What is attention bias variability? Examining the potential roles of attention control and response time variability in its relationship with anxiety

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Abstract

The present study examined the underlying role of attention control and response time variability in explaining the relationship between anxiety and two commonly computed measures of attention bias variability: 'moving average' and 'trial-level bias score' measures. Participants (final $n=195$) completed measures of anxiety symptomatology, antisaccade performance (attention control), a stand-alone measure of response-time variability, and a probe task measure of attention bias. Average bias and moving average bias variability measures both recorded significant, but low split-half reliability. Both attention bias variability measures and average attention bias were associated with anxiety, and attention control. Both attention bias variability measures correlated with response time variability. Neither attention bias variability measure correlated with average attention bias. Attention control was the single significant mediator of the relationship between anxiety and the trial-level bias score measure of attention bias variability. Neither response time variability nor attention control significantly mediated the relationship between anxiety and the moving average measure of attention bias variability. No evidence was found for the mediating role of response time variability. The present findings suggest that the relationships observed between anxiety and the trial-level bias score measure of attention bias variability in particular may be attributable to the over-arching role of attention control.

Recent years have seen a surge in research focused on the construct of attention bias variability. Interest in attention bias variability (AB-Var) appears to have stemmed in part from the proposed role that variation in attention bias may play in specific types of psychopathology (in particular posttraumatic stress disorder; Iacoviello et al., 2014; Swick & Ashley, 2017). In addition, there is increasing recognition that traditional measures of average attention bias (AB-Ave) show low levels of reliability (Price et al., 2015) as compared to measures of AB-Var (Zvielli, Bernstein, & Koster, 2015). A number of studies have now shown that measures of AB-Var are more reliable, and appear to be more strongly associated with variation in different measures of psychopathology as compared to traditional measures of attentional bias (e.g. Alon, Naim, Pine, Bliese, & Bar-Haim, 2019; Zvielli, Bernstein, et al., 2015).

Amongst the most thoroughly investigated has been the relationship between AB-Var and symptoms of posttraumatic stress disorder (PTSD). Based on mixed findings showing that attention bias in PTSD can be variously characterised by vigilance toward threat cues, attentional avoidance of threat-related stimuli and that there is interference of negative information on attentional processes, Iacoviello et al. (2014) speculated that intra-individual variability of attention bias may be associated with PTSD and potentially explain past inconsistent findings. To examine this they employed a measure of AB-Var that assesses variance in a moving average of attention bias index scores, demonstrating that individuals with PTSD showed higher levels of AB-Var compared to trauma-exposed individuals without PTSD, and controls. They also showed a positive relationship between variation in AB-Var and PTSD symptoms. Subsequent findings in this area have also shown broadly consistent effects, indicating that AB-Var for negative and/or trauma-relevant stimuli is higher among individuals with PTSD, and that AB-Var consistently correlates with PTSD symptom severity (Mazidi, Vig, Ranjbar, Ebrahimi, & Khatibi, 2019; Naim et al., 2015; Swick & Ashley, 2017).

At a similar time to Iacoviello et al. (2014), other researchers were also considering the possibility that dynamic patterns of attention bias toward and away from threat may be associated with patterns of emotional vulnerability. Zvielli, Bernstein, et al. (2015) specifically examined

patterns of biased attention on a trial-by-trial basis by extracting multiple indices of attention bias over time. Using this approach they derived a number of measures including averages of attention bias toward and away from threat, minimum and maximum bias scores, and a measure of attention bias variability over time. Zvielli, Bernstein, et al. (2015) compared healthy controls to individuals with spider phobia using this trial-level approach. They found that AB-Var significantly predicted spider phobia diagnostic status across the two groups. Using a similar approach, Davis et al. (2016) assessed attention bias variability over the course of therapy for social anxiety disorder, finding significant reductions in AB-Var in response to treatment, though no evidence that such reductions were causally related to symptom improvement. With a relatively small sample, Yuan, Mao, Chen, Zhang, and Cui (2019) showed trend data suggesting that high socially anxious participants ($n=18$) exhibited higher AB-Var compared to low anxious participants ($n=13$). Using an approach incorporating multiple categories of threat and neutral stimuli with neutral-neutral trials as a baseline (rather than threat-neutral comparison trials as in past studies) Schäfer, Zvielli, Höfler, Wittchen, and Bernstein (2018) examined the relationship between measures of bias variability and intrusive memories in response to an experimental trauma-film paradigm. They found that the frequency of negative thought intrusions experienced in the week following exposure to the trauma video was predicted by AB-Var for trauma-related threat and trauma-related neutral words. In a real-world design, Schäfer et al. (2016) found associations between pre and post-deployment AB-Var for happy and angry faces and higher levels of posttraumatic stress symptoms post-deployment among German soldiers. Finally, Zvielli, Vrijzen, Koster, and Bernstein (2016) found that individuals with remitted depression showed higher levels of AB-Var compared to non-depressed controls. Collectively, the findings reviewed above are consistent with the position that higher levels of emotional vulnerability are associated with higher AB-Var.

