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# The Impact of Working Memory Load and Anxiety on Attention Bias Modification Training

by

David Yap

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of the requirements for the degree of
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**Abstract**

Anxiety is associated with an attentional bias (AB) toward threat. Attention bias modification training (ABMT) is a novel computer-based intervention used to train attention away from threat. However, little is known about the cognitive conditions under which ABMT may be most effective. To address this, recent studies have investigated the impact of introducing a working memory load (WML) during ABMT on training efficacy but have produced mixed results (Booth, Mackintosh, Mobini, Oztop, & Nunn, 2014; Clarke et al., 2017). Overlooked key individual differences, namely working memory capacity (WMC) and anxiety, may account for the apparent conflicting results. Thus, the present study evaluated the effect of low and high WML on ABMT in a large, college-aged sample (N=204) with trait anxiety and WMC assessed. Participants were trained to either avoid or attend to threat. WML was manipulated via a digit-recognition task delivered concurrently with ABMT. Baseline and post-ABMT AB were assessed. Results showed greater efficacy of training in the low-WML condition, particularly among those with low trait anxiety. These findings reconcile conflicting results from prior studies and align with the growing body of evidence showing ABMT effects are susceptible to interference and vary with individual differences.

*keywords*: attentional bias, attention bias modification training, working memory load, anxiety

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The Impact of Working Memory Load on Attention Bias Modification Training

Facilitated attention to threat is an adaptive trait that is essential to survival. However, selective and exaggerated attention toward threat, known as an attention bias (AB) toward threat, has been theorized as both a product of and contributor to anxiety (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Gale & Eysenck, 1992; MacLeod, Mathews, & Tata, 1986) and psychopathology in the form of social anxiety disorder (Hofmann, 2007) and general anxiety disorder (Bradley, Mogg, White, Groom, & de Bono, 1999). Knowledge of this link has driven the development of attention bias modification training (ABMT: Mathews & MacLeod, 2002; Van Bockstaele et al., 2014), a computer-based technique that trains attention away from threat. Studies have shown ABMT to reduce generalized and social anxiety (Hakamata et al., 2010) and stress reactivity (O'Toole & Dennis, 2012).

Despite early studies showing success of ABMT at reducing AB and associated pathological symptoms (e.g., Amir, Beard, Burns, & Bomyea, 2009; Hazen, Vasey, & Schmidt, 2009; Schmidt, Richey, Buckner, & Timpano, 2009), more recent studies have yielded null and mixed results with small effect sizes (e.g., Carlbring et al., 2012; Cristea, Kok, & Cuijpers, 2015; Julian, Beard, Schmidt, Powers, & Smits, 2012; Rapee et al., 2013). These mixed findings underscore the need for a greater understanding of processes underlying ABMT's efficacy and the cognitive conditions that could moderate its effect. Working memory load (WML) has been identified as a potential moderator of ABMT's effects due to findings that anxious individuals who tend to show AB to threat also tend to show deficits in working memory and cognitive control (e.g., Ashcraft & Kirk, 2001; Crowe, Matthews, & Walkenhorst, 2007). It has been suggested that ABMT disrupts the hold on attention of threatening stimuli by strengthening the central executive's ability to regulate attention (Klumpp & Amir, 2010). A study by Paulewicz, Blaut, and Kłosowska (2012) reported that initial levels of attention control predicted the success of ABMT to change attention bias. Therefore, a working memory load that impairs the central executive may disrupt ABMT.

Prior studies have found that greater WML did have an effect on ABMT, however, the nature of this impact, facilitative or inhibitive, is unclear from their results (Booth et al., 2014; Clarke et al., 2017). Booth and colleagues (2014) created low- and high-WML conditions by asking participants to remember and recognize one- or six- digit strings during ABMT. They observed ABMT effects only when delivered with a low WML compared to a high WML, suggesting that greater load interferes with ABMT. Clarke and colleagues (2017) used a similar working memory load task and found, in contrast, ABMT effects only when delivered with a high WML compared to no WML.

These contradictory results may be due to individual characteristics that moderate the impact of WML on cognition. One such key factor is working memory capacity (WMC), which underlies the ability of the central executive to control attention resources (Conway et al., 2005; Kane, Conway, Bleckley, & Engle, 2001; Kane & Engle, 2002, 2003). Individuals with larger WMC are able to maintain more items in active memory and therefore experience less dual-task interference. In one study comparing performance on an antisaccade task between low- and high-WMC groups, individuals with higher WMC were better able to orient their attention away from a peripheral cue in order to respond to a target stimulus that consistently appeared in a location opposite the cue (Kane et al., 2001). In another study, Kane and Engle (2001) showed subjects with low WMC were more vulnerable to disruption in incongruent trials of the Stroop task.

Taken together, these studies suggest greater WMC moderates the size of the WML in a dual-task.

Anxiety is another important individual characteristic that could interact with WMC to influence the size of the load created by a working memory task. Anxiety has deleterious effects on high-demand tasks involving working memory and attentional control (Eysenck & Calvo, 1992; Eysenck, Derakshan, Santos, & Calvo, 2007; Owens, Stevenson, Hadwin, & Norgate, 2014). For example, Owens and colleagues (2014) investigated the interactive impact of WMC and trait anxiety in adolescent performance in demanding cognitive tasks. They found that trait anxiety was negatively associated with performance only for individuals with low WMC. It follows that those with a low WMC are at greater risk of experiencing anxiety’s detrimental effect on performance. In another study investigating performance on a dual-task, Johnson and Gronlund (2009) found that participants with a low WMC were particularly vulnerable to anxiety’s disruptive effects while those with a high WMC were buffered against anxiety’s disruptive effects.

