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Attention bias modification training under working memory load increases the magnitude of change in attentional bias

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ABSTRACT

Background and objectives: Attention bias modification (ABM) procedures have shown promise as a therapeutic intervention, however current ABM procedures have proven inconsistent in their ability to reliably achieve the requisite change in attentional bias needed to produce emotional benefits. This highlights the need to better understand the precise task conditions that facilitate the intended change in attention bias in order to realise the therapeutic potential of ABM procedures. Based on the observation that change in attentional bias occurs largely outside conscious awareness, the aim of the current study was to determine if an ABM procedure delivered under conditions likely to preclude explicit awareness of the experimental contingency, via the addition of a working memory load, would contribute to greater change in attentional bias.
Methods: Bias change was assessed among 122 participants in response to one of four ABM tasks given by the two experimental factors of ABM training procedure delivered either with or without working memory load, and training direction of either attend-negative or avoid-negative.
Results: Findings revealed that avoid-negative ABM procedure under working memory load resulted in significantly greater reductions in attentional bias compared to the equivalent no-load condition.
Limitations: The current findings will require replication with clinical samples to determine the utility of the current task for achieving emotional benefits.
Conclusions: These present findings are consistent with the position that the addition of a working memory load may facilitate change in attentional bias in response to an ABM training procedure.

1. Introduction

Attention bias modification (ABM) procedures have shown promise as an intervention for a range of emotional and non-emotional conditions, with the majority of research having focused on the effects of ABM tasks on anxiety (MacLeod & Clarke, 2013). Some research into the potential benefits of ABM has been highly encouraging, with a number of studies demonstrating significant reductions in emotional vulnerability for individuals with anxiety disorders across a range of symptoms (e.g. Amir, Beard, Burns, & Bomyea, 2009; Eldar et al., 2012; Schmidt, Richey, Buckner, & Timpano, 2009). Other, recent findings have been more mixed however, with a number of studies failing to observe benefits of ABM (e.g. Boettcher, Berger, & Renneberg, 2012; Carlbring et al., 2012). Given such inconsistent findings, there has been some confusion regarding the distinction between ABM as a training procedure and ABM as an effect on patterns of attention. In line with recent recommendations (MacLeod & Grafton, 2016), in the following we consistently distinguish between 'ABM training procedures and/or tasks' which are designed to, but may or may not achieve intended changes in biased attention, from the consequent impact of such tasks on change in attentional bias. As such, the term 'ABM training procedure/task' is used in reference to the intended purpose of the task, which is distinct from the degree to which it achieves its intended goal of 'change in attentional bias'.

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In light of these inconsistent findings, there are three distinct issues that are critical when evaluating the clinical relevance of ABM procedures. The first is whether the delivery of an intended ABM procedure contributes to improvements in emotional vulnerability, *regardless* of whether it succeeds in achieving the intended change in attentional bias. This question has been the focus of a number of recent reviews and meta-analyses which have suggested that intended ABM procedures may not reliably contribute to emotional benefits (Cristea, Kok, & Cuijpers, 2015; Cristea, Mogoase, David, & Cuijpers, 2015). The second question concerns whether current ABM tasks are capable of achieving the desired change in attentional bias. The answer to this appears to be 'yes', with the proviso that these tasks are not always successful in achieving the desired change in bias (Mogoaşe, David, & Koster, 2014). The final question, which is crucial to informing whether ABM is worthy of pursuit as an intervention into the future, has been overlooked in recent meta-analyses (Cristea, Kok, et al., 2015; Cristea, Mogoase, et al., 2015). This concerns whether the mechanistic link between change in attentional bias and consequent change in emotional vulnerability is indeed sound. If bias change is a genuine agent of therapeutic action, then studies that achieve changes in attentional bias should also observe concurrent changes in emotional vulnerability, whereas those that fail to change bias should not. In a recent commentary and subsequent systematic review, we showed that such a pattern of effects is overwhelmingly consistent across ABM studies (Clarke, Notebaert, & MacLeod, 2014; MacLeod & Clarke, 2015). Specifically, of the 36 studies reviewed, the overwhelmingly consistent pattern was that successful bias change reliably led to changes in emotional vulnerability, and when bias change did not succeed, emotional benefits were not forthcoming. This consistent pattern clearly suggests that the therapeutic potential of ABM is likely to be best realised by determining the cognitive task conditions that are most conducive to achieving change in attentional bias. In line with this over-arching goal, the specific aim of the current study was to determine if ABM delivered under conditions of working memory load will increase the magnitude of bias change produced by a standard ABM task.

