reflects an attentional bias toward threat.

As before, a repeated-measures general linear model was employed, with attentional bias score as the dependent variable, WM load as the factor, and trait anxiety as a continuous predictor. There was a main effect of WM load, $F(1, 51) = 5.59$, $\eta_p^2 = .10$, $p = .02$, so that participants generally showed more bias under low load (M = 8.83ms, SD = 21.92ms) than they did under high load (M = 2.38ms, SD = 28.83ms), and of trait anxiety, $F(1, 51) = 6.20$, $\eta_p^2 = .11$, $p = .02$, so that higher trait anxiety generally predicted more bias to threat. Importantly however, there was a significant interaction (see Figure 2), $F(1, 51) = 4.71$, $\eta_p^2 = .08$, $p = .03$, due to the fact that the model parameter for the trait anxiety effect under high load was positive and significant, unstandardized B = 1.59, 95% CI [0.53, 2.65], $p = .004$, whereas the parameter for the trait anxiety effect under low load was not significant, $B = 0.06$, 95% CI [−0.81, 0.94], $p = .89$. In other words, Study 2 replicated Study 1's basic finding that WM load exaggerates the effect of trait anxiety on bias. When we replicated these analyses with state anxiety instead of trait anxiety as the continuous predictor, no effects approached significance, all F values < 0.46, p values $>$ .50, suggesting that it is trait rather than state anxiety that influences RT measures of attentional bias. Similarly, adding both trait and state anxiety to the model also yielded no significant effects, all F values < 1.46, p values $> .23$.

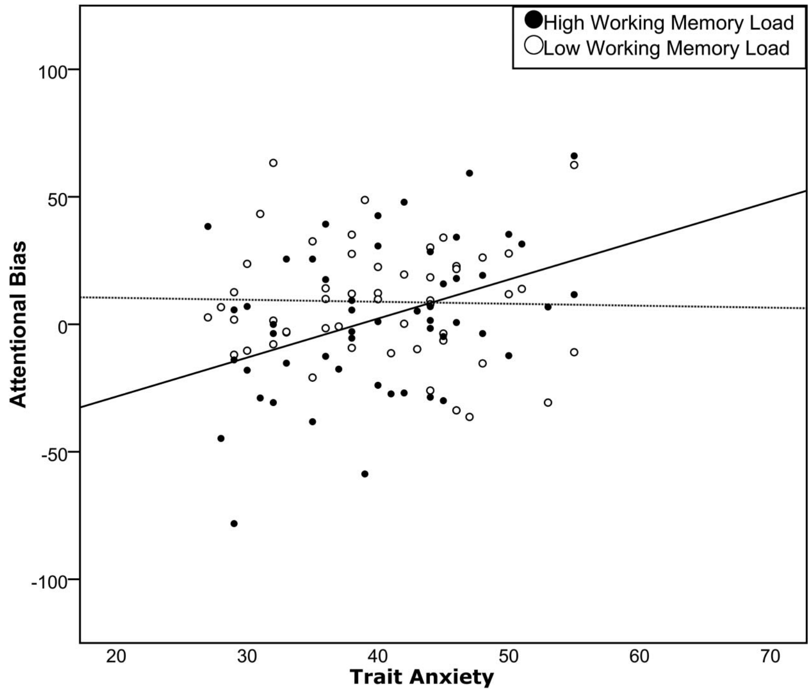

Figure 2. Relationship between trait anxiety and attentional bias under high (solid line) and low (broken line) working memory load. A more positive attentional bias score indicates more attentional bias to threat as opposed to neutral stimuli.

To check whether these effects could be simply explained by the stressful effects of WM load, we calculated the difference between the mean probability of a skin conductance response under high load and the mean probability of a skin conductance response under low load. One-sample t tests indicated that participants did indeed show more responses during the high WM load study phase, M difference = .27, 95% CI [.22, .32], $p < .001$, and during the high WM load test phase, M difference = .03, 95% CI [.01, .06], $p = .003$. However, participants showed *less* responses under high WM load during the actual dot probe component of the task, M difference = −.06, 95% CI [−.11, −.02], $p = .006$. Most importantly, including the difference in response probability for any of these three phases as a covariate in our model did not weaken our key interaction, all F values > 4.26, p values < .05, suggesting that emotional responses to the WM load itself were not driving our interaction between WM load and trait anxiety on attentional bias. Similarly, participants showed an eyeblink EMG waveform of greater area during the high WM load study phase, M difference = .024, 95% CI [.004, .044], $p = .02$, although not during the test phase, M difference = .01, 95% CI [−.002, .013], p = .14, or during the dot probe phase, M difference = .00, 95% CI [−.003, .001], $p = .47$. Again, including the difference in EMG waveform area for any of these three phases as a covariate in our model did not weaken our key interaction, all F values > 4.69, p values < .04.

