Attentional control predicts change in bias in response to attentional bias modification.

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Abstract

Procedures that effectively modify attentional bias to negative information have been examined for their potential to be a source of therapeutic change in emotional vulnerability. However, the degree to which these procedures modify attentional bias is subject to individual differences. This generates the need to understand the mechanisms that influence attentional bias change across individuals. The present study investigated the association between individual differences in attentional control and individual differences in the magnitude of bias change evoked by an attentional bias modification procedure. The findings demonstrate that individual differences in two facets of attentional control, control of attentional inhibition and control of attentional selectivity, were positively associated with individual differences in the magnitude of attentional bias change. The present findings inform upon the cognitive mechanisms underpinning change in attentional bias, and identify a target cognitive process for research seeking to enhance the therapeutic effectiveness of attentional bias modification procedures.

Introduction

Cognitive models of anxiety vulnerability implicate a bias in attentional processing that favours the processing of negative information as a key factor in the aetiology and maintenance of heightened anxiety vulnerability (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Mathews & Mackintosh, 1998; Mogg & Bradley, 1998). This attentional bias is assessed via procedures that attempt to measure the distribution of attentional deployment to stimuli that vary in emotional tone. The most common means of assessment is the attentional-probe task (MacLeod, Mathews, & Tata, 1986). In this task, individuals are briefly presented with pairs of emotionally discrepant stimuli, often words. One stimulus depicts emotionally negative material (e.g. "kill") while the other depicts neutral material (e.g. "chair"). After presentation of the stimulus pair, participants must discriminate the identity of a probe that appears in a location previously occupied by one of the stimuli. Attentional bias to negative information is revealed by relative speeding to discriminate probes presented in the location of emotionally negative information, as compared to emotionally neutral information. Using this task, MacLeod, Mathews, and Tata (1986) affirmed earlier research demonstrating anxious individuals displayed heightened attentional bias to negative information as compared to non-anxious individuals. The association between heightened anxiety vulnerability and heightened attentional bias to negative information has since been firmly established (Bar-Haim et al., 2007).

Discovery of the association between anxiety vulnerability and attentional bias to negative information has led researchers to investigate the causal nature of this relationship. By manipulating attentional bias to negative information directly, researchers have demonstrated that this bias can causally contribute to anxiety vulnerability. For example, MacLeod et al. (2002) employed a modified attentional-probe procedure designed

to increase, or decrease, participants' attentional bias to negative information through the implementation of a contingency. Specifically, in order to encourage the adoption of an attentional bias towards negative information, probes always appeared in the location previously occupied by emotionally negative stimuli. Conversely, in order to encourage the adoption of an attentional bias away from negative information, probes always appeared in the location opposite the emotionally negative stimuli (i.e. in the location of the emotionally neutral stimuli). MacLeod et al. (2002) observed that the implementation of these contingencies effectively manipulated attentional bias to negative information in the intended direction, and changes in attentional bias to negative information were associated with corresponding changes in anxiety vulnerability.

It has since been demonstrated that procedures designed to attenuate attentional bias to negative information hold potential value as a treatment for anxiety symptomatology (Linetzky, Pergamin-Hight, Pine, & Bar-Haim, 2015). For instance, Schmidt, Richey, and Buckner (2009) investigated the impact of an attentional bias modification procedure on patients diagnosed with generalised social anxiety disorder. As predicted, patients who completed a training procedure involving a contingency designed to facilitate an attentional bias away from negative information exhibited significantly greater reductions in social anxiety compared to patients who received a control procedure. In another example, Amir et al. (2009) demonstrated that completion of a multi-session programme attentional bias modification procedures, but not completion of a placebo control programme, was able to effectively reduce symptoms of generalised anxiety amongst individuals meeting diagnostic criteria for generalised anxiety disorder.

Crucially however, while early studies examining the potential value of attentional bias modification procedures demonstrated evidence supporting their therapeutic potential

(Hakamata et al., 2010), in more recent years a number of meta-analytic studies have failed to demonstrate commensurate effects (Cristea, Kok, & Cuijpers, 2015; Heeren, Mogoşe, Philippot, & McNally, 2015; Mogoşe, David, & Koster, 2014). These mixed findings have led theorists to correctly note that attentional bias modification procedures do not yet demonstrate sufficient efficacy to serve as a formal treatment for emotional dysfunction, and that greater research is needed prior to their adoption in this way.

With the aim of further understanding the circumstances under which attentional bias modification procedures successfully lead to therapeutic benefits, researchers have highlighted the distinction between the process of attentional bias change and the ability of attentional bias modification procedures to successfully evoke this process. For example, in a recent review of the literature MacLeod and Clarke (2015) demonstrated that when the completion of an attentional bias modification procedure successfully evoked change in attentional bias (i.e., the process), then a consistent and reliable change in social anxiety symptoms was also observed. In contrast, when the procedures had failed to evoke this process, then change in symptoms was absent. Additionally, researchers have identified that the degree of symptom reduction that arises from the completion of an attentional bias modification procedure is associated with the degree of bias change that resulted from the modification procedure (Kuckertz & Amir, 2015; Price et al., 2016).

This has led some theorists to propose that recent failures of some meta-analyses to demonstrate a therapeutic effect of attentional bias modification, are likely due to the unreliability of attentional bias procedures in evoking the process of attentional bias change (Clarke, Notebaert, & Macleod, 2014; Macleod & Clarke, 2015; MacLeod & Grafton, 2016). Hence, in order for attentional bias modification procedures to be maximally effective in their capacity to serve as therapeutic tools, it is critically important that research identifies

the mechanisms that influence the degree to which the process of attentional bias change is evoked by attentional bias modification procedures.