It has commonly been assumed that the contingency used in ABM tasks to encourage bias change is registered without explicit awareness (MacLeod, Koster, & Fox, 2009). This is consistent with the observation that, despite measurable changes in attentional bias, participants largely have no awareness of this contingency (e.g. Amir, Beard, Taylor, et al., 2009; Grafton, Mackintosh, Vujic, & MacLeod, 2014). Interestingly, MacLeod, Rutherford, Campbell, Ebsworthy, and Holker (2002) found that while ABM-induced changes in attentional bias were observed at 500 ms stimulus exposure durations, such bias change was not observed at brief (20 ms) exposure durations. This suggests that while bias change may occur without awareness, it may not immediately result in rapid direction of attention at brief stimulus exposure durations. Therefore, the observation that changes in attentional bias and emotional symptoms can occur in the absence of awareness of task goals and training contingency suggests that bias change can occur outside of conscious awareness.

Of relevance to this, one of the few studies that failed to show a link between successful bias change and changes in emotional vulnerability involved an ABM procedure delivered with explicit contingency awareness. In one experimental condition, Grafton et al. (2014) told participants that probes would consistently replace either the negative or neutral word in each pair (depending on ABM condition allocation), and they should shift their attention towards this stimulus on each trial. Results showed that a standard version of the ABM training task resulted in the expected change in attentional bias and consequent emotional effects, however the instructed version of the task showed no emotional effects despite an observed bias change. Such a finding is consistent with the possibility that explicit contingency awareness may contribute to more fragile bias change, while conditions that discourage explicit processing of the contingency may more effectively contribute to bias change.

Converging evidence for this perspective comes from the implicit learning literature which postulates that conscious, reflective strategies, and efforts to learn, may interfere with the learning of implicit rules (Reber, 1989). This is thought to be because explicit learning is associated with active attempts to remember and strategically apply rules, which will be easily disrupted by changes in context or cognitive processing priorities (Green & Flowers, 2003). Consistent with this, some research has shown that conditions which limit conscious awareness of learned rules via the addition of a secondary task (i.e. working memory load task) may result in superior performance on implicit learning tasks (Hayes & Broadbent, 1988). Thus, if the addition of a working memory load can indeed discourage potential interference that may occur via explicit processing, the addition of a working memory load during ABM could conceivably enhance change in attentional bias.

A recent study by Booth, Mackintosh, Mobini, Oztop, and Nunn (2014) sought to compare bias change under conditions of high and low working memory load. Interestingly, the authors made the reverse prediction to that proposed above. Specifically, they reasoned that because change in attentional bias has been associated with cortical regions related to 'top-down' attentional control, the addition of a working memory load would likely impair top-down control and decrease bias change. They found that evidence of bias change was restricted to a low working memory load condition.

There are, however some limitations with Booth et al. (2014) study that suggest caution in drawing firm conclusions on the basis of this initial finding. Firstly, the study did not compare patterns of bias change under working memory load to a standard ABM task delivered under no-load. Rather, they compared the magnitude of bias change across a high load and a low load condition. As such, the study was unable to determine whether the addition of *any* working memory load produced superior pattern of bias change to a standard ABM task. Furthermore, while Booth et al. delivered ABM under high and low load conditions, they assessed biased attention under no load only. Because an attentional bias may be detected more readily under the same conditions in which it was acquired, it is important to assess bias change under conditions of both load and no-load.