In prior studies that investigated WML impact on ABMT, Booth and colleagues (2014) used a trait-anxious sample, while Clarke and colleagues (2017) used a non-anxious sample. Neither study, therefore, could analyze whether differences in anxiety and its interaction with WMC within their samples may have contributed to their results. The importance of anxiety and WMC may provide keys to explaining why Clarke and colleagues’ non-anxious sample still benefitted from ABMT with a high WML while Booth and colleagues’ trait-anxious sample did not. In a sample that includes a range of trait anxiety, we would expect individual differences in anxiety to moderate the impact of the WML.

Thus the aim of the current study was to clarify the effect of WML on ABMT and to investigate the potential impact of individual differences in WMC and trait anxiety on these effects. ABMT was administered concurrently with a low or high WML. Individuals were trained to either attend to or avoid threat, which is important for comparing post-training scores as an indicator of training success in an unselected sample that is not expected to evidence a substantial threat bias. Participants were randomly assigned to one of four conditions: high or low WML and either in avoid-threat or attend-threat ABMT condition. We tested the hypothesis that greater WML would interfere with ABMT such that post-ABMT AB scores in the avoid-threat condition would be significantly lower than the attend-threat condition in the low WML but not the high WML condition. Furthermore, we investigated whether WML's impact was moderated by trait anxiety and WMC with the expectation that greater anxiety and lower WMC would increase the working memory load and therefore predict smaller post-ABMT AB scores between the attend-threat and avoid-threat conditions.

## Method

### Participants

Participants were 211 adults drawn from a pool of undergraduate psychology students at Hunter College, City University of New York, where they received course credit for their participation. Seven participants were excluded due to low accuracy on the dot probe task. The final sample consisted of 204 adults 18-41 ($M = 19.94$, $SD = 3.56$). There were 149 (73%) females and 55 (27%) males. Self-reported race and ethnicity were as follows: 74 (36.3%) Caucasian, 15 (7.4%) Black or African American, 80 (39.2%) Asian, 3 (1.5%) American-Indian, 2 (1%) Native Hawaiian or other Pacific Islander, 20 (9.8 %) identified as multiple races, and 10 (4.9%) declined to report. Participants were also asked if they identified as Hispanic/Latino and reported the following: 50 (24.5%) Hispanic/Latino, 140 (68.6%) Not-Hispanic/Latino, and 14 (6.9%) declined to report.

Participants were randomly assigned to one of four ABMT conditions: Attend-threat with a high (n=48) or low WML (n=54), and avoid-threat with a high (n=54) or low WML (n=48).

**Procedure**

Participants spent approximately 2 hours in the laboratory seated alone in private booths equipped with a Dell Optiplex 390 PC, running Microsoft Windows 7 with a Dell 18" monitor with 1920 x 1080 screen resolution. Informed consent was obtained followed by a brief questionnaire period in which they completed demographic questions and self-reported anxiety and mood symptoms. Next, an administrator entered the booth to measure baseline working memory capacity. After completing the baseline attention bias assessment using the dot probe, participants completed a practice session and four consecutive sessions of ABMT, followed by a post-ABMT attention bias assessment.

**Measures**

*Trait anxiety.* The trait subscale of the State-Trait Anxiety Inventory (STAI: Spielberger, Gorsuch, & Lushene, 1970) was used to assess trait anxiety. The STAI-Trait subscale consists of 20 statements describing how people generally feel (e.g., content) rated on a 4-point frequency scale ranging from almost always to almost never. Higher scores indicate greater severity of anxiety symptoms. The STAI has demonstrated reliability and validity across populations (Barnes, Harp, & Jung, 2002; Spielberger et al., 1970).

*Working Memory Capacity*. The digit span working memory core subtests of the Weschsler Adult Intelligence Scale (WAIS: Weschler, 2008) measures WMC, thought to be an integral component of intelligence (Conway, Kane, & Engle, 2003). The subtests consist of an administrator verbally presenting subjects increasingly large spans of digits to be verbally recalled as read (Digit Span Forward), inversed (Digit Span Backward), or reordered ascending (Digit Span Sequencing).

**Attention Bias**

Attention bias was assessed using the dot probe task (Bar-Haim et al., 2007; Mathews & Mackintosh, 1998) which followed the parameters of the Tel-Aviv University/National Institute of Mental Health protocol (http://www.tau.ac.il/~yair1/ABMT.html). The task was programmed and delivered using EPrime version 2.0 (Schneider, Eschman, & Zuccolotto, 2002). Stimuli for the dot probe task comprised of pictures of 20 different individuals (10 males, 10 females) from the NimStim stimulus set (Tottenham et al., 2009) with one female included from the Matsumoto and Ekman (1989) set. Stimuli were cropped to a length-by-width size of 191 pixels by 143 pixels. There were three types of trials: (1) threat-cue trials which presented an angry and neutral face pair with the following probe at the location of the angry face, (2) neutral-cue trials which presented an angry and neutral face pair with the following probe at the neutral face, and (3) control trials which presented a two neutral faces.

The dot probe was preceded by instructions displayed on the screen and read aloud to the participant. Participants were instructed that each trial would begin with a cross appearing in the center of the screen followed by a pair of faces and then a target arrow pointing either to the left or to the right. Participants were to respond to the direction of the arrow using the mouse buttons with their dominant hand. Participants were instructed to respond as quickly as possible without making mistakes. The task included 120 trials (80 angry-neutral faces and 40 neutral-neutral faces). Trials were counterbalanced for probe location above or below the cross, probe direction pointing left or right, and location of the threatening face above or below the cross.