Some researchers have sought to shed light on these mechanisms by examining genetic markers that may be associated with individual differences in magnitude of change in attentional bias in response to a bias modification procedure. Specifically, Fox et al. (2011) compared change in attentional bias in response to a modification procedure designed to induce a bias toward negative information, or induce a bias away from negative information, across individuals with alternate forms of the serotonin transporter gene (5-HTTLPR). Comparison of these groups revealed that individuals with a low-expression form of the gene demonstrated greater change in attentional bias, relative to those with the high-expression form of the gene. Importantly, this effect was consistent regardless of the direction in which the modification procedure altered attentional bias, leading the authors to propose that this genetic mechanism may underpin variation in generalised malleability of attentional responding to environmental contingencies, rather than the capacity to adopt bias in a single direction.

While such studies are informative for understanding biological factors that influence individual differences in the magnitude of attentional bias change evoked by bias modification procedures, research has yet to investigate cognitive mechanisms that may also influence such variability. This has important clinical implications, as identifying such mechanisms could reveal targets for cognitive interventions seeking to improve the effectiveness of attentional bias modification procedures. Hence, the investigation of cognitive mechanisms represents an important avenue for research.

One candidate cognitive mechanism is attentional control, reflecting the capacity to execute goal-directed attentional deployment. A large scope of research has suggested that

heightened anxiety vulnerability is associated with a reduced capacity to exert attentional control effectively (Berggren & Derakshan, 2013). Theoretical accounts of the relationship between attentional control and anxiety vulnerability have espoused the theoretical importance of investigating the association between attentional control and other cognitive processes associated with anxiety vulnerability (Eysenck, Derakshan, Santos, & Calvo, 2007). Hence, the importance of investigating attentional control is not only derived from practical concerns but also holds strong theoretical relevance by expanding understanding of the associations between cognitive processes that underpin anxiety vulnerability.

Chen et al. (2014) observed that individuals who completed an attentional bias modification procedure subsequently demonstrated heightened performance on inhibitory attentional control measures, as compared to individuals who received no attentional modification procedure. Additionally, some researchers have suggested that heightened attentional control may enhance the process of bias change evoked in response to attentional bias modification procedures. Clarke et al. (2014) induced stimulation of the dorsolateral prefrontal cortex (DLPFC) via transcranial direct current stimulation (tDCS) while participants completed an attentional bias modification procedure. The DLPFC is a cortical region believed to be involved in the regulation of attentional control (Miller & Cohen, 2001; Ochsner, Silvers, & Buhle, 2012). The investigators observed that participants receiving active stimulation, as compared to a sham stimulation procedure, showed enhanced acquisition of attentional bias in the targeted training direction. Crucially however, while these findings support the hypothesis that increased attentional control may contribute to bias change, this study did not examine the impact of tDCS stimulation on attentional control, and then therefore not rule out that the effects were driven by the impact of tDCS on some other cognitive construct. Therefore, a complementary approach to

examining this hypothesis involves the assessment of attentional control and its contribution to bias change.

Importantly, if individual differences in attentional control processes do influence the efficacy of attentional bias modification procedures, then this would suggest that anxiety-linked impairment in attentional control may inhibit the efficacy of current bias modification procedures in achieving change in attentional bias and anxiety vulnerability, and would highlight the amelioration of anxiety-linked impairment in attentional control would therefore sit as a key objective for procedures seeking to enhance the efficacy of bias modification procedures in decreasing anxiety vulnerability. This possibility further reinforces the importance of understanding the effect of attentional control on the process of attentional bias change.

Researchers have identified a number of different attentional processes that underpin attentional control, including processes that function to inhibit attentional deployment to goal-irrelevant stimuli (Friedman & Miyake, 2004; Smith & Jonides, 1999), and processes that function to selectively direct attentional deployment towards goal-relevant stimuli (Hopfinger, Buonocore, & Mangun, 2000; Lavie, Hirst, de Fockert, & Viding, 2004; Smith & Jonides, 1999). Importantly, the effective adoption of a bias consistent with the contingency presented during an attentional bias modification procedure requires both successful inhibition of attention to a contingency-irrelevant stimulus, as well as selective attentional deployment towards a contingency-relevant stimulus. Hence, it is plausible that variation in each of the aforementioned facets of attentional control could positively predict variability in the degree of bias change evoked by an attentional bias modification procedure. More specifically, individual differences in the capacity to inhibit attentional deployment to goal-irrelevant stimuli could positively predict the degree to which individuals are able to inhibit

attentional movements that are inconsistent with the attentional contingency (e.g. inhibit attentional deployment to negative stimuli in an attentional bias modification procedure design to encourage avoidance of negative information). Additionally, individual differences in the capacity to selectively direct attentional deployment towards goal-relevant stimuli could positively predict the degree to which individuals are able to selectively orient attention towards stimuli in a manner consistent with the attentional contingency (e.g. orient towards negative stimuli in an attentional bias modification procedure designed to encourage vigilance towards negative information).

In the light of this, the aim of the present study was to investigate the association between individual differences in attentional control and individual differences in the magnitude of bias change elicited in response to an attentional bias modification procedure. Individual differences in the magnitude of change in attentional bias were measured using an attentional-probe methodology similar to MacLeod et al. (2002). This task assessed attentional bias prior to, and subsequent to, exposure to a contingency designed to encourage a change in attentional bias. In keeping with previous methodologies used to investigate mechanisms underpinning attentional bias change (e.g. Fox et al., 2011) this present study examined this association under alternate contingency conditions, each designed to either encourage the adoption of heightened attentional bias towards negative information, or encourage the adoption of heightened attentional bias away from negative information. Though existing research is silent on whether the relationship between attentional control and change in attentional bias will differ under alternative training conditions, the inclusion of both training conditions in the present study will allow us to determine if this is the case.