Thus, the aim of the current study was to examine whether ABM task conditions that discourage explicit contingency awareness will contribute to more change in attentional bias as compared to standard ABM training. A secondary aim was to assess whether the degree of bias change observed, will differ across attentional bias assessment tasks that either do, or do not involve a working memory load. To achieve this, we delivered between-subject ABM training under one of four conditions: either towards (attend-negative) or away from (avoid-negative) negative stimuli, under conditions that either did, or did not include a working memory load. The magnitude of change in attentional bias was assessed under conditions of both load and no-load. If task conditions that discourage explicit contingency awareness contribute to greater bias change, then we would expect to observe greater magnitude of change in attentional bias (towards and away from negative information) under task conditions that involve ABM training under load, compared to task conditions that involve ABM training under no-load (i.e. standard ABM).

2. Method

2.1. Participants

Participants were drawn from the University of Western Australia School of Psychology research participant pool. Participant selection was guided by initial screening of 826 undergraduates on the trait version of the Spielberger State Trait Anxiety Inventory (STAI-T; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants were considered eligible for inclusion if their trait anxiety scores fell within the middle tercile of the sample distribution (STAI-T scores 37–45 inclusive). This was designed to decrease the likelihood that participants would have a strong existing attentional bias toward or away from threat. Of those eligible, the first 122 to accept an invitation to participate were included in the study and were randomly assigned to one of the four attention bias modification conditions. Between-subject effects commonly observed in studies implementing alternative ABM training conditions tend to occur within the range of $\eta^2 = 0.06–0.15$ (Clarke, Browning, Hammond, Notebaert, & MacLeod, 2014; Eldar, Ricon, & Bar-Haim, 2008; Grafton, Ang, & Macleod, 2012; Notebaert, Clarke, Grafton, & MacLeod, 2015). As such a sample of 122 participants provides an approximately 87% chance of detecting an effect in the middle of this range ($\eta^2 = 0.10$). The subsequent exclusion of 17 participants (see results) reduced this to approximately 80%. This total sample comprised 40 male and 82 females with a mean age of 19.79 years (SD = 5.33).

3. Materials

3.1. Emotional assessment

To permit potential comparison with other studies that have also examined optimising the modification of attentional bias (e.g. Everaert, Mogoaşe, David, & Koster, 2015; Grafton et al., 2014), anxiety assessment and participant pre-screening was conducted using the trait (screening and assessment) and state (assessment) subscales of the Spielberger State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983). Each subscale consists of 20 items, with higher scores indicating higher levels of state (STAI-S) or trait (STAI-T) anxiety. The STAI has demonstrated validity and reliability across a range of populations, including undergraduates (Barnes, Harp, & Jung, 2002; Spielberger et al., 1983).

3.2. Task stimuli

The current study employed paired negative and non-negative pictures derived from the International Affective Picture System stimulus set (IAPS; Lang, Bradley, & Cuthbert, 1997). Forty-eight stimulus pairs were employed for use in the assessment and training components of the experiment. We included highly negative images - disgust-related content, physical injury, and death (e.g. soiled toilet, wounds, dead bodies) - to ensure a lack of ambiguity in the stimulus valence, and to maximize the likelihood that stimulus valence would register in the presence of a cognitive load. These negative images were paired with neutral images (additional details on stimulus selection is provided in the Appendix).

3.3. Attention bias assessment tasks

Attentional bias was assessed under load and no-load both prior to and immediately following the delivery of the ABM training task. In each of the pre and post-training assessments, one block of 48 assessment trials was delivered under load, and one block of 48 assessment trials was delivered under no-load. The no-load trials followed the standard format of attentional probe assessment tasks whereby each trial began with a fixation cross in the middle of the screen for 500 ms, followed by the simultaneous presentation of two horizontally aligned stimulus images (one negative and one neutral). These images were presented centrally on the Y axis, each occupied a space 60 mm × 75 mm, and were separated by 90 mm. They remained on screen for 500 ms and were replaced by a small probe (the icon '..' or ':') appearing in the location of one of the two stimuli. Participants were required to indicate if the dots were aligned horizontally or vertically by pressing the left or right mouse key respectively. When a correct response was recorded the task progressed to the next trial following a 500 ms inter-trial interval. If an incorrect response was recorded the message 'ERROR − 3s timeout' was presented and a delay of 3 s occurred before the commencement of the next trial.