Each trial progressed as follows: (a) 500 ms fixation cross, (b) 500 ms face-pair cue, (c) target probe (arrow) in the location of one of the faces until a response is made with the left or right mouse button to indicate the direction which the arrow is pointing, and (d) 500 ms intertrial interval.

**Quantifying Attention Bias**

Response times the pre- and post-ABMT bias assessments were extracted via eMerge. Only correct responses and responses within 150ms and 2000ms were included. Seven participants were excluded from analyses due to a mean accuracy score below 85% for either the pre- or post-ABMT bias assessments, resulting in a final N = 204. This was to insure that only participants who followed the dot probe task instructions properly were included in analyses. The mean accuracy score for the pre-and post-ABMT bias assessments were *M* = 98.45% (*SD* = 1.90) and *M* = 97.01 (*SD* = 2.98) respectively. Mean RT was calculated for threat-cue, neutral-cue, and control trials. Data points three standard deviations above or below the session mean were adjusted using extreme value replacement.

AB scores were calculated using dot probe RTs by subtracting the mean threat-cue RT from the neutral-cue RT. Faster responses to threat probes produce higher scores, indicating an AB toward threat. Examples of neutral- and threat-cue trials can be seen in Figure 1.

**ABMT**

Participants received one practice session of ABMT, consisting of eight trials, followed by four consecutive sessions of ABMT, each containing 160 trials. Instructions displayed on the screen and read by administrators repeated the instructions for the dot probe. In addition, participants were instructed that some trials would be preceded by a set of digits that they should remember. Participants were instructed that after a few trials, they would be presented with a single digit and must identify if the digit was in the set they had previously seen. Participants were informed this was to repeat throughout the task. ABMT's key mechanism is the contingency between the cue stimuli and probe such that the probe nearly always follows the stimuli to which attention is being trained (MacLeod et al. 2002). Of the 160 trials in a single session, 40 were control trials. For the remaining 120 trials, those in the avoid-threat condition saw neutral-cue trials, while those in the attend-threat condition saw threat-cue trials. Through multiple trials of ABMT, subjects learn to attend to the target stimuli.

Cognitive load was introduced via a working memory task that interleaved digit string presentations and recognition tests every eight trials. Each block of eight trials was preceded with a digit-string presentation. Participants in the low-WML condition were shown two-digit strings for 1000ms, and participants in the high-WML condition were shown six-digit strings for 2000ms. Above the digits strings was the instruction "Remember these digits". Following eight trials of ABMT, participants were presented with a recognition slide presenting a single test digit. Participants were asked to indicate if the test digit was present in the previously-viewed string by clicking the left mouse button for "yes" or the right mouse button for "no". The recognition test digit was present 50% of the time. Feedback was given in the following slide that displayed either 'CORRECT' for 1000ms in black or 'INCORRECT' for 5000ms in red.

The next set of digits was presented after an inter-trial interval of 1000ms displayed "Get ready for a new set of digits". This was followed by the next 8 trials of ABMT. The sets of digits for both the digit strings and the test digits were randomly generated without replacement, with each digit, 0 to 9, equally represented throughout the entire four sessions. The order of digit strings and test digits was uniform across all sessions of ABMT. A timeline of a single session of ABMT can be seen in Figure 2.

## Results

### Baseline measures and manipulation checks

Table 1 shows baseline AB, anxiety (STAI trait), and WMC (WAIS subscores) for the four experimental conditions. There were no significant differences in baseline measures (largest $F = 1.469$, $p \geq .224$). Pearson correlations were conducted to examine associations among baseline AB, anxiety, and WMC. No correlations reached significance (smallest $p = .457$).

To check that we successfully manipulated WML during ABMT, independent samples *t* tests compared the accuracy and mean RTs to the test digit probe between the low- and high-WML conditions. As expected, the low-WML condition had significantly higher accuracy ($M$ = 93.726, $SE$ = .72), than the high-WML condition ($M$ = 91.498, $SE$ = .817), $t(198.33) = 2.046$, $p$ = 0.04. Additionally, the low-WML condition was significantly faster to respond to the recognition probe ($M$ = 1291.93, $SE$ = 30.619) than the high-WML condition ($M$ = 1774.34, $SE$ = 47.265), $t(171.868) = -8.566$, $p < .001$. In the working memory paradigm of limited cognitive resources, faster RT and higher accuracy is to be expected with greater availability of cognitive resources. The difference in accuracy and RT suggests that the high-WML condition used more of these cognitive resources.

To ascertain the role of WMC in cognitively loading ABMT, Pearson correlations between WAIS subscores and digit recognition accuracy were conducted separately in the low- and high-WML conditions. We expected greater WAIS subscores to be significantly positively associated with digit recognition accuracy. Higher WMC indicates greater ability to control attention resources which should result in greater capacity to remember the digits while completing the ABMT trials. There was a significant positive relation in the high-WML condition only, $r(101) = 0.397$, $p < 0.001$. The non-significance of the relationship in the low-WML condition suggests that the two-digit working memory task was easy enough that individual differences in WMC were not reflected in the performance on the recognition test.