We should explicitly note that while some research has focused broadly on trial-level measurement of attention and behaviour more generally (Zvielli, Amir, Goldstein, & Bernstein, 2015; Zvielli et al., 2016), including the incorporation of such principles into attention bias modification

(Zvielli, Amir, et al., 2015), the current study focuses specifically on the construct of attention bias variability in particular which has been examined across a number of populations, and using different methods of quantification. In doing so, we focus on two of the most common methods used to assess this construct, the approach assessing variance in a moving average of attention bias, and the approach assessing variance in consecutive indices of attention bias.

While emerging research in this area has shown associations with a number of psychopathology measures, concerns have been noted about the potential validity of attention bias variability measures, with research suggesting that measures of AB-Var may be heavily influenced by, and potentially the product of, response time variance. Kruijt, Field, and Fox (2016) highlighted that any measure of AB-Var is likely to reflect both genuine variability in attention bias, and also variability in response times that is unrelated to AB-Var. Using modelled data, they examined this by varying standard deviations in response times and the frequency and magnitude of 'switches' in attention bias toward and away from 'threat' (target) stimuli to examine the effect on measures of AB-Var. Kruijt et al., (2014) found that while AB-Var measures were sensitive to genuine changes in bias variability, these measures also responded strongly to increases in response time variability (RT-Var) in the form of increased standard deviations of reaction times, that are unrelated to attention bias. They therefore concluded that it is not possible to know whether levels of AB-Var reflect genuine fluctuations in attention bias, or simply greater RT-Var. While limited by the use of modelled data, these findings highlight the possibility that AB-Var could partially or completely represent an artefact of variation in response times.

Regardless of whether RT-Var explains the relationship between AB-Var and anxiety, it nevertheless still begs the question as to why either of these processes is related to emotional vulnerability. In considering higher-order cognitive processes that could potentially contribute to RT-Var and also explain the relationship between AB-Var and emotional vulnerability, attention control presents as a plausible candidate. Attention control refers to the ability focus and move attention according to intention and is often divided into shifting (movement in space or between different

aspects of information), updating (monitoring and updating of information), and inhibition (ignoring of distracting information to retain focus; Miyake et al., 2000). There is evidence that variability in response times may reflect executive dysfunction, and specifically attentional control (Ode, Robinson, & Hanson, 2011). Imaging studies have found that activation levels within the distributed inhibitory network correspond with variability in reaction times among children with attention-deficit hyperactivity disorder (Bellgrove, Hester, & Garavan, 2004). Such findings suggest that impaired attentional control, and particularly inhibitory attentional control, is associated with increased reaction time-variability.

A number of researchers have also highlighted the possibility that AB-Var may reflect impaired attention control (Iacoviello et al., 2014; Zvielli, Bernstein, et al., 2015). Attention control is consistently implicated in the relationship between biased attention and anxiety (Eysenck, Derakshan, Santos, & Calvo, 2007) and could conceivably contribute to both AB-Var and emotional vulnerability, and so underpin the relationship between these measures. Specifically, poor attention control could potentially underpin both higher AB-Var and increased emotional vulnerability. There is some evidence that attention control may have an impact on AB-Var. Bardeen, Tull, Daniel, Evenden, and Stevens (2016) found that only individuals with lower levels of attention control showed a relationship between AB-Var and PTSD symptomatology. This was examined in a relatively small sample however ($n=29$), and the study did not seek to examine if attention control mediated the relationship between AB-Var and PTSD symptomatology. Given the noted role of attention control in emotional vulnerability, and its potential role in AB-Var, the first aim of the current study was to examine the possibility that attention control may underpin the relationship between AB-Var and anxiety. Furthermore, as research has suggested that AB-Var may be a product of RT-Var (Kruijt et al., 2016), with further findings having linked RT-Var and attention control (Ode et al., 2011), the present study also examined whether response time variability, either alone, or as a product of attention control, mediates the relationship between AB-Var and anxiety. We chose to focus on symptoms of anxiety in particular as this represents a transdiagnostic process with an established

relationship with attention bias (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007), and is implicated in almost all conditions in which AB-Var has been shown to be relevant.