The load assessment trials were identical in format to the no-load trials with the exception that at the beginning of each set of 8 probe assessment trials, participants were presented with a string of six single digit numbers in the center of the screen for 2000 ms. Participants were instructed that they should actively hold these digits in memory to correctly identify whether a subsequent digit was present/absent in the set. Following 8 trials of the probe task participants were presented with a single target digit and asked to indicate whether this was present in the original string by pressing the 'Y' key if it was present and the 'N' key if it was absent. This target digit was present and absent in the original string on an equal number of occasions. To encourage correct performance of the load task the feedback 'CORRECT' or 'INCORRECT' was given, for 1000 or 5000 ms, respectively. The next string of 6 digits was presented after an inter-trial interval of 500 ms, and this was then followed by the next 8 probe assessment trials. Across all assessment trials probes appeared in the location of the negative and non-negative stimulus image with equal frequency. The order of delivery of the load and no-load assessment trials in the pre and post-training assessments was counter-balanced across participants. Across all trial types the type of probe ('..' or ':'), probe position (left/right), and negative stimulus position (left/right) was counter-balanced.

3.4. Attention bias modification tasks

Both the load and the no-load ABM tasks followed the same format as the assessment versions of these tasks with the exception that probe position was fixed in relation to the assigned training task direction condition. In line with other recent studies in which participants have shown no awareness of a 100% training contingency (Grafton et al., 2014; Milkins, Notebaert, MacLeod, & Clarke, 2016), we adopted the same 100% contingency in both conditions. Thus, for those in the attend-negative training condition, probes consistently replaced the negative member of the stimulus pair while for those in the avoid-negative training condition, probes consistently replaced the non-negative member of the stimulus pair. Participants completed 384 training trials in total involving 16 repetitions of the 24 stimulus pairs. Training trials were delivered within randomized blocks of 96 trials, with each stimulus pair being delivered four times, once in each combination of image position (left/right) and probe position (left/right) before subsequent repetition. In addition to the 384 probe task trials, those in the load condition therefore completed 48 repetitions of the working memory load task across these training trials.

3.5. Procedure

Allocation to experimental conditions occurred prior to participant arrival and was random within the constraint that an equal proportion of participants were allocated to each condition. This was achieved by randomly pre-allocating participant numbers (sorted according to excel random number generation) to one of the four experimental conditions. Participants were then allocated participant numbers based on their sequential participation in the study. The current study was approved by the Human Research Ethics Committee of the University of Western Australia (protocol number RA415243) with all participants viewing an approved information sheet and providing informed consent prior to beginning the study. Participants were seated approximately 60 cm from the computer screen. Participants then answered demographic questions, and completed the STAI-S and STAI-T. The experimenter initially provided detailed verbal instructions on the requirements of both the attentional probe task and the running of the working memory component of the task. Participants were then given 16 practice trials of the load version of the probe task, and 16 practice trials of the no-load versions of the probe task, with neutral novel stimuli. Participants then completed the pre-ABM attentional bias assessment tasks the ABM task and the post-ABM assessment tasks, with a repetition of the instructions before each task. Questionnaires measures and all experimental tasks were delivered on a PC with a high resolution 20.5 inch monitor using E-Prime software (Version 2.0, Psychology Software Tools, Pittsburgh, PA, USA).

4. Results

4.1. Data preparation

One participant failed to record data for the post-assessment and was excluded from the dataset. Accuracy across all participants was high on average for probe discrimination ($M = 94.42\%$, $SD = 3.60\%$) and was also generally high in the working memory load task ($M = 89.76\%$, $SD = 12.25\%$). To be eligible for inclusion participants must have scored above 80% accuracy on probe discrimination on each assessment and training task. Three participants fell outside this cutoff and were excluded. As the working memory load task was deliberately designed to be more taxing, an inclusion criterion indicative of correct responses on at least two thirds of the trials (i.e. at or above 67%) during each load component was adopted. Employing this criterion, an additional 7 participants were excluded.