Individual differences in attentional control were also measured using an attentional-probe methodology. It was considered plausible that change in attentional bias evoked by an attentional bias modification procedure could be associated with individual differences in either (or both) the capacity to inhibit attentional deployment to goal-irrelevant stimuli, or individual differences in the capacity to selectively direct attention towards goal-relevant stimuli. Hence, the present study incorporated measures of both these facets of attentional control. The measure of control of attentional inhibition adopted a probe-based assessment methodology, similar in design to an anti-saccade paradigm. The anti-saccade paradigm is a validated and frequently employed paradigm used to assess control of attentional inhibition. This paradigm has been employed to investigate the relationship between attentional inhibition and other cognitive processes independent of anxiety (Miyake et al., 2000; Roberts, Hager, & Heron, 1994), as well as in examining putative anxiety-linked impairments in cognitive processing (Ansari, Derakshan, 2010; Derakshan et al., 2009). The measure of control of attentional selectivity in the current study was an adaptation of a probe-based methodology commonly used to assess selective attention amongst competing stimuli (MacLeod et al., 1986). This task was adapted in a manner that permitted assessment of the ability of participants to control selective allocation of attention.

The hypothesis under scrutiny in the current study was that individual differences in the capacity to inhibit attention to goal irrelevant stimuli, and individual differences in the capacity to selectively direct attention towards goal relevant stimuli, would positively predict individual differences in the magnitude of change in attentional bias to negative information elicited by an attentional bias modification procedure. If this hypothesis is correct, it would be expected that individuals who demonstrated greater performance on

either, or both, measures of attentional control will also demonstrate greater magnitude of change in the directed targeted by the attentional bias modification procedure.

Method

Participants

Ethical approval for the project was granted by the University of Western Australia Human Research Ethics Committee. Participants were local community volunteers recruited via advertising through the University of Western Australia. Participants received no compensation for their participation. Recruitment occurred over a two-week period. The recruited sample consisted of 87 participants (34 male; Age, $M = 27.72$ yrs, $SD = 12.44$). The program allocated participants to attentional bias modification conditions at random. Forty-four participants were assigned to the attentional bias modification condition designed to elicit heightened attentional bias towards negative information, and 43 participants were assigned to the attentional bias modification condition designed to elicit heightened attentional avoidance of negative information.

Materials

Spielberger State-Trait Anxiety Inventory (STAI). The Spielberger State-Trait Anxiety Inventory was used in order to assess participants' level of trait anxiety and state anxiety immediately prior to attentional assessment. The STAI is a 40-item questionnaire that provides measures of current (state) anxiety and dispositional (trait) anxiety. The 20 item state anxiety subscale (STAI-S) asks participants to indicate the degree to which they are experiencing a variety of anxiety symptoms "at this moment". The trait anxiety subscale (STAI-T) contains 20 items requiring participants to indicate how often they "generally feel" a similar variety of anxiety symptoms. Scores on each subscale range from 20 to 80, with higher scores representing higher levels of state anxiety or trait anxiety. The STAI has been

shown to have adequate reliability and validity amongst university student populations (Spielberger & Sydeman, 1994).

Attentional bias change assessment task stimuli. The stimuli used in the attentional bias change assessment task consisted of 48 unique word pairs that were adopted from the set of word pairs used by MacLeod et al. (2002). Each word pair contained one word that was negative in emotional tone, and one word that was neutral in emotional tone. Within each pair, words were matched in letter length. This set of 48 word pairs was divided in order to create two unique subsets of 24 word pairs. For each participant, one subset was used during the initial assessment of attentional bias and during contingency trials that intended to modify attentional bias. The other subset was employed during the second assessment of attentional bias that allowed assessment of the degree of bias change elicited following exposure to the contingency trials.

Attentional control assessment task stimuli. Stimuli used in the attentional control assessment comprised two easily discriminable shapes, a circle and a diamond. The shapes had equivalent spatial areas of 34 cm² and were represented via a white outline 5 mm wide on a black background.

Attentional bias change assessment task. The attentional bias change assessment task was intended to assess individual differences in attentional bias change in response to an attentional bias modification procedure. The design of the task mirrored that developed by Macleod et al. (2002). This task comprised three sequential blocks of trials. The first and third block were designed to assess attentional bias to negative information. The second block was designed to elicit change in attentional bias to negative information by presenting a contingency that would encourage the adoption of an attentional bias to negative stimuli (*attend-negative training condition*), or an attentional bias away from negative stimuli

(*avoid-negative training condition*).

Common trial characteristics across all blocks. Across all three blocks of trials the basic trial structure was the same. All trials were presented on a black background. Each trial started with the presentation of a fixation cue consisting of a white cross eight millimetres in height. This cue was presented in the centre of the screen for 500 ms, before being replaced by a word pair. Words in each word pair were vertically aligned, with one word presented 16 mm above, and one word presented 16 mm below, the location of the initial fixation cue. The negative word appeared in each location with equal frequency. Each word was presented in white monospaced text, 1 cm in height. After 500 ms, the word pair was removed and a probe was presented in the location previously occupied by one of the words. As this task measured probe discrimination latencies, this probe was designed to be easily discriminable. Hence, the probe comprised a pair of small red dots spaced 5 mm apart that were aligned either horizontally or vertically with equal frequency across trials. Participants were required to discriminate the alignment of the dots as quickly and accurately as possible. Participants identified the alignment of the dots by pressing one of two mouse buttons. Incorrect responses triggered a 3 second error message. The inter-trial-interval was 500ms.