**Main Analyses**

To test the main hypothesis that ABMT was more effective in the low-WML group, post-ABMT AB scores were subjected to a 2 x 2 ANCOVA with WML (low vs. high) and Training Type (avoid-threat vs. attend-threat) as between subject factors. Baseline AB, WMC, and Anxiety were included as covariates. There was no main effect of WML, $F(1,197) = 0.129$, $p = .781$, $\eta_p^2 = .114$ or Training Type, $F(1,197) = 0.030$, $p = .891$, $\eta_p^2 = .029$ on post-ABMT AB scores. However, a significant interaction between WML and Training Type emerged, $F(1,197) = 12.639$, $p < .001$, $\eta_p^2 = .060$. Follow-up pairwise comparisons were conducted to explore the significant interaction (see Figure 3).

As expected, there was a significant of effect of Training Type such that the avoid-threat condition had significantly lower post-ABMT AB scores ($M = -0.937$, $SE = 3.052$) than the attend-threat condition ($M = 7.827$, $SE = 2.850$), $F(1,197) = 4.366$, $p = .038$, $\eta_p^2 = .022$, but only in the low-WML condition. In contrast, the avoid-threat condition had significantly *higher* post-

ABMT AB scores (*M* = 5.857, *SE* = 2.891) than the attend-threat condition (*M* = -6.561, *SE* = 3.041), $F(1,197) = 8.743$, $p = .003$, $\eta_p^2 = .042$, but only in the high-WML condition. There was also a significant effect of WML in the attend-threat condition only such that low-WML had significantly higher post-ABMT AB scores (*M* = 7.827, *SE* = 2.850) than the high-WML condition (*M* = -6.561, *SE* = 3.041), $F(1,197) = 11.859$, $p = .001$, $\eta_p^2 = .057$. WMC was not a significant predictor of post-ABMT AB scores, $F(1,197) = 2.277$, $p = .133$, $\eta_p^2 = .011$. Anxiety, however, was a significant predictor of post-ABMT AB scores, $F(1,197) = 5.039$, $p = .026$, $\eta_p^2 = .025$.

We next turned to further examine the role of anxiety as a moderator of WML effects on ABMT. The ANCOVA was rerun with Anxiety (low vs. high) included as a between subjects factor[1]. A significant three-way interaction between WML, Training Type, and Anxiety emerged, $F(4,194) = 4.633$, $p = .001$, $\eta_p^2 = .087$. Follow-up pairwise comparisons were conducted to explore the significant interaction[2]. Post ABMT-AB means and standard errors are presented in Table 2.

There was a trend in the effect of Training Type such that the avoid-threat condition produced significantly lower AB scores than the attend-threat condition for the low-WML condition, but only in the low-anxiety group, $F(1,194) = 5.743$, $p = .018$, $\eta_p^2 = .029$. In contrast, the avoid-threat condition produced, counterintuitively, significantly *greater* AB scores than the

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[1] Low- and high- anxiety groups were created using the sample median as the divider. An independent samples *t* test established equivalence in baseline AB between the low-anxiety (*M* = 2.3077, *SE* = 2.4771) and high-anxiety groups (*M* = -.1200, *SE* = 2.0593), $t(202) = .751$, $p = .454$.

[2] Post hoc analyses were conducted with a Bonferonni adjusted alpha of .0083 per test.

attend-threat condition among those in the high-anxiety group, $F(1,194) = 12.311$, $p = .001$, $\eta_p^2 = .060$.

Within the attend-threat condition, there was an effect of WML such that the low-WML condition had significantly greater AB scores than the high-WML condition, but only in the high-anxiety group, $F(1,194) = 8.602$, $p = .004$, $\eta_p^2 = .042$. A trend in the same direction was observed in the low-anxiety group, but did not reach significance $F(1,194) = 5.135$, $p = .025$, $\eta_p^2 = .026$.

Within the avoid-threat condition, there was an trend in effect of anxiety level such that the low-anxiety group had significantly lower AB scores than the high-anxiety group in both the high-WML condition $F(1,194) = 6.500$, $p = .012$, $\eta_p^2 = .032$ and the low-WML condition, $F(1,194) = 4.076$, $p = .045$, $\eta_p^2 = .021$.

## Discussion

This study aimed to investigate whether ABMT delivered to a non-clinical sample with a low WML would be more effective in changing AB than ABMT delivered with a high WML. Our results support this, with findings demonstrating that ABMT produced expected changes in AB in the low-WML, low-anxiety group only. High WML and high anxiety alone and in interaction disrupted the beneficial effects of ABMT. Taken together, these results support our hypothesis that in a non-clinical sample, ABMT is most effective when WML and trait anxiety are at low levels.

The results of the current study align with prior studies (Booth et al., 2014; Clarke et al., 2017) demonstrating that WML has an effect on ABMT, adding to the body of research that asserts that ABMT targets top-down executive processes responsible for attention control.

Congruent with the current study's findings, Booth and Colleagues (2014) found that ABMT with a low WML resulted in significant change in AB while ABMT with a high WML failed to significantly move AB scores away from zero. The current study bolsters Booth and colleagues' findings by addressing some methodological issues that limited their results, namely their small sample size and choice of word stimuli. Cowan & Morey (2007) found that holding information in working memory from a particular domain like the phonological loop (i.e., digit strings) can interfere with the ability to encode information in that same domain (i.e., words). Thus, diminished efficacy in Booth and colleagues' high cognitive load condition may be the result of the failure to encode the negative words' valence rather than diminished cognitive resources (Clarke et al., 2017). The current study used pictorial and number stimuli for ABMT and cognitive loading, respectively, which occupy different working memory domains.