Probe reaction time data was prepared by first excluding incorrect responses, and reaction times shorter than 200 ms and longer than 2000 ms. Reaction times outside three standard deviations from each participant's own mean for each trial type (probe negative or probe non-negative) were also removed. Four separate indices of attentional bias were initially computed for each participant to correspond with the load and no-load assessment tasks at both the pre and post-training assessment points. These were computed by subtracting reaction times to probes appearing in the vicinity of negative images from reactions times to probes appearing in the vicinity of neutral images. Higher scores on this index therefore represent greater attentional bias favoring negative over neutral stimuli. Examination of standardized scores for each bias index revealed a number of extreme scores which fell more than 3 SD from the overall group mean. Six further participants were excluded on the basis of recording outlying bias index scores.[1] The final sample therefore comprised 105 participants. Experimental groups did not systematically differ according to state anxiety, trait anxiety, or age at the time of testing (all $p > 0.13$). Table 1 provides descriptive data on these variables across each of the experimental conditions. Descriptive data on attentional bias index scores for participants in each experimental condition are presented in Table 2. There were no differences between experimental conditions on attentional bias prior to training (largest $F = 2.87$, smallest $p = 0.093$) and no interactive effects across ABM training direction and training load conditions (largest $F = 1.23$, smallest $p = 0.269$).

To address the primary hypothesis, we further computed indices of change in attentional bias in response to the ABM training task. This was achieved by subtracting pre-training attention bias index scores from post-training attention bias index scores to yield an overall index of attention bias change for both the load and no-load assessment tasks. A larger positive value of this change score represents greater change in attentional bias toward negative stimuli from pre to post-training.

4.2. Comparing the magnitude of attentional bias change under load vs. no-load training conditions

Bias change scores were subjected to a 2 × 2 × 2 ANOVA with load training condition (load vs. no-load) and ABM training direction (attend vs. avoid-negative) as between subject factors, and load assessment type (load vs no-load assessment) as the repeated measures factor. Consistent with the hypothesis that working memory load exerts an impact on attention bias acquisition, a two-way interaction between load training condition and ABM training direction was observed, $F(1, 101) = 6.33$, $p = 0.013$, $\eta_p^2 = 0.059$. This was not further modified by load assessment type ($F < 1$), indicating that the conditions under which attentional bias was assessed did not differ across experimental conditions. The only other significant effect to emerge from this analysis was a main effect of load assessment type, $F(1, 101) = 44.50$, $p < 0.001$, $\eta_p^2 = 0.306$, such that the probe assessment task involving load registered a greater overall decrease in attentional bias ($M = -94.71$, $SD = 73.71$) compared to the assessment task involving no-load ($M = 0.43$, $SD = 122.81$).

The interaction between load training condition and ABM training direction is depicted in Fig. 2. In examining the component effects that comprise this 2-way interaction, overall there was no evidence of a significant effect of training direction in the no-load condition $F(1, 53) < 1$. In the load condition however, there was a significant effect of training direction $F(1, 51) = 9.39$, $p = 0.004$, $\eta_p^2 = 0.164$. Furthermore, those in the avoid-negative ABM condition delivered under load showed a significantly greater change in attentional bias away from threat as compared to those in the avoid-negative ABM condition delivered under no-load $F(1, 53) = 7.07$, $p = 0.010$, $\eta_p^2 = 0.118$. However, those in the load and no-load attend-negative conditions did not differ in terms of degree of bias change $F(1, 48) < 1$. Thus the interaction depicted in Fig. 1 appears to be primarily driven by the greater change in attentional bias away from threat in the avoid-negative load condition.

Also evident from Fig. 1, participants generally appeared to reduce their attentional bias for negative stimuli across all conditions. Indeed average bias change was negative overall ($M = -51.30$, $SD = 67.39$) and differed significantly from zero, $t(104) = -7.80$, $p < 0.001$. Thus, the effect of training direction in the load condition can be re-examined when correcting for this general effect of bias reduction. We subtracted the value of this general bias-reduction effect (−51.30) from the mean bias change index scores for both training direction conditions in the load condition. As can be seen by the pattern of effects observed in Fig. 2, when controlling for this general effect, those in the attend negative ABM load condition showed a comparative increase in attention to threat while those in the avoid negative ABM load condition showed a comparative

[1] Neither the direction not the significance of any effects reported were affected by the inclusion or exclusion of these participants' data.