Trial characteristics of the attentional bias contingency block. The block of trials designed to elicit change in attentional bias to negative information delivered 288 trials on which the probe position relative to the negative word was fixed. Under the condition designed to increase attentional bias, the probe always appeared in the location previously occupied by negative words. Alternately, under the condition designed to decrease attentional bias, the probe always appeared in the location opposite to the location previously occupied by negative words (i.e. in the location of neutral words).

Trial characteristics of attentional bias assessment blocks. Each block of trials designed to assess attentional bias delivered 48 trials in which the probe appeared in the location previously occupied by the negative word or the neutral word with equal frequency. The latency for participants to respond to the probe, and the accuracy of the response, was recorded for each trial. An index of attentional bias to negative information was derived from each block of assessment trials. Specifically, shorter probe discrimination latencies on trials where the probe replaced the negative words, as compared to trials where the probe replaced the neutral words, reflected greater attentional bias to negative information. Importantly, this resulted in two indices of attentional bias for each participant, one for participants' attentional bias prior to contingency exposure ($AB_{Pre-contingency}$), and one for their attentional bias following exposure to the contingency ($AB_{Post-contingency}$).

To permit examination of relationships between attentional control and magnitude of change in attentional bias, an index of the degree of change in attentional bias was computed. This index of *attentional bias change* (AB_{Change}) reflected the difference between indices of attentional bias assessed before and after the attentional bias contingency block. For participants in the attend-negative training condition, this index was computed by subtracting $AB_{Pre-contingency}$ scores from $AB_{Post-contingency}$ scores. A greater score thus indicated a greater increase in attentional bias to negative information. For participants in the avoid-negative training condition, this index was computed by subtracting $AB_{Post-contingency}$ scores from $AB_{Pre-contingency}$ scores. A greater score thus indicated a greater decrease in attentional bias to negative information. Hence, for each training condition greater positive scores on the AB_{Change} index reflected greater amounts of change in attentional bias in the direction encouraged by the contingency block.

Attentional control assessment task. The attentional control assessment task was

comprised of two subtasks. The *attentional control-inhibition assessment task* measured the ability of participants to inhibit the allocation of attention to a pre-potent stimulus. The *attentional control-selectivity assessment task* measured the ability for participants to selectively allocate attention to a specified stimulus among competing alternatives. Each of these task subtypes are described in turn below.

Attentional control-inhibition assessment task. This task was designed to measure individual differences in the cost to inhibit, rather than attend to, visually salient stimuli.

The task consisted of two trial types, each delivered in separate blocks of 32 trials each. For each trial type, a trial started with the presentation of a fixation cross in the centre of the screen. Participants then progressed the trial by pressing the space-bar key on their keyboard, after which the cross was removed, and a shape was presented 50 mm to the left or right of the centre of the screen. With equal frequency across trials, the shape image was either a circle or diamond, and appeared in the left or right location. A target probe was presented simultaneously to this shape. The location of this target probe depended on the trial type. An example of each type of trial is presented in Figure 1.

INSERT FIGURE 1 HERE

In inhibition trials the probe was presented in the location opposite the shape. These trials thus required participants to inhibit a pre-potent attentional movement towards the shape and execute an attentional movement to a location opposite to the salient shape stimulus. Alternately, in non-inhibition trials the probe was presented in the centre of the shape image. These trials thus required participants to execute an attentional movement towards a salient stimulus, thereby requiring no inhibition of a pre-potent attentional

movement towards to stimulus. Crucially, for each type of trial the shape image served as a fully reliable indicator of probe location, thereby permitting participants to produce fast attentional movements to maximise probe identification speed.

As this task measured probe discrimination latencies, this probe was designed to be easily discriminable. Across both types of trial, the probe was a small grey arrow, 5 mm in length, pointed upward or downward with equal frequency. Participants were required to indicate the orientation of the arrow as quickly and accurately as possible. Participants responded by pressing the corresponding arrow key on their keyboard. Incorrect responses triggered a 3 second error message. The inter-trial-interval was 500ms. At the start of each block, participants were instructed that in the upcoming trials, they had to attend towards (for blocks with non-inhibition trials) or away from (for blocks with inhibition trials) the single stimulus that would be presented.

For each trial, the latency for participants to respond to the probe, and the accuracy of the response, was recorded. An index of control of attentional inhibition ($AC_{Inhibition}$) was computed by subtracting the mean probe discrimination latency on the non-inhibition trial types, from the mean probe discrimination latency on the inhibition trial types. Hence, smaller scores on this index reflected a smaller cost to perform inhibition trials as compared to non-inhibition trials, and thus reflected greater control of attentional inhibition.

Attentional control-selectivity assessment task. This task was designed to assess control of attentional selectivity by measuring the time taken for participants to allocate attention to a specified stimulus under conditions that delivered competing stimuli, as compared to conditions that did not deliver competing stimuli. The design of the task adapted a probe-based methodology commonly used to assess selective attention amongst competing stimuli (MacLeod et al., 1986) in a manner that permitted assessment of the ability of participants to control selective allocation of attention. The task consisted of two trial types, labelled *selection trials* and *non-selection trials*, each delivered in separate trial blocks. An example of each type of trial is presented in Figure 2.

INSERT FIGURE 2 HERE

Selection trials required participants to selectively allocate attention towards an image they were instructed to attend to, and then to discriminate the identity of a probe presented in that location. At the start of each block, participants were instructed that during each trial two shapes (diamond and circle) would be presented, and they were required to attend to one of these shapes only in order to identify the probe. In half of these blocks, participants were instructed to attend to the diamond, in the other half they were instructed to attend to the circle shape. The probe was always presented in the shape participants were instructed to attend to. These shapes, which were identical to those described earlier, were presented to the left and right of the initial fixation, separated by 50 mm. Each shape was presented in the left and right screen position with equal frequency.