Eye movements. Next, we checked to see if these RT effects corresponded to eye movements, concentrating on trials where the probe appeared in the nonthreat CS2's location. Trials with blinks or other tracking losses were discarded. We then calculated the proportion of trials where, if a saccade was made, that saccade was made in the direction of the probe. These proportions were used to calculate an attentional bias index, by subtracting the proportion for trials where the probe appeared in the nonthreat CS2's location from the proportion for trials where the probe appeared in the threat CS1's location. Again, this bias was calculated separately for each WM load condition.

These eye movement bias scores were analyzed with the same WM load × Trait anxiety general linear model as used for the RT analyses above. The main effect of trait anxiety was not significant, $F(1, 49) = 2.35$, $\eta_p^2 = .05$, $p = .13$, and neither was the main effect of load, $F(1, 49) = 0.96$, $\eta_p^2 = .02$, $p = .33$; although the parameter for trait anxiety was somewhat larger under high load, $B = 0.006$, 95% CI [0.000, 0.012], $p = .06$, than it was under low load, $B = 0.002$, 95% CI [−0.004, 0.008], $p = .53$, the WM load × Trait anxiety interaction did not reach significance, $F(1, 49) = 1.66$, $\eta_p^2 = .03$, $p = .20$. However, when the analysis was repeated with state anxiety as the continuous predictor instead of trait anxiety, the main effect of state anxiety was significant, $F(1, 49) = 7.24$, $\eta_p^2 = .13$, $p = .01$, indicating that more state anxious participants were more likely to make a saccade to probes when they appeared in the threat CS1's location. There were no other significant effects, F values < 0.70, p values > .40. When both trait and state anxiety were included in the model, no effects reached significance, all F values < 2.21, all p values > .14.

Discussion

Study 2 replicated and extended the results of Study 1. We ensured that our threat stimuli were relevant to all participants, by using fear-conditioned Japanese kanji as stimuli. Trait anxiety was only related to attentional bias to threat under high working memory load.

Psychophysiological measurements indicated that this effect was not simply due to emotional responses to the WM load itself. These results support the hypothesis that biased processing of emotional information is regulated by executive control processes.

Interestingly, anxiety and WM load differentially predicted attentional bias as measured with RTs, as opposed to eye movements: only trait anxiety predicted RT attentional bias and only under high WM load, but only state anxiety predicted eye movement attentional bias, and this was not moderated by WM load. Discrepancies between RT and eye movement data are not unheard of in the anxiety literature (Bradley, Mogg, & Millar, 2000; Broomfield & Turpin, 2005; Mogg, Millar, & Bradley, 2000). Eye movements potentially give a more accurate assessment of overt, early stage attentional orienting than do RTs (Armstrong & Olatunji, 2009), as RTs can be affected by both early attentional and later computational and response processes (Santee & Egeth, 1982). As WM load did not influence eye movements in this study, we tentatively suggest that executive control regulates these later processes, probably including appraisal, and does not so strongly regulate earlier processes such as orienting toward threat. Further support for this notion comes from the fact that eye movements to threat were associated with state rather than trait anxiety: evidence suggests that state anxiety is more closely associated with alerting and orienting, whereas trait anxiety is more closely associated with overall executive control deficits (Bishop et al., 2007; Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010). Note that these eye movement results do not invalidate our interpretation of the RT data, because attention is able to operate independently from eye movements (e.g., Corbetta, 1998). Further research is needed to elucidate the relationships between biased attention and biased eye movements in state and trait anxiety.