Table 1
Participant gender ratios, mean age and STAI-T, and STAI-S across experimental groups. Standard deviations given in parentheses.

Experimental condition	N	Gender F/M	Age (years)	STAI-T	STAI-S
Training Under Load					
Attend-negative	22	14/8	20.41 (7.78)	42.18 (5.02)	34.18 (8.22)
Avoid-negative	28	18/10	18.57 (1.20)	40.29 (6.79)	32.64 (5.57)
Training Under No-Load					
Attend-negative	28	20/8	19.75 (4.03)	40.79 (7.54)	34.57 (9.07)
Avoid-negative	27	20/7	18.93 (2.83)	39.89 (5.60)	35.89 (9.83)

Table 2
Mean attentional bias index scores at pre and post-attentional bias modification training assessment points, for load and no-load assessment conditions, across both experimental load conditions (load and no-load) and ABM conditions (attend-negative and avoid-negative). Standard deviations given in parentheses.

ABM training condition	Pre-Training Assessment		Post-training assessment	
	No-Load	Load	No-Load	Load
Training Under Load				
Attend-negative	−14.00 (44.87)	−5.74 (50.08)	−11.43 (49.10)	−73.35 (121.40)
Avoid-negative	18.27 (50.59)	4.26 (59.63)	−8.99 (47.00)	−137.90 (89.08)
Training Under No-Load				
Attend-negative	6.03 (56.78)	−19.68 (54.08)	3.14 (43.59)	−112.10 (87.90)
Avoid-negative	−16.76 (43.72)	11.92 (57.54)	−0.96 (45.40)	−71.06 (141.74)

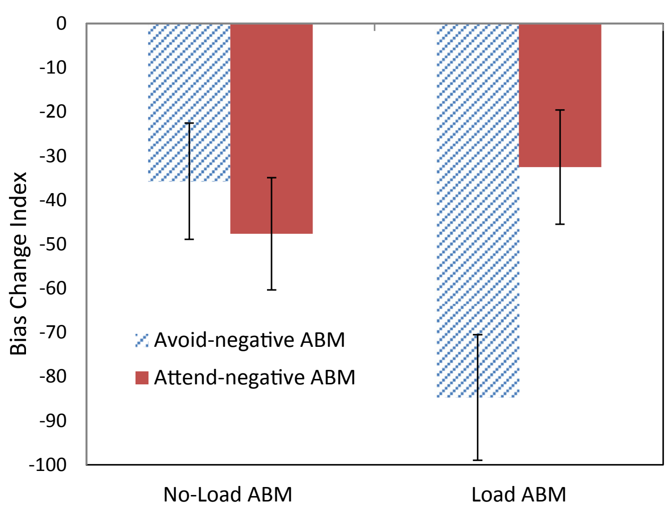

Fig. 1. Degree of change in attentional bias across the load and no-load ABM conditions, and for the attend-negative and avoid-negative training direction conditions. More negative values represent a greater reduction in attentional bias from the pre-training to the post-training assessment.

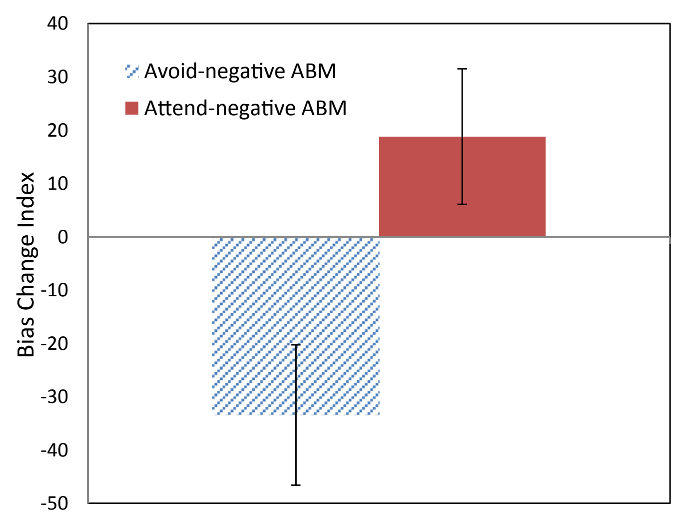

Fig. 2. Degree of change in attentional bias for the ABM load condition when correcting for the effect of general reduction in bias across the attend-negative and avoid-negative training direction conditions. More negative values represent a greater reduction in attentional bias from the pre-training to the post-training assessment.

decrease in biased attention to threat.