Non-selection trials provided a comparison condition under which no selective attention was required. On these trials participants were required to attend to a single

shape presented in an already attended location, and to discriminate the identity of a probe presented in that location. At the start of the block participants were instructed that during each trial, they should simply attend to the centrally presented shape in order to identify the probe. The presented shape was a circle image or diamond image, identical to those described earlier, with equal frequency.

Across both types of trials, each trial began with the presentation of a fixation cross in the centre of the screen. Participants progressed the trial by pressing the space-bar key on their keyboard, after which the cross was cleared and the shape or shapes were presented simultaneously with the probe. As in the attentional control-inhibition assessment task, this task measured probe discrimination latencies and so this probe was designed to be easily discriminable. Thus, this probe was also a small grey arrow, 5 mm in length, pointed upward or downward with equal frequency. Responses were coded in the same manner, and error feedback was given in the same manner. The block of selection trials delivered 32 trials, as did the block of non-selection trials. An index of control of attentional selectivity ($AC_{Selectivity}$) was computed for each participant by subtracting the mean probe discrimination latency recorded on non-selection trials, from the mean probe discrimination latency recorded on selection trials. Hence, smaller scores on this index reflected greater capacity to selectively allocate attention to the instructed shape, and thus reflected greater control of attentional selectivity.

Block rotation in the attentional control assessment task. The order of blocks in the attentional control assessment task was rotated across participants such that half the participants started with the attentional control-inhibition assessment task, while the other half started with the attentional control-selectivity assessment task. Within the former, the order of the blocks of non-inhibition trials-and inhibition trials was counterbalanced across participants. Within the latter, the non-selection trial block was always presented last.

Subsequent to completion of blocks from both subtasks, participants completed a final block of 16 filler trials that presented no attentional stimuli, and were unrelated to the focus of the present study.

Procedure

The experiment was delivered via the World Wide Web to participants' personal computers using the Inquisit Web software package (Millisecond Software, 2015). Upon receiving an invitation to participate in the study, participants were directed to a URL at which they loaded the experimental program on their computer. Upon loading the program participants were first required to provide informed consent and demographic information, before then completing the STAI questionnaire. Participants then started the attentional component of the experimental program. Participants first completed the attentional control assessment tasks, after which they started the attentional bias change assessment task. The programme did not require participants to complete the tasks under any specific circumstances. No specific time constraints were placed on participants during the completion of the task, with participants being permitted self-paced breaks between each task. The tasks were programmed to maintain equivalent spatial characteristics amongst stimuli across different screen sizes and resolutions. Upon completion of the tasks, participants were debriefed.

Results

Participant inclusion

As probe discrimination latencies were used to compute measures of interest, it was important to ensure that participants were highly accurate in discriminating the identity of probes. Probe identities in each attentional task were designed to be easily discriminable, thus participants were required to display a level of at least 90% accuracy across the experimental tasks for inclusion in data analysis. Fifteen participants failed to meet this criterion, and so data recorded from these participants were not included in subsequent analyses. The accuracy of probe discrimination responses for the remaining 72 participants was reassuringly high ($M = 95.66\%$, $SD = 2.31\%$). Demographic information and anxiety scores of these participants are present in Table 1. There was no significant difference in probe response accuracy, age, gender ratio, or level of state or trait anxiety between participants in the two training conditions (all $p > .1$).

INSERT TABLE 1 HERE

Data preparation

Prior to computing measures of interest from probe discrimination latencies, these data were filtered to exclude outlying latencies for each participant. This approach excluded latencies recorded from incorrect responses, as well as latencies that fell outside 2.5 standard deviations above or below a participant's mean probe discrimination latency. This resulted in 7.58% of probe discrimination latencies being excluded. Mahalanobis distances were computed for each correlational analysis below to ensure that extreme index scores

would not unduly influence the results. For each analysis, participants whose distance values exceeded a chi-square critical value corresponding to $p < .001$ were excluded.

Assessment of the association between change in attentional bias and measures of attentional control

Descriptive statistics of attentional measures are provided in supplementary material. To examine whether elevated levels of attentional control were associated with an elevated degree of attentional bias change, we first sought to assess whether the degree of change in attentional bias was associated with control of attention inhibition. To do so, a correlation was computed between $AC_{Inhibition}$ scores and AB_{Change} scores. Importantly, an association consistent with the hypothesis elevated levels of attentional control of inhibition are associated with an elevated degree of attentional bias change would be demonstrated by a negative statistical correlation between $AC_{Inhibition}$ scores and AB_{Change} scores. Three participants were found to have extreme Mahalanobis distances and so were excluded from this analysis. A graphical representation of this data is present in Figure 3.

INSERT FIGURE 3 HERE

The analysis revealed a significant negative correlation, $r(67) = -.287, p = .017$. This correlation demonstrated that greater control of attentional inhibition, as shown through lower $AC_{Inhibition}$ scores, was associated with greater change in attentional bias for negative information in the direction encouraged by the bias modification procedure.

Next, to examine the association between degree of change in attentional bias and control of attentional selectivity, a correlation between AB_{Change} scores and $AC_{Selectivity}$ scores was conducted. Importantly, an association consistent with the hypothesis that elevated

levels of control of attentional selectivity are associated with an elevated degree of attentional bias change would be demonstrated by a negative statistical correlation between AB_{Change} scores and $AC_{Selectivity}$ scores. One participant was found to have an extreme Mahalanobis distance, and so was excluded from the analysis. A graphical representation of this data is present in Figure 4.