The results of Study 2 are apparently at odds with those of Schoorl et al. (2014), who found that PTSD patients' symptom severity predicted attentional bias away from threat, rather than toward threat, in patients with poorer attentional control ability. The results of these two studies are, however, quite compatible. It has often been found that anxious individuals first attend toward, and then away from, threat stimuli ("vigilance-avoidance," see Koster, Crombez, Verschuere, Van Damme, & Wiersema, 2006; Mogg, Bradley, Miles, & Dixon, 2004; Onnis, Dadds, & Bryant, 2011). The present study used a short interval between the threat stimuli and the probe (100 ms), and was therefore more likely to find vigilance for threat in more trait anxious participants. Schoorl et al. (2014) used a longer interval of 500 ms, which has sometimes produced avoidance in previous studies (e.g., Koster et al., 2006). Importantly, although avoidance of threat has been assumed to be a strategic coping mechanism (Mogg & Bradley, 1998), recent evidence suggests that avoidance of threat can also occur ballistically and unintentionally; Booth (2014) found that avoidance of threat correlated negatively with a measure of executive control. Booth's results suggest that Schoorl et al.'s (2014) results reflect a similar pattern to those of the current study; Schoorl et al. (2014) simply sampled their participants' attention at a later point in time, where avoidance was more likely to be observed rather than vigilance.

Relatedly, note that the short interval between threat and probe stimuli used in the present study does not allow the participant much time for reactive shifts of attention. Similarly, Bardeen and Orcutt (2011) manipulated this interval and found that posttraumatic stress symptom severity and attentional control only interacted on attentional bias when the threat-probe interval was 150 ms, this interaction was not significant when the interval was 500 ms. It could be argued that 100–150 ms is not enough time to register the threat's location and shift attention accordingly. In fact, this may be true, but such reactive shifts of attention are not important for performance in the dot probe task. In this task, optimum performance requires the participant to ignore the threat and neutral stimuli completely, and hold their attention on the center of the screen, so as to detect and identify the probe as quickly as possible. Therefore, attentional control can be applied preemptively, to inhibit any shift of attention toward (or away from) the threat stimulus. Indeed, attentional control theory specifies that attentional bias represents a failure to inhibit attentional shifts toward threat. It is therefore expected that executive control would moderate attentional bias even at short threat-probe intervals. More surprising is Bardeen and Orcutt's (2011) failure to detect the effect with a longer interval of 500 ms: these authors suggest that the longer interval allows more time for attention to "slip" (Lachter, Forster, & Ruthruff, 2004) to the threat stimulus, regardless of the initial level of control employed. Note however that Susa, Pitică, Benga, and Miclea (2012) found that attentional control did negatively predict bias with an interval of 500 ms in a sample of children.

General Discussion

These two studies showed that WM load moderates trait anxiety's influence on cognitive biases, supporting the hypothesis that executive control can regulate biased processing of emotional information. Although correlational studies have previously suggested this might be the case (e.g., Helzer et al., 2009; Reinholdt-Dunne et al., 2009; Salemink & Wiers, 2012), these studies go one step further by directly manipulating control within subjects. In two studies with different samples and dependent measures, trait anxiety did not predict threat bias under low WM load, but did predict bias *in the same participants* under high WM load. However, this only seemed to be the case when the threat stimuli had some relevance for the participants. Study 2 further suggested that control regulates later cognitive processing, perhaps including appraisal, rather than initial, more reflexive processes such as alerting and orienting. Practically speaking, these studies show that WM loads can exaggerate cognitive biases and so are a useful tool for affective scientists requiring accurate assessments of threat processing, unbiased by the effects of executive control. Theoretically speaking, these studies support attentional control theory's (Eysenck et al., 2007) assertion that cognitive biases represent a failure of cognitive control (see also Bishop et al., 2007; Mathews & MacLeod, 2005; Ouimet et al., 2009). Clinically, they reinforce the claim that executive control may constitute a protective factor against high trait anxiety, and that weaknesses of control may lead to exaggerated threat-processing biases in anxious patients.

Another model that posits a role for cognitive control in cognitive bias is the model of Mathews and Mackintosh (1998), which conceptualizes bias as the result of competing representations: representations of the threat stimulus, neutral stimulus, and probe in the case of attentional bias, and representations of the positive and negative interpretations in the case of interpretive bias. The model includes an "effortful task demand" unit, which is able to boost the activation of the probe stimulus/positive interpretation in situations where there is little actual danger. This aspect of the model seems consistent with our findings. However, another assumption of this model is that both state and trait anxiety influence bias by modulating the activity of a "threat evaluation system," which monitors all incoming stimuli for potential danger. This is inconsistent with the dissociation between trait and state anxiety effects on RTs in our Study 2. Evidence supports the notion that trait and state anxiety may have differentiable effects on cognition (Pacheco-Unguetti et al., 2010); further research is required to fully investigate this difference with regard to both performance-based and eye movement-based biases.