While a small number of studies have attempted to control for the influence of general response time variability, the measures of RT-Var have been derived either from a brief number of practice trials (Mazidi et al., 2019; Zvielli et al., 2016), or from the same trials used to compute AB-Var (Alon et al., 2019; Swick & Ashley, 2017). The small number of practice trials involved, in addition to their purpose of reducing potential noise in a main experimental task, means that measures of RT-Var from such trials may not reflect general patterns of RT-Var. Deriving a measure of RT-Var from the same trials used to compute AB-Var (i.e. trials including threat and neutral stimuli), also means that measures of RT variability could be influenced by processes involved in attention bias which may also have been present on such trials. As such, to determine whether RT-Var underpins the relationship between AB-Var and emotional vulnerability without potential contamination by patterns of selective attention, the measure of RT-Var in the current study used only non-emotional stimuli but was otherwise matched in visual and temporal parameters to the attentional bias assessment.

Thus, the current study examined three alternative accounts regarding the cognitive underpinnings of the relationship between AB-Var and anxiety as outlined in the model depicted in Figure 1 below. The first hypothesis considered is that attention control alone mediates the relationship between AB-Var and anxiety. The second hypothesis is that response time variability alone mediates the relationship between AB-Var and anxiety. The third hypothesis is that attention control and RT-Var jointly mediate the relationship between AB-Var and anxiety. These were examined separately for the two most common methods of computation of AB-Var: the moving average approach (AB-Var_{MOV}) employed by Iacoviello et al. (2014), and the trial-by-trial approach (AB-Var_{TLS}) employed by Zvielli, Bernstein, et al. (2015). To address these hypotheses the current study delivered separate tasks designed to measure AB-var (dot probe task), and RT-var (non-

emotional dot probe task), an assessment of attention control (antisaccade task), and self-report anxiety symptomatology, in a large unselected sample.

Figure 1. Hypothesised mediators under examination in the current study; attention control and response time variability (RT Variability) underpinning the relationship between attention bias variability (AB Variability) and anxiety. The ‘attention control alone’ hypotheses predicts only a significant $a \rightarrow b$ mediation path. The ‘response time variability alone’ hypothesis predicts only a significant $c \rightarrow d$ mediation path. The ‘joint mediation’ hypothesis predicts a significant $a \rightarrow e \rightarrow d$ mediation pathway.

Method

Participants

The initial sample comprised 258 (182 female, 74 male) undergraduate students and members of the community recruited through undergraduate participant pools at Curtin University and the University of Western Australia, and via social media advertising ($M_{age} = 22.64$, $SD = 7.21$). The project was approved by both University’s research ethics committees. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975 (as revised in 2000). Informed consent was obtained from all participants included in the study.

Emotional assessment measure

Participants completed the 21 item version of the Depression Anxiety and Stress scale (DASS; Lovibond & Lovibond, 1995), with the anxiety subscale forming the primary dependent measure in the current study. The internal consistency of each subscale was observed to be high (Cronbach's alpha for Depression = .92, Anxiety = .88, Stress = .89).

Assessment of attention bias and attention bias variability

Measures of attention bias were assessed using an attentional probe task employing a stimulus subset comprising 24 negative and 24 neutral words adapted from MacLeod and Mathews (1988). Negative stimuli focused on themes of social and academic threats with such items as 'Inept', 'Foolish', 'Idiotic', with neutral words matched in terms of length and frequency of use (e.g. 'Click', 'Pottery', 'Cartoon'). On each trial of this task a fixation cross appeared in the centre of the screen for 500ms followed by a stimulus word pair presented vertically aligned in the centre of the screen, separated by 25mm in 8mm black block text on a white screen background. These stimuli remained on screen for 500ms and were then replaced by a probe comprising two dots either vertically or horizontally aligned (':' or '..'). Participants were required to identify the orientation of the dots by pressing the left mouse key for horizontal, and the right mouse key for vertically aligned probes. The participant's response cleared the screen and the next trial began after a 500ms delay. Participants completed a total of 96 trials, involving 4 repetitions of the 24 word pairs in randomised blocks. The position of threat and neutral word stimuli (upper or lower), and the position of the target probe (negative or neutral word location) was randomised within blocks, and counter-balanced across stimulus pairs across blocks. Similarly, probe identity (horizontal vs. vertical) was random within the constraint that an equal number of each probe type appeared within each block.