INSERT FIGURE 4 HERE

The analysis revealed a significant correlation, $r(69) = -.261, p = .028$, demonstrating that greater control of attentional selectivity was also associated with greater change in attentional bias for negative information in the direction encouraged by the bias modification procedure.

Analyses next examined whether control of attentional inhibition and control of attentional selectivity were independent predictors of change in attentional bias, and whether the interaction between attentional control measures additionally predicted change in attentional bias. A two-step liner hierarchical regression was conducted using AB_{Change} scores as the outcome variable. $AC_{Inhibition}$ scores and $AC_{Selectivity}$ scores were entered as simultaneous predictor variables in the first step, and the interaction term of the attentional control measures was entered as a predictor in the second step. Multivariate analysis revealed that four participants had an extreme Mahalanobis distance, and so were excluded from this analysis. The overall regression model in the first step was significant, $F(2, 65) = 4.84, p = .011, r = .36$, explaining 13% of the variance in bias change. Moreover, there was evidence to suggest each measure of attentional control was a predictor of independent variance in change in attentional bias. Specifically, $AC_{Inhibition}$ scores were a

significant predictor of AB_{Change} scores, $B = -.29$, $t = 2.03$, $p = .047$, and $AC_{Selectivity}$ scores demonstrated a trend towards being a significant predictor of AB_{Change} scores, $B = -.18$, $t = 1.87$, $p = .066$. In the second step, inclusion of the interaction term did not account for a significantly greater amount of variance ($r^2_{change} = .009$, $p = .41$). Hence, the interaction of the attentional control measures did not predict change in attentional bias to a greater degree than the component attentional control measures alone.

The preceding analyses implicate individual differences in attentional control to be associated with individual differences in the degree of attentional bias change in the direction targeted by the attentional bias modification procedure. Though the present hypothesis does not make predictions concerning the relationship between attentional control and change in attentional bias under alternative training conditions, to determine whether attention control was more associated with change in attentional bias in one condition over another we employed two regression analyses. These analyses examined whether training condition moderated the association between control of attentional inhibition and change in attentional bias, or control of attentional selectivity and change in attentional bias. Neither analysis revealed a significant moderating effect of training condition (change due to moderation variable; largest r^2 change = .02, largest $F = 1.33$, smallest $p = .25$). Hence, the association between each measure of attentional control and change in attentional bias to negative information did not differ amongst the alternative attentional training conditions.

Discussion

The purpose of the present study was to evaluate the association between individual differences in attentional control and individual differences in the magnitude of change in attentional bias to negative information evoked in response to an attentional bias

modification procedure. Specifically, the study hypothesized that individual differences in control of attentional inhibition, and control of attentional selectivity, would be positively associated individual differences in the magnitude of change in bias resulting from an attentional bias modification procedure designed to encourage adoption of an attentional bias towards, or away from, negative information. The findings of the present study supported this hypothesis. Furthermore, the present study demonstrated some evidence to suggest that individual differences in control of attentional inhibition, and control of attentional selectivity, were independent predictors of change in attentional bias. Finally, the findings suggested that the association between individual differences in attentional control and magnitude of bias change did not differ as result of the direction of attentional training.

The finding that attentional control is associated with the degree of attentional bias change evoked through a modification procedure is consistent with findings of investigators who have sought to directly alter attentional control through neurostimulation (Clarke et al., 2014). The present findings showing that greater performance on attentional control measures is associated with enhanced attentional bias change provide converging evidence for the assertion by Clarke et al. (2014) that heightened attentional control may lead to enhanced bias change in response to attentional bias modification procedures. Critically however, neither of these studies in isolation identify a precise causal pathway between enhanced activation of the pre-frontal cortex, leading to enhanced attentional control, and greater attentional bias change. Future research could usefully serve to establish this pathway by examining whether change in attentional control indeed mediates the effect of tDCS stimulation on the DLPFC on the degree of attentional bias change evoked by attentional bias modification procedures. In addition, when considered along with the

findings of Chen et al. (2014) the present findings suggest there may be a reciprocal relationship between attentional control and processes of attentional bias change. Research specifically intended to evaluate the degree of reciprocity between attentional control and change in bias evoked through modification procedures represents a clear avenue for investigators seeking to clarify the nature of the relationship between these constructs.

The present findings hold clear implications for attentional training procedures designed to reduce attentional bias to negative information. Researchers have demonstrated that reduction in emotional vulnerability in response to an attentional bias modification procedure is contingent upon the successful modification of attentional bias, though achievement of bias change does not consistently follow from the deployment of these procedures (Clarke, Notebaert, et al., 2014; Macleod & Clarke, 2015; MacLeod & Grafton, 2016). This generates the critical need for the identification of mechanisms that influence bias change in response to these procedures. The present findings identify attentional control as one such mechanism, and in doing so promotes attentional control as a target for researchers seeking to maximise the therapeutic potential of attentional bias training procedures.

Investigators have demonstrated the potential effectiveness of computer-based cognitive training procedures in improving attentional control, and provided tentative evidence that improving attentional control may serve to reduce anxiety vulnerability (Course-Choi, Saville, & Derakshan, 2017; Koster et al., 2017; Owens, Koster, & Derakshan, 2013; Sari, Koster, Pourtois, & Derakshan, 2016). For example, Sari et al. (2016) demonstrated that the completion of a multi-week attentional control training programme resulted in the reduction of anxiety vulnerability amongst a group of dysphoric participants. Similarly, Course-Choi et al. (2017) reported that the completion of an attentional control

training programme in conjunction with meditative training by participants with elevated anxiety vulnerability resulted in a significantly greater reduction in anxiety symptoms, as compared to meditative training alone. Of course, it will be important for research to continue to rigorously investigate the direct influence of attentional control on anxiety vulnerability. Nevertheless, the present findings further reinforce the importance of attentional control within anxiety vulnerability by demonstrating that variation in attentional control may not only underpin anxiety vulnerability directly, but may also underpin the malleability of other cognitive processes that are known to characterise heightened anxiety vulnerability.