In apparent contradiction to our results, Clarke and colleagues (2017) compared ABMT with a high WML to ABMT with no WML and found the greatest change in pre- to post-ABMT AB scores in their high-WML condition. Clarke and colleagues suggested that their high-WML condition benefitted from ABMT more than their no-load group because the WML task facilitated recruitment of greater cognitive resources for a task that typically requires very little attention control.

Findings from the current study that anxiety impacts the relationship between WML and ABMT provide keys to understanding prior, conflicting findings about WML impact on ABMT. Clarke and colleagues (2017) restricted their sample to individuals with trait anxiety scores that fell within the middle tercile while Booth and Colleagues (2014) selected for high trait-anxious individuals. In these two prior studies, the non-anxious sample benefitted from ABMT with a high WML while the trait-anxious sample did not. This aligns with our findings that the high-anxiety group experienced the greatest disruption to training with the high WML. Thus, the difference between prior findings about the impact of high WML may be a result of differences in anxiety severity in the two samples. Future research could include high-, low- and no-WML conditions taking into account trait anxiety to further clarify the relationship between WML and ABMT.

Counterintuitively, we found that ABMT with high-WML increased AB in the opposite direction of the Training Type. This finding challenges our original conception of interference being reflected only as diminished effects of ABMT. This suggests that the impact of greater cognitive load may not be simply blocking of learning the stimulus-cue contingency, but rather may influence processes underlying ABMT in such a way that produces an AB in the opposite direction. In a meta-analysis (Mogoaşe, David, & Koster, 2014), ABMT was found to be more effective when subjects have a baseline attention bias. Moreover, this meta-analysis found AB acquired through training eventually disappeared in non-clinical samples. It may be that healthy individuals exhibit resilience to acquiring an artificially induced AB through training, returning to no AB. This homeostatic effect may be compromised by the high WML, leading to a swing in AB in the opposite direction of training. As this is all speculative, further research is warranted here.

High trait anxiety has been shown to result in enhanced processing of task-irrelevant stimuli (Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010) and is associated with reduced efficiency in cognitive processing (Berggren & Derakshan, 2013). Thus, high trait-anxious individuals may require a greater amount of cognitive resources to perform at the same level as low trait-anxious individuals (Eysenck et al., 2007). While differences in performance between high and low trait-anxious individuals may not be evident when ample cognitive resources are available, in periods of diminished cognitive resources (i.e., greater WML), differences in attention control may surface. This may explain why in the current study, ABMT with a low WML was successful in the low-anxiety group but not in the high-anxiety group. In this latter group, the low WML may have sufficiently diverted cognitive resources to prevent the proper learning of the stimulus-cue contingency in the avoid-threat condition (Shmoe, 2018).

The current study's findings contribute to our understanding of the optimal cognitive conditions in which to deliver ABMT and have bearing on the deployment of ABMT as a potential intervention for disorders associated with attention biases. ABMT is self-directed (e.g., it requires no more than a computer), can be delivered on-the-go through a mobile device, and may be especially suitable for subjects for whom traditional forms of therapy (e.g., talk therapy) are difficult, such as young children. It has therefore been conceived of as a potential "homework" that can be delivered alongside other forms of therapy (Amir & Taylor, 2012). The finding that the WML task disrupted the effect of ABMT, particularly for those with high trait anxiety, suggests this potential intervention would be most appropriate in conditions of minimal distraction. Furthermore, high trait-anxious individuals may be more susceptible to the disruptive effects of WML such that even a low load on cognition could have adverse effects on attention training. Thus, extra caution against distracting environments may be warranted for anxious individuals, to whom ABMT is most likely to be prescribed.

A potential limitation of this study is the sequential order of digit string and test digit pairs that were uniformly presented to participants. Ideally the order of the digit strings and test digits pairs would have been counterbalanced to avoid potential order effects from this design. However, the random generation of the digit strings and the equal frequency of each digit across the training allows for cautious optimism that order effects were minimal or nonexistent.

An avenue for further research into the relationship between WML and ABMT is investigating whether the negative impact of WML is reflected in emotional resilience against stress. Meta-analyses of ABMT studies have shown the causal relationship between change in AB and emotional benefits to be moderate (e.g., Hakamata et al., 2010) or weak (e.g., Hallion & Ruscio, 2011). The addition of a stress task would allow for additional analyses regarding whether any disruptive or facilitative effects of WML on ABMT have downstream effects on emotional wellbeing. Of special concern here are the results of the high-WML group in the present study in which change in AB was opposite the training direction. Should the effects of training extend to emotional wellbeing, it follows that training away from threat with a high working memory load may actually produce negative emotional consequences.

In summary, the current study builds on recent attempts to examine the impact of WML on ABMT and provides evidence that high WML disrupts training efficacy. Furthermore, individuals who are highly anxious may be more susceptible to these disruptive effects. These findings join the growing body of literature that aims to maximize the impact of ABMT and identify the individuals for whom attention training is most effective (e.g., Bernstein & Zvielli, 2014; Dennis & O'Toole, 2014; Notebaert, Clarke, Grafton, & MacLeod, 2015).

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*Appendix*

Table 1.

*Demographic and Baseline Measures in the Low and High Working Memory Load Conditions*

| Measure | Low WML | | High WML | | Full sample (*N* = 204) |
|---|---|---|---|---|---|
| | Avoid-Threat (*n* = 48) | Attend-Threat (*n* = 55) | Avoid-Threat (*n* = 53) | Attend-Threat (*n* = 48) | |
| Gender | | | | | |
| Female | 33 | 36 | 40 | 40 | 149 |
| Male | 15 | 19 | 13 | 8 | 55 |
| Age | 19.229 (2.611) | 20.291 (4.126) | 20.057 (3.870) | 20.104 (3.341) | 19.936 (3.562) |
| AB | 3.625 (17.594) | 0.836 (19.842) | 0.566 (24.733) | -0.458 (29.157) | 1.118 (23.067) |
| WMC | 8.688 (2.484) | 8.764 (2.575) | 8.585 (2.240) | 8.667 (2.300) | 8.676 (2.391 |
| STAI | 41.375 (10.076) | 46.000 (11.225) | 44.491 (11.598) | 42.667 (11.869) | 43.735 (11.279) |

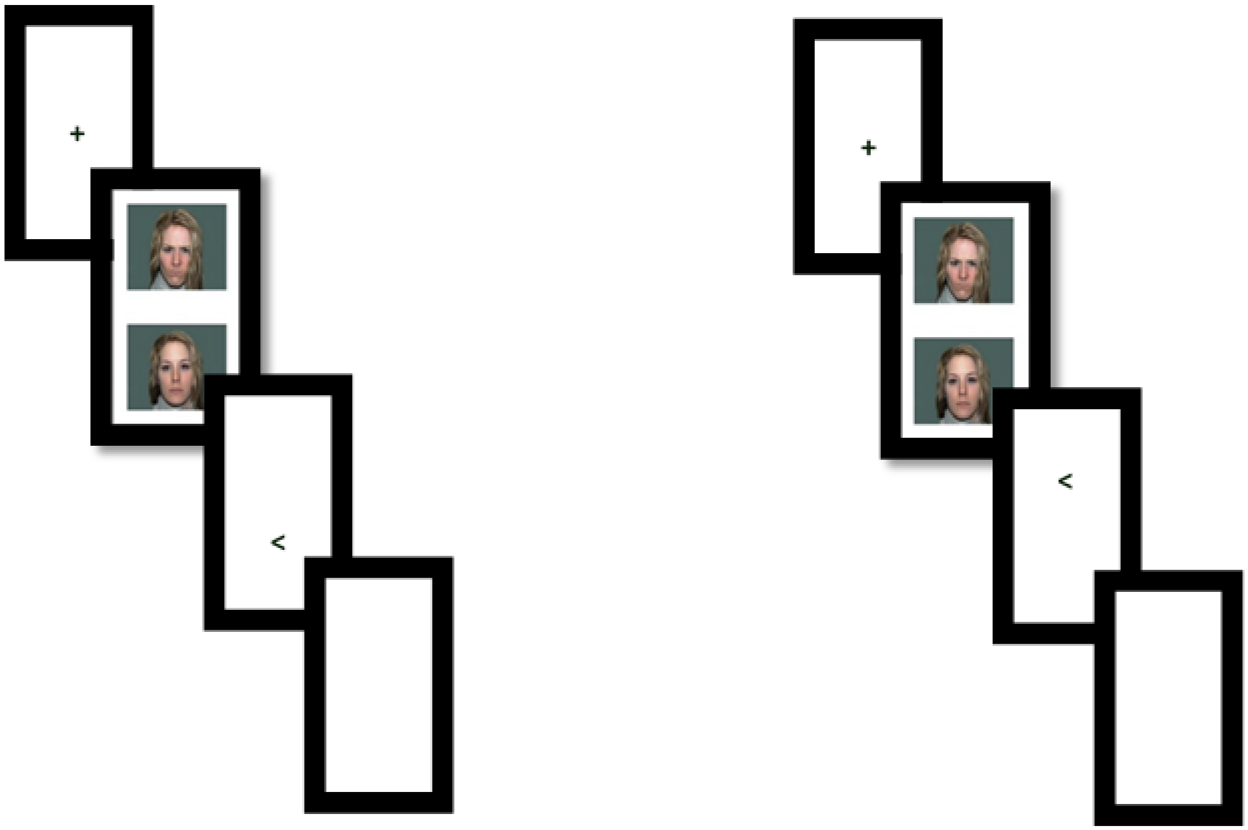
*Note*. AB = Attentional Bias; WML = working memory load; STAI = State Trait Anxiety Index; WMC = working memory capacity; Standard deviations for Age, Attentional Bias, WMC, and STAI are in parentheses.

Table 2.

*Post-Training Bias Assessment Mean Scores from each condition*

| Measure | | | *N* | *M* | *SE* |
|---|---|---|---|---|---|
| Low Anxiety | Low WML | Avoid-Threat | 29 | -6.506 | 3.884 |
| | | Attend-Threat | 23 | 7.476 | 4.363 |
| | High WML | Avoid-Threat | 25 | -1.688 | 4.190 |
| | | Attend-Threat | 27 | -5.99 | 4.025 |
| High Anxiety | Low WML | Avoid-Threat | 19 | 5.952 | 4.796 |
| | | Attend-Threat | 32 | 9.128 | 3.699 |
| | High WML | Avoid-Threat | 28 | 13.087 | 3.969 |
| | | Attend-Threat | 21 | -8.095 | 4.559 |

*Note*. WML = working memory load. Negative means indicate an attention bias away from threat. Positive means indicate an attention bias toward threat. Mean scores were adjusted for covariates (baseline attention bias and working memory capacity) evaluated at their overall sample means.



a. A neutral-cue trial in which the probe follows the neutral face

b. A threat-cue trial in which the probe follows the angry face

Figure 1. Examples of trial types in the dot probe task. Attention bias modification training (ABMT) used the same trial types except the avoid-threat condition saw neutral-cue trials 75% of the time and the attend-threat saw threat-cue trials 75% of the time.

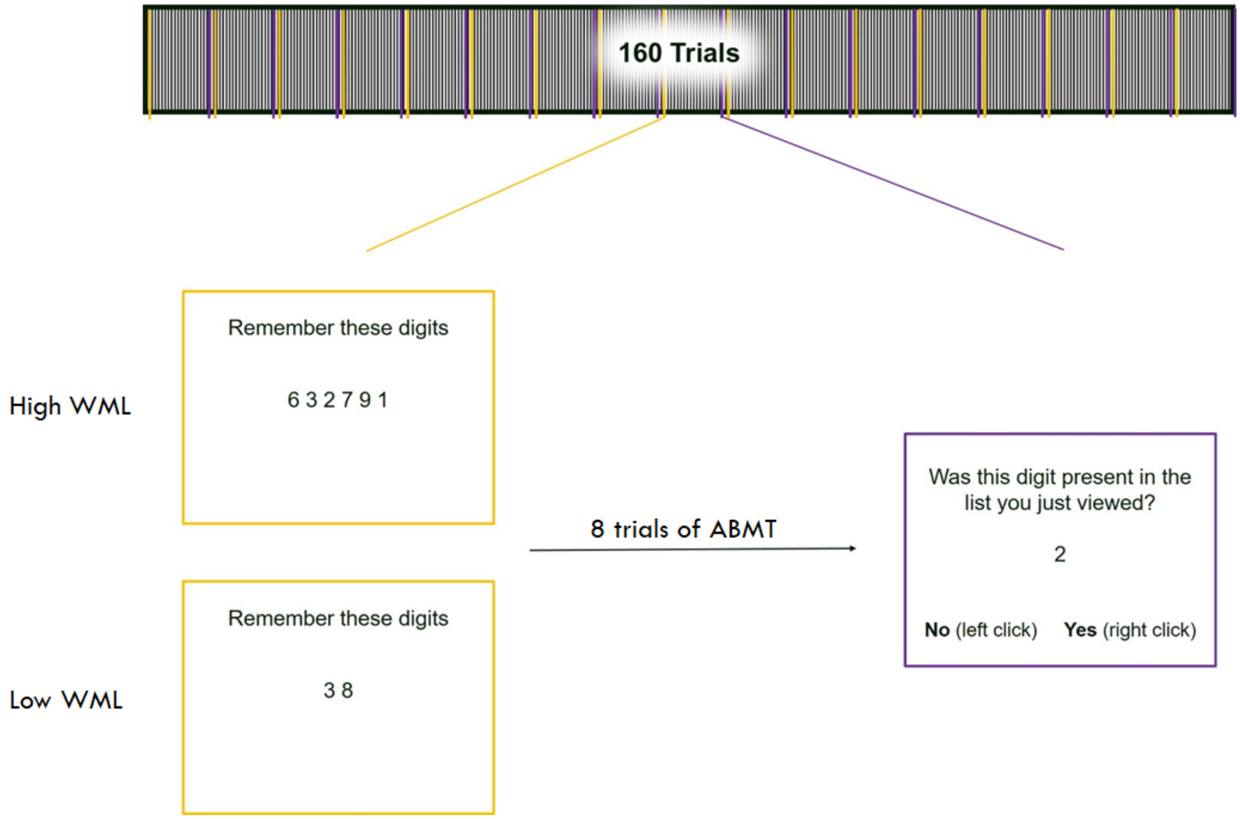



Figure 2. Schematic of a single session of attention bias modification training (ABMT) with examples of digit presentation and recognition trials. Cognition was loaded via a working memory task that interleaved digit string presentations and recognition tests every 8 trials. Participants in the high working memory load condition saw six-digit strings for 2000ms, while those in the low working memory load condition saw two-digit strings for 1000ms. Participants received four consecutive sessions of ABMT.

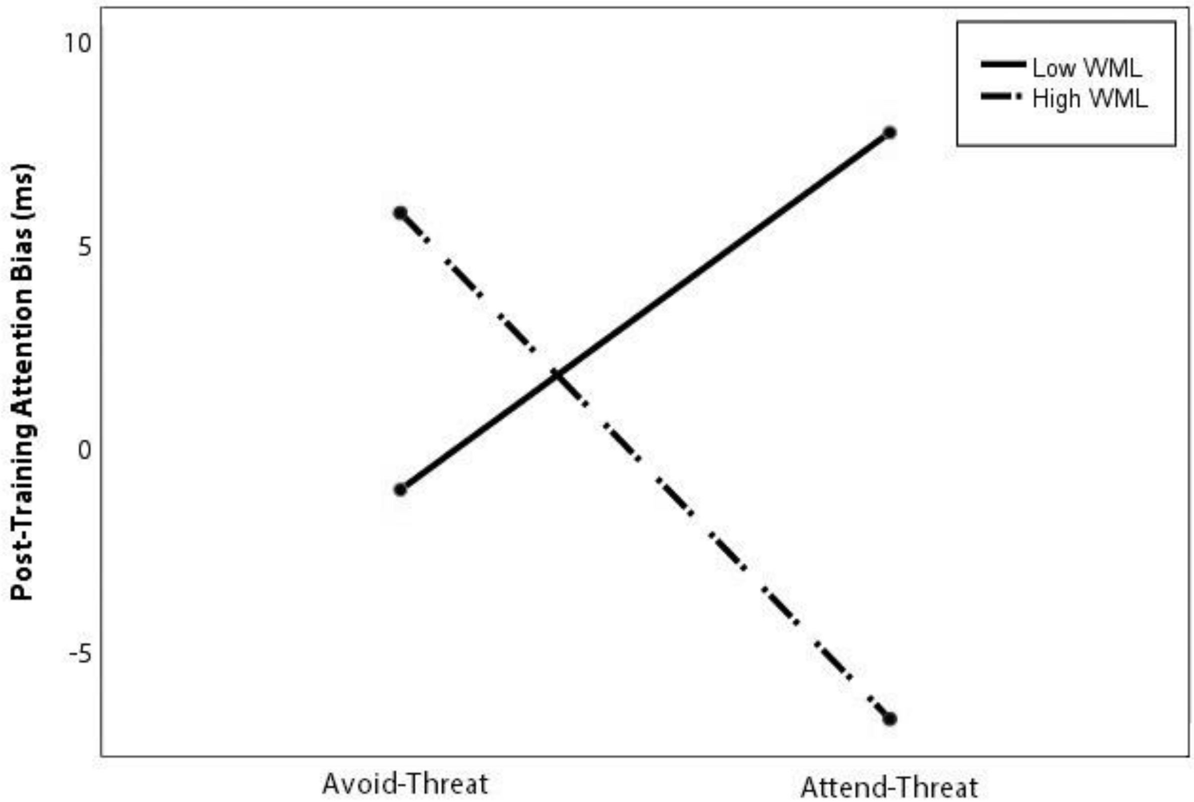



Figure 3. Mean post-training attention bias scores in the high and low working memory load (WML) conditions by Training Type.

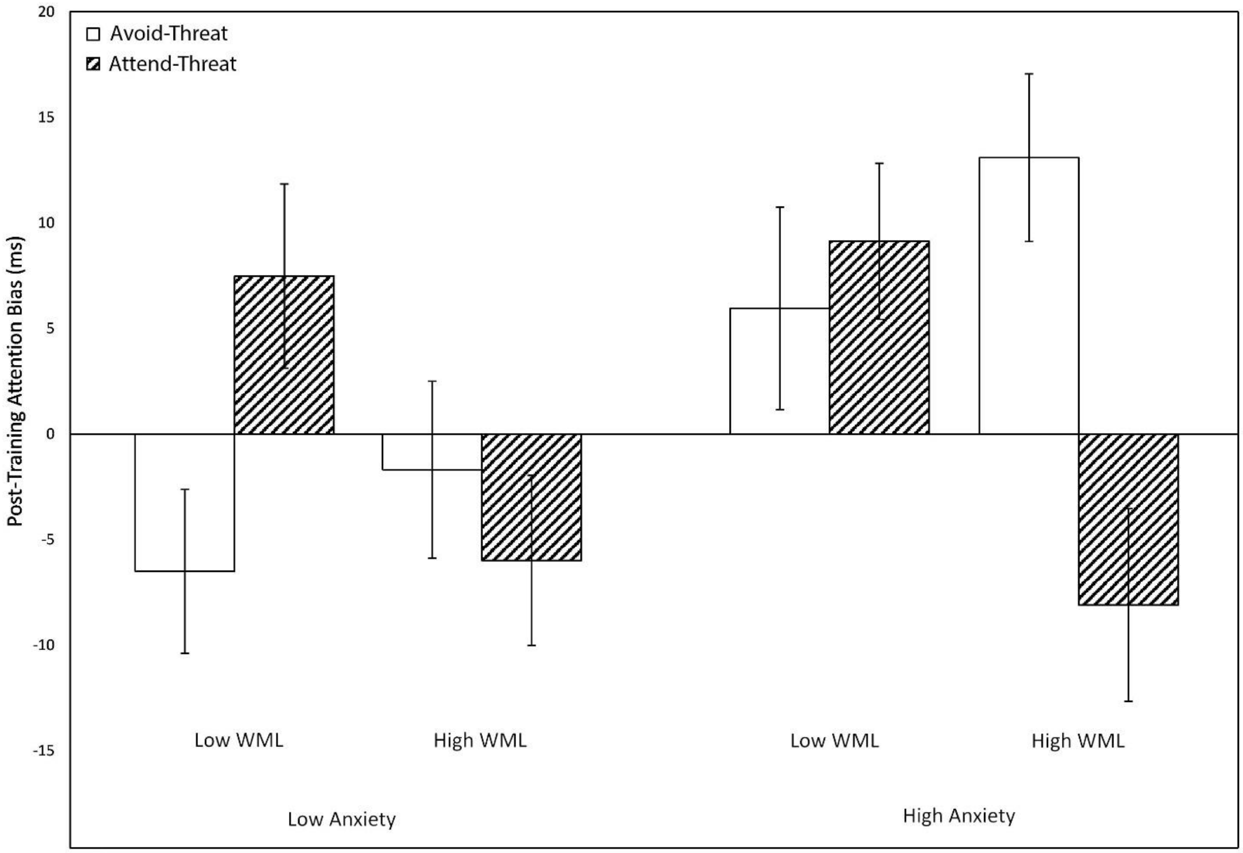



Figure 4. WML = working memory load. Mean post-training attention bias scores were adjusted for baseline attention bias and working memory capacity which were evaluated at their overall means. Scores below zero indicate an attention bias away from threat. Scores greater than zero indicate an attention bias toward threat.