Three measures of attention bias were obtained from this task. The traditional average measure of attention bias (AB-Ave) was computed by subtracting the average response latency for trials where the probe appeared in the location of the negative stimulus word from the average response latency for trials where the probe appeared in the location of the neutral stimulus word.

The moving average measure of attention bias ($AB-Var_{Mov}$) involves the initial computation of multiple attention bias index scores for each participant, subtracting reaction times of individual probe-threat trials from reaction times of individual probe-neutral trials according to their temporal appearance in the task. A moving average of these attention bias index scores is then computed for groups of 10 index scores (i.e. for index scores 1-10, 2-11, 3-12 etc). The standard deviation of these average bias scores is then calculated and divided by the participant's overall mean reaction time forming the final measure of $AB-Var_{Mov}$. Finally, the second attention bias variability measures was computed using a similar 'trial level bias score' ($AB-Var_{TLBS}$) approach employed by Zvielli, Bernstein, et al. (2015). To compute this measure, multiple indices of attention bias were initially computed by pairing individual probe negative and probe neutral trials. Trials were paired according to their temporal order of appearance on the task. Specifically, the first presented probe-neutral trial was paired with the first presented probe-threat trial, the second presented probe-neutral trial was paired with the second presented probe-threat trial and so on. This method resulted in a minimum number of trials lost due to not having a pair and a median trial distance between each pair = 5. Individual probe-negative trials were then subtracted from individual probe-neutral trials. After computing a temporal sequence of multiple attention bias index scores, the difference between each index score and the subsequent index is then computed. To illustrate, for the following string of attention bias index scores; Index1 = -20, Index2 = 60, Index3 = 5, Index4 = 40, Index5 = -10, the difference between these sequential scores is computed (i.e. index1 - Index2, Index2 - Index3 etc.) resulting in values of: -80, 55, -35, and 50. Because these differences scores include negative/positive values that represent the direction of change that is not relevant when computing the final measure of attention bias variability, these values are then normalised: 80, 55, 35, 50. Finally, these values are summed and divided by the number of observations to arrive at the final index of $AB-Var_{TLBS}$.

Assessment of response time variability

The task assessing RT-Var was structurally identical to the attentional probe task described above, however, rather than paired negative-neutral word stimuli, this task included paired non-words. Specifically, the stimuli comprised 24 paired strings of X's matched in length to the word stimuli on the attention bias assessment probe task and presented in the same format and duration as the probe task. The task comprised 96 trials delivered in a separate block to the attention probe assessment task. Probe type and position on each trial were randomised within each block of 24 trials. The standard deviation of response times across all trials of the task was taken as the measure of RT-Var.

Attention control assessment

To measure attention control, we employed an antisaccade task. The antisaccade is recognised as a measure of inhibitory attention control (Miyake et al., 2000) with a number of studies showing an association between poorer performance and higher levels of anxiety (Ansari & Derakshan, 2011; Basanovic et al., 2018; Garner, Ainsworth, Gould, Gardner, & Baldwin, 2009). In the current study, we used a variant of this task based on that employed by Miyake et al. (2000), in turn based on the task employed by Roberts, Hager, and Heron (1994). The trial structure of the task is depicted in Figure 2. On each trial, a small fixation cross was presented in the centre of the screen for one of eight random variable durations between 1500 and 3500ms (250ms increments). This was then replaced by a cue stimulus comprising a black square 20mm x 20mm presented 85mm horizontally to the left or right of the initial fixation for 225ms. Following this, a small black target arrow 5mm in length facing left, right, or up, appeared in the screen position opposite the cue for 150ms. This exposure duration is designed to ensure that participants inhibit saccades to the cue, and direct attention to the opposite screen position in order to successfully identify the target arrow. The target arrow was then masked with the icon '###'. Participants responded by pressing the corresponding left, right, or up key on the keyboard. The response cleared the screen and the next

trial began following a 500ms inter-trial-interval. The total task comprised 90 trials with the proportion of correct responses forming the critical dependent measure.