The demonstration that attentional control can successfully be enhanced through the delivery of attentional control training procedures has important implications for the present research. Specifically, the present findings suggest that the enhancement of attentional control via delivery of an attentional control training procedure could subsequently increase the capability of attentional bias modification procedures to alter attentional bias. This possibility is especially relevant when considering theorists have identified a need for methodologies that can more effectively manipulate attentional bias to negative information in order to more successfully reduce anxiety vulnerability (Clarke, Notebaert, & Macleod, 2014; Macleod & Clarke, 2015; MacLeod & Grafton, 2016). Though the potential value of neurostimulation techniques to enhance attentional control in such a scenario has also been identified (Clarke, et al., 2014), computer-based attentional control training procedures may present a more feasible opportunity to implement such training in clinical settings. As described above, cognitive methodologies for improving attentional control amongst individuals with heightened anxiety vulnerability have been developed (Course-Choi, Saville, & Derakshan, 2017; Sari, Koster, Pourtois, & Derakshan, 2016). Future

research could usefully ascertain whether the delivery of these procedures prior to, or during, delivery of attentional bias modification can indeed enhance the capability of the bias modification procedure to successfully alter attentional bias, and reduce anxiety vulnerability.

The present findings also have implications for research concerning the relationship between attentional bias malleability and change in emotional vulnerability. Research has demonstrated that attentional bias to negative information can change across time in response to individual experiences. For example, researchers have demonstrated that attentional bias to negative information can be increased in response to individuals' exposure to anxiety-provoking events (Macleod & Rutherford, 1992; Mogg, Mathews, Bird, & Macgregor-Morris, 1990), or reduce in response to therapy regimens (Mogg, Bradley, Millar, & White, 1995; Pishyar, Harris, & Menzies, 2008; Tobon, Ouimet, & Dozois, 2011). This readiness of individuals to alter cognitive processing styles in response to anxiolytic or restorative experiences has been coined *attentional bias malleability*, and researchers have started to investigate whether this malleability corresponds to changes in anxiety vulnerability in response to these different experiences. For example, Clarke et al. (2012) observed that the degree of change in attentional bias evoked by the completion of a single session of an attentional bias modification procedure (measured prior to the start of the therapy program) positively predicted the degree to which anxiety symptoms were reduced in response to the therapy program. These findings suggest that improving an individual's capacity to modify attentional biases may heighten the degree of symptom reduction achieved in response to therapy. Crucially, the findings of the present study implicate the enhancement of attentional control as a potential avenue for how this may be achieved.

Lastly, the present findings highlight the value of investigating cognitive mechanisms

that may underlie the process of attentional bias change, of which attentional control is just one. Theorists have proposed other mechanisms that may influence change in attentional bias resulting from attentional bias modification procedures, including sensitivity to registering emotional valence (Macleod & Clarke, 2015). Future research could investigate whether such individual differences in valence sensitivity also predict magnitude of change in attentional bias, and whether procedures designed to modify sensitivity to registering emotional valence can impact attentional bias change.

Of course, some limitations of the present study must be considered. First, the present methodology employed a novel set of tasks to assess individual differences in attentional control. These tasks are similar in design to existing tasks used to assess attentional inhibition (Derakshan, Ansari, Hansard, Shoker, & Eysenck, 2009; Miyake et al., 2000; Roberts et al., 1994) and selective attention (MacLeod et al., 1986), though have not been subject to formal evaluations of their validity. Second, the present methodology did not include an assessment of emotional vulnerability, and so the relationship between individual differences in attentional control and change in emotional vulnerability subsequent to the evocation of an attentional bias towards or away from negative information cannot be examined here. It is often the purpose of procedures that modify attentional bias to negative information to engender subsequent change in emotional vulnerability (Bar-Haim, 2010; Hakamata et al., 2010; Notebaert, Clarke, Grafton, & MacLeod, 2014). Hence, it serves as an important avenue for research to investigate whether individual differences in attentional control also predict individual differences in change in emotional vulnerability resulting from these procedures. Third, the present study aimed to investigate mechanisms of bias change, and so delivered a single session of attentional bias modification training. In contrast, attentional bias modification schedules

intended to provide therapeutic reduction in anxiety vulnerability commonly deliver multiple training sessions (Amir, Beard, Taylor, et al., 2009; Carleton et al., 2015; Riemann, Kuckertz, Rozenman, Weersing, & Amir, 2013). It is possible that attentional control may differentially influence the capacity of attentional bias modification procedures to yield bias change within longer training schedules. For example, while individuals with greatest attentional control may demonstrate greatest attentional bias change during initial sessions, attentional control may be less associated with change in bias resulting from completion of a prolonged attentional bias modification training schedule. Examination of whether attentional control is indeed associated with bias change over prolonged periods of bias modification training could be easily achieved through the incorporation of measures of attentional control into existing bias modification training schedules. This makes such an examination a prime avenue for future research. Lastly, it must be noted that although significant associations between measures of attention control and attentional bias change were observed in the present study, participants did not demonstrate statistically significant change in attentional bias as a result of the bias modification procedure (see supplementary material). Researchers seeking to further investigate the association between attentional control and attentional bias change may wish to lengthen the duration of attentional bias training in order to enhance the probability of observing significant change. Crucially however, such designs must also ensure that prolonging training does not result in a ceiling effect of bias change, which would limit the ability to observe its association with attentional control by limiting variability.