5. Discussion

The aim of the current study was to examine whether attention bias modification training delivered under working memory load would produce greater change in attentional bias as compared to standard ABM probe task training delivered in the absence of a working memory load. Our results provide partial support for this hypothesis, with findings demonstrating that there was significantly more reduction in attentional bias in response to the avoid-negative ABM training under load than under no load, while there was no observed difference between the two load conditions in the magnitude of change in attentional bias for those who received the attend-negative ABM training. Furthermore, we found no evidence to suggest that bias change was registered differentially when assessed with or without load.

Interestingly, evidence of successful bias change in the current study was restricted to the condition involving working memory load, with no evidence of change in attentional bias in the traditional ABM probe task. While ideally we would have been able to replicate the original effect to then demonstrate the superiority of ABM under load in achieving attentional change, a number of recent studies have also failed to achieve the intended change in attentional bias using the traditional ABM probe task. For example, Clarke, Browning, et al. (2014), found evidence for bias change when an ABM probe task was combined with transcranial direct current stimulation, but no evidence of bias change in the standard version of this task. Similarly, Notebaert et al. (2015) showed that a 'gamified' version of an ABM task successfully modified attentional bias, but observed no evidence of bias change with the standard ABM task. Finally, in three separate studies Everaert et al. (2015) failed to achieve a change in biased attention using a probe-based ABM task. As such, the increasing number of failures to achieve the intended change in attentional bias using variants of the original ABM probe task clearly highlight the need to identify the precise task conditions that may be most conducive to achieving change in attentional bias. The results of the current study have highlighted one potential avenue to achieving this, though others that have been identified include increasing how engaging ABM tasks are, finding optimal stimuli for individuals, and identifying those specific individuals most likely to benefit (MacLeod & Clarke, 2015).

An interesting additional feature of the current results was the observation that overall, participants all reduced their attentional bias for negative stimuli. In considering the potential reasons for this, one possibility was the strongly negative valence of the images employed as negative stimuli in the current study. It is possible that repeated exposure to these highly negative IAPS images could have contributed to increased attentional avoidance of these stimuli, regardless of the training condition. While the pattern of bias reduction in the load condition clearly supported the efficacy of training in this condition, there was no evidence that the intended bias change was achieved in the standard ABM task. It is possible therefore, that the intensity of these negative stimuli could have overridden any more subtle ABM effects that may otherwise have been achieved with this standard task. As such it will be crucial for future research to replicate the current findings using negative stimuli with more moderate intensity to confirm that the addition of a cognitive load does in fact enhance bias change above and beyond standard ABM procedures.

Interestingly the results of the current study stand in contrast to findings of Booth, Standage, and Fox (2015) who found no evidence of bias change under high working memory load. It is important therefore to consider methodological differences between these studies that could potentially account for such discrepant findings. One potentially crucial difference concerns the task stimuli employed. While Booth et al. employed negative and neutral word stimuli in the attentional probe assessment and training tasks, our study employed pictorial stimuli. Past research (Cowan & Morey, 2007) has shown that the ability to encode stimuli belonging to one information processing domain (e.g. verbal) can be compromised when information belonging to that same stimulus domain is held in current working memory. This highlights the possibility that in Booth et al.'s study, holding the verbal information of the digit string in working memory could have reduced participants' ability to encode the emotional valence of word stimuli, and so interfered with the registration of the training contingency. In the current study however, the lack of overlap in the information processing domains of the working memory task and the probe stimuli (verbal and visual respectively) may have still permitted detection of the emotional content, allowing registration of the training contingency. This could also suggest that the absence of bias change in Booth et al.'s high load condition could have been due to disruption of stimulus encoding. This obviously remains speculative as neither the current study nor Booth et al.'s study (2014) sought to compare the ability to detect the emotional content of stimuli under load/no load. Nevertheless, it may be very important for future research to consider the match/mismatch of information employed in the working memory task and ABM task stimuli to still permit registration of the emotional content.