Figure 2. Schematic representation of the antisaccade task trial structure with exposure durations.

Procedure

Participants accessed the study remotely via an online link using their own computer. Delivery of questionnaires and cognitive tasks was managed by Inquisit 4 online software (Inquisit 4.0.8, 2015). Participants were presented information on the requirements of the study and indicated informed consent by clicking 'I agree' before the study commenced. Participants first completed basic demographic information before responding to questionnaire measures including the DASS (additional questionnaires were associated with an alternative research project). Participants then completed all cognitive tasks including the attentional probe bias assessment task, the response time variability assessment task, the antisaccade task, and a brief word priming task associated with an alternative project. The order of delivery of these tasks was counter-balanced across participants to ensure no sequence effects. Each task commenced with detailed instructions on its completion in addition to practice trials involving non-emotional stimuli. Given the brief

exposure duration of targets on the antisaccade task, practice of this included the initial completion of a number of prosaccade trials to ensure participant understanding of the task, before then completing practice antisaccade trials, and finally the antisaccade task itself. Upon conclusion of the cognitive tasks, participants received debrief information and contact details for mental health services. The time taken to complete the study was approximately one hour.

Results

Data preparation

In the preparation of response time data for the probe task assessing attention bias, the following exclusions were applied: individual response times falling below 200ms or above 2000ms (3.50% trials), incorrect responses (6.84% trials) and response times falling further than 3 median absolute deviations (MAD; Leys, Ley, Klein, Bernard, & Licata, 2013) from each participant's average response time for each trial type (2.41% trials). These same criteria were applied to the RT-Var probe assessment task ($<200\text{ms}$ & $>2000\text{ms}$ = 6.49%, incorrect = 8.79%, $\pm 3 \text{ MAD}$ = 1.95%).

To identify participant outliers, we adopted 3 SD exclusion criterion for all indices computed. Six participants were excluded on the basis of AB-Ave scores above this cut-off, five on the basis AB-Var_{TLBS}, three on the basis of AB-Var_{MOV}, and a further three participants on the basis of RT-Var scores.

Accuracy was consistently high on both the attention bias probe assessment task ($M = 92.22\%$, $SD = 8.61$) and the RT-Var assessment task ($M = 88.54\%$, $SD = 11.17$) for the entire sample. An inclusion criterion of at least 70% accuracy on these tasks was adopted. Three participants were excluded based on low accuracy in the attention bias probe assessment task, and a further four on the basis of accuracy on the RT-Var probe assessment task.

As accuracy on the antisaccade task represented the dependent measure for this task, we adopted an inclusion criterion that balanced capturing individuals with lower levels of attention control while excluding those that did not follow the task instructions or did not appear to understand the task. With chance responding of 33.3% on this task, a minimum accuracy rate of 40%

was adopted, resulting in the exclusion of 39 participants who fell below this level. The final sample therefore comprised 195 individuals (Male = 51, Female = 144, $M_{age} = 22.41$, $SD = 7.16$) reported in all analyses below. Examination of those excluded showed that they did not differ significantly from the final sample in terms of age or any of the DASS subscales (all $t < 1.67$, all $p > .10$), though the excluded group did contain proportionally more males than the final sample ($\chi^2(1, 258) = 4.19$, $p = .041$; 39.68% vs. 26.15%).

Reliability data were examined for each of the cognitive measures. This was computed through correlation of first/second split halves for all measures. Large correlations were observed for antisaccade accuracy $r(195) = .69$, $p < .001$, RT-Var, $r(195) = .86$, $p < .001$, and AB-Var_{TLBS}, $r(195) = .63$, $p < .001$. Smaller split half correlations were observed for AB-Var_{MOV}, $r(195) = .24$, $p < .001$ and AB-Ave scores $r(195) = .18$, $p < .011$. Despite relatively higher power in the current study compared to many others, low levels of reliability for such measures necessarily dictate caution in interpreting effects involving these.