Though the present study yielded sufficient power to detect associations between attentional control and attentional bias change, it is sensible to recommend that studies wishing to replicate the present findings adopt either a larger sample than was employed in

the present study. This would allow for a more precise estimate of the association between each measure of attentional control and bias change, and would also ensure heightened power when estimating differential effects in the strength of such associations under alternate attentional bias modification training conditions.

For the moment however, the present study demonstrates that individual differences in attentional control predict individual differences in the degree to which the process of attentional bias change is evoked from an attentional bias modification procedure. The present findings hold important implications for understanding attentional bias and its modification, and for the development of procedures that seek to enhance the effectiveness of therapeutic applications of attentional bias modification. It is hoped that the present study will stimulate further research into the mechanisms that underpin individual differences in attentional bias change, with the aim of informing the development of procedures that can more effectively evoke the process of attentional bias change and reduce anxiety vulnerability.

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Table 1. Mean and standard deviation of measures of probe discrimination accuracy (across all tasks), age, anxiety, and gender ratio for participants in each training condition; *M(SD)*.

Training Condition	Probe discrimination accuracy	Age	State Anxiety (STAI-S)	Trait Anxiety (STAI-T)	Gender ratio (M:F)
<i>Attend-negative training condition (N = 38)</i>	95.37% (2.41)	29.08 (13.12)	34.05 (11.70)	39.29 (9.65)	18:20
<i>Avoid-negative training condition (N = 34)</i>	95.98% (2.18)	27.82 (12.78)	35.29 (13.47)	42.79 (12.04)	12:22

Figure 1. Example of an anti-saccade trial (left), and a pro-saccade trial (right), delivered in the attentional control-inhibition assessment task. Items in figure not to scale.

Figure 2. Example of a selection trial (left), and a non-selection trial (right), delivered in the attentional control-selectivity assessment task. Items in figure not to scale.

Figure 3. Scatterplot of participant AB_{Change} scores and AC_{Inhibition} scores. Solid line identifies linear line of best fit.

Figure 4. Scatterplot of participant AB_{Change} scores and AC_{Selectivity} scores. Solid line identifies linear line of best fit.

Supplementary data file

Supplementary Table 1. *Descriptive statistics of probe discrimination response latencies (RT) per trial type and index for each attentional control assessment task.*

Attentional Measure	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Attentional Control – Inhibition							
Inhibition trials	72	530.6667	1738.9355	813.373239	252.2910785	1.844	3.182
Non-inhibition trials	72	544.4828	1694.9630	813.547171	239.0029244	1.977	4.368
Inhibition Index ¹	72	-937.4748	864.8710	-.173932	203.1929411	-1.470	14.694
Attentional Control – Selectivity							
Selection trials	72	608.1364	2028.6129	874.627608	245.6514190	2.493	7.738
Non-selection trials	72	433.6774	1300.6000	596.912390	135.9937395	3.102	12.679
Selectivity Index ¹	72	50.0030	832.6088	277.715218	142.7869840	1.904	4.103

Note: ¹Correlation between AC_{Inhibition} index scores and AC_{Selectivity} index scores is $r(68) = .22$, $p = .077$. Two participants were excluded from this analysis due to demonstrating extreme Mahalanobis distances.

Supplementary Table 2. *Descriptive statistics of probe discrimination response latencies (RT) per trial type and index for each attentional bias assessment block of the attentional bias change assessment task.*

Attentional Measure	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Attention Bias Assessment – Pre ABM							
Probe in neutral location	72	423.5652	1360.9474	741.517797	188.9746635	1.135	1.422
Probe in negative location	72	409.6316	1483.7273	735.348214	196.4808646	1.670	4.508
Attentional Bias Index ¹	72	-231.4805	249.6000	6.169584	72.4157849	.418	3.320
Attention Bias Assessment – Post ABM							
Training Direction – Attend Negative							
Probe in neutral location	38	461.6190	1249.3636	716.621468	180.9254908	1.238	1.621
Probe in negative location	38	428.1739	1291.5909	720.282663	209.3599271	1.153	.956
Attentional Bias Index ²	38	-261.2727	131.9000	-3.661195	69.6326400	-1.138	4.117
Attention Bias Assessment – Post ABM							
Training Direction – Avoid Negative							
Probe in neutral location	34	571.9091	1121.0000	756.790981	160.4537142	.921	-.052
Probe in negative location	34	554.0500	1146.4167	758.187643	157.8001946	.820	-.147
Attentional Bias Index ³	34	-221.4119	305.7016	-1.396662	81.0982794	1.131	6.450

Note: ¹Scores on this index were not significantly different from zero, $t(71) = .72, p = .47$; ²Scores on this index were not significantly different from pre-ABM scores for participants in the attend-negative training condition, $t(37) = .33, p = .75$; ³Scores on this index were not significantly different from pre-ABM scores for participants in the avoid-negative training condition, $t(33) = .71, p = .49$.

Supplementary Table 3. *Descriptive statistics of percentage of correct probe discrimination responses (accuracy) per trial type for the attentional bias change assessment task and each attentional control assessment task.*

Attentional Measure	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Attentional Control – Inhibition							
Inhibition trials	72	81.30	100	96.83	3.57	-1.83	4.68
Non-inhibition trials	72	65.60	100	96.22	6.27	-3.56	14.91
Attentional Control – Selectivity							
Selection trials	72	75.00	100	96.70	4.98	-2.25	5.65
Non-selection trials	72	87.50	100	98.26	2.67	-1.85	3.75
Attention Bias Change Assessment							
Probe in neutral location	72	79.17	100	94.57	4.35	-.926	.920
Probe in negative location	72	66.67	100	94.57	6.24	-1.75	4.59