A limitation of both the current study and also of Booth et al. (2014) is that neither sought to determine the degree to which the observed bias change contributed to consequent changes in emotional vulnerability. It is possible to consider the relative likelihood of the observed change in bias translating into emotional benefits given past findings regarding the consistency of the relationship between bias change and its consequent impact on emotional vulnerability. Given that one of the few exceptions to this relationship was observed when ABM was delivered under conditions of explicit contingency awareness (Grafton et al., 2014), and that the current ABM load task was explicitly designed to discourage awareness of the contingency, there may be reason for cautious optimism that such bias change will lead to reductions in emotional vulnerability. However, this obviously remains to be confirmed by future research via the inclusion of a stress task.

It is relevant to also consider the current research findings in light of evidence linking change in attention bias and attention control. A study by Chen, Clarke, Watson, MacLeod, and Guastella (2015) found that successful change in attention bias led to improvement in inhibitory attention control. Another study revealed that a neurostimulation procedure associated with improved attention control delivered in combination with a standard ABM probe task led to greater evidence of change in attentional bias (Clarke, Browning, et al., 2014). In considering how attention control could potentially have been involved in the current findings, it is apparent that the traditional ABM task requires very little attention control to successfully complete, while the task delivered under cognitive load places much greater demand on working memory. As such, it is possible that the recruitment of greater working memory resources in the load condition may have elicited (and potentially enhanced) attention control, and this contributed to greater sensitivity to the ABM contingency. Future research could thus potentially examine whether improvements in attention control from pre-to post training may account for the magnitude of bias change observed.

In summary, the current study provides initial evidence that attention bias modification delivered under working memory load may produce more significant bias change as compared to ABM delivered in the absence of load. These findings make a contribution to the over-arching goal of identifying the optimal task conditions to achieve change in attentional bias and ultimately realising the therapeutic potential of ABM.

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Appendix. Details of stimulus selection

Images were selected based on their original affective valence ratings on a nine-point scale assessing image 'pleasantness' with scores ranging from 1 (highly unpleasant) to 9 (highly pleasant). Negative images were selected on the basis of being consistently rated as highly unpleasant, with an overall mean affective valence score of 2.10 ($SD = 1.43$). These negative images were paired with neutral images selected on the basis of having been consistently rated as neutral, with scores clustering around 5 ($M = 5.03$, $SD = 1.26$). The 48 image pairs were divided into two subsets (Set A and Set B). One subset was used in the pre-training assessment and attentional training components of the study, while the other subset was used in the post-training assessment tasks to ensure that any observed change in selective attention was not stimulus-specific. Allocation of these two subsets was counterbalanced across participants.

IAPS codes for the negative stimuli included the following items: 2345.1; 2375.1; 2800; 3001; 3110; 3150; 3150; 6350; 6560; 6563; 6022; 9043; 9300; 9320; 9326; 9414; 9611; 9901; 9904;

9921; 2352.2; 9301; 9325; 2900; 2730; 3103; 3140; 3550.1; 6021; 9940; 9910; 9902; 6243; 9040; 9075; 9400; 9810; 9810; 9800; 9635.1; 9500; 9560; 9570; 9254; 3301; 3181; 9252; 3500; 3530.

IAPS codes for the neutral stimuli included the following items: 7004; 7000; 2190; 2211; 2214; 2200; 2411; 2880; 5534; 5535; 6150; 7017; 7090; 7077; 7100; 7170; 7175; 7161; 9070; 7187; 7233; 7547; 7640; 7632; 7497; 7032; 7235; 7038; 7179; 7041; 7484; 7034; 7002; 8475; 2514; 2377; 1675; 1675; 2026; 1350; 2487; 2850; 5471; 7217; 7491; 2102; 2393; 7130; 2397.

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