Relationships between variables

Bivariate correlations between all measures were first examined to evaluate the presence of anticipated relationships. Table 1 presents correlations between all variables under examination. Consistent with expectations, AB-Ave ($r(195) = .211$, $p = .003$) and both AB-Var measures (AB-Var_{MOV}: $r(195) = .254$, $p < .001$; AB-Var_{TLBS}: $r(195) = .183$, $p = .011$) showed significant positive associations with anxiety. Of note, AB-Var_{MOV} and AB-Var_{TLBS} had significant relationships with both proposed mediators, showing a positive association with RT-Var (AB-Var_{MOV}: $r(195) = .404$, $p < .001$; AB-Var_{TLBS}: $r(195) = .559$, $p < .001$) and a negative association with attention control (higher AB-Var being associated with lower antisaccade accuracy; AB-Var_{MOV}: $r(195) = -.152$, $p = .034$; AB-Var_{TLBS}: $r(195) = .314$, $p < .001$). Interestingly, AB-Ave showed no evidence of an association with either of these variables (antisaccade: $r(195) = .09$, $p = .209$; RT-Var: $r(195) = -.009$, $p = .212$) nor with either measure of AB-Var (AB-Var_{MOV}: $r(195) = -.009$, $p = .898$; AB-Var_{TLBS}: $r(195) = -.009$, $p = .212$). Antisaccade performance also showed the anticipated negative relationship with measures of

anxiety ($r(195) = -.203, p = .004$), confirming the predicted association between lower attention control and higher levels of anxiety.

Table 1. Pearson's correlations showing the relationships between average attention bias index (AB Average), moving average (AB-Var_{Mov}) and trial-level (AB-Var_{TLBS}) measures of attention bias variability, response time variability (RT-Var), attention control (Antisaccade) and measures of emotional vulnerability (depression, anxiety and stress).

	AB-Ave	AB-Var _{Mov}	AB-Var _{TLBS}	RT-Var	Antisaccade
ABVar _{Mov}	-.009				
ABVar _{TLBS}	-.090	.431**			
RT-Var	-.019	.404**	0.503**		
Antisaccade	.090	-.152*	-0.314**	-0.271**	
DASS - Depression	.165*	.183*	0.147*	0.123	-0.138
DASS - Anxiety	.211**	.254**	0.183*	0.085	-0.203**
DASS - Stress	.200**	.233**	0.152*	0.179*	-0.230**

* $p < .05$, ** $p < .01$

Do attention control and/or response time variability mediate the relationship between attention bias variability and anxiety?

To examine whether attention control and RT-var mediate the relationship between AB-var and anxiety, the indirect effect of AB-Var on anxiety through attention control and RT-Var (independently and sequentially) was examined using the bias-corrected bootstrapping procedures outlined by Preacher and Hayes (2004). This was conducted separately for the AB-Var_{TLBS} and AB-Var_{Mov} measures of attention bias with the Process macro in SPSS (Hayes, 2017) using 5000 bootstrap resamples and 95% confidence interval. Standardised coefficients are reported throughout.

AB-Var_{TLBS} was first examined. Significance and path coefficients are shown in the full mediation model depicted in Figure 3, Table 2 shows indirect effects. Consistent with the observed correlations, the model in Figure 3 shows significant effects between AB-Var_{TLBS} and Attention control (path a), RT-Var (path c), and Anxiety (path F). Statistically significant effects were also recorded between attention control and both RT-Var (path e), and anxiety (path b). No significant effect was recorded between RT-Var and anxiety (path d). The direct effect of AB-Var_{TLBS} on Anxiety

after accounting for the effect of mediator variables was no longer significant (path c'), consistent with the potential mediating role of these variables.

To examine the significance of individual mediation pathways, the bias corrected bootstrap confidence intervals were examined for each pathway. The confidence interval for the indirect ab path ($AB\text{-}Var_{TLBS} \rightarrow \text{Attn Control} \rightarrow \text{Anxiety}$) was entirely above zero (see Table 2), indicating a significant indirect effect of $AB\text{-}Var_{TLBS}$ on anxiety via attention control. The confidence limits for all remaining indirect effects ($AB\text{-}Var_{TLBS} \rightarrow \text{RT-Var} \rightarrow \text{Anxiety}$, and $AB\text{-}Var_{TLBS} \rightarrow \text{Attn Control} \rightarrow \text