Clinically, these results are important because they evidence an indirect link between biased processing of threat and executive control deficits in trait anxiety. Executive control deficits do not directly bias processing, but they do increase the chance of latent biases manifesting themselves. This is consistent with neuroimaging evidence suggesting that processing threat information is unavoidable, but can be modulated according to task demands (Mathews, Yiend, & Lawrence, 2004).

Given that both interpretive and attentional biases help cause or maintain trait anxiety (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002; Mathews & Mackintosh, 2000), these results also imply that poor executive control may increase vulnerability to anxiety disorders (Mathews & MacLeod, 2005; Ouimet et al., 2009). Indeed, this hypothesis has been tested in correlational studies. Susa et al. (2012) found that attentional bias to threat faces only predicted anxiety in children with low attentional control. Of course, the correlational studies reviewed in the introduction, which appear to show that trait anxiety more strongly predicts cognitive bias when control is low, may equally show that bias more strongly predicts trait anxiety when control is low. A potential mechanism is implied by the findings of Bardeen and Read (2010) and Compton (2000), who found that attentional control predicted resilience to and recovery from negative emotion. Preliminary investigations have begun into executive control training programs as a potential therapy for emotional disorders (Owens, Koster, & Derakshan, 2013; although see Onraedt & Koster, 2014). It is not a circular argument to say that impaired executive control makes threat bias clearer in more anxious people, therefore impaired executive control can make people more anxious. First, evidence suggests that trait anxiety and cognitive bias exacerbate one another in a feedback loop (see Mathews, Mogg, Kentish, & Eysenck, 1995; Mogg, Bradley, Millar, & White, 1995), so any increase in bias expression may lead to increased anxiety. Indeed, this is why improving executive control through training may ameliorate anxiety, by reducing the expression of cognitive biases; in this way it may interrupt one factor maintaining the anxiety. Second, we are arguing that impaired executive control can exaggerate individual differences in cognitive bias: therefore impaired executive control may increase an individual with somewhat elevated trait anxiety's risk of developing clinical anxiety.

One puzzling aspect of both these studies is the fact that trait anxiety was not related to cognitive bias under low WM load. Many studies that did not employ any kind of WM or cognitive load have found significant attentional or interpretive bias in anxious groups, so why were these effects absent here? The most obvious answer is that these studies might be underpowered in the low WM load condition. Attentional bias in particular, although replicated in dozens of studies, is known to have a relatively modest effect size (Bar-Haim et al., 2007) and to be somewhat unreliable (Waechter & Stolz, 2015; Zvielli, Bernstein, & Koster, 2014). Studies of cognitive bias also tend to employ extreme-groups designs, selecting participants to be high or low on trait anxiety, which inflates power relative to correlational studies such as ours (e.g., Preacher, Rucker, MacCallum, & Nicewander, 2005). Bar-Haim et al. (2007) report a meta effect size of $d = 0.38$ for dot probe studies assessing the difference in bias between anxious and nonanxious groups. This is equivalent to a correlation r of .19 (Rosenthal, 1994), and a sample of 53 participants only has power of approximately .27 to detect an effect of this size. This is not however a weakness of the present studies, as our intent was not to assess the presence of bias—many studies have already established this—but to assess whether WM load would moderate bias. This highlights the utility of WM loads in cognitive bias research: the present studies suggest that applying a WM load may make biases more detectable in smaller and/or less extremely trait anxious samples.

Our findings that trait anxiety-related cognitive biases are more likely to manifest themselves when executive control processes are impaired are important for theories of cognitive biases, and potentially for understanding the etiology of anxiety itself. The generalizability of our findings is limited by our fairly small, nonclinical samples; however, cognitive bias effects are typically comparable between patient and anxious analogue groups (Bar-Haim et al., 2007). Furthermore, the mechanism by which WM load moderates bias is unclear; the concept of executive control has often been underspecified in the cognitive bias literature (although see Eysenck et al., 2007). Further research is needed to understand which aspects of executive control are most important for regulating biased cognition and threat-processing, and whether other cognitive biases seen in trait anxiety—and indeed cognitive biases seen in other conditions and affective states—are regulated in the same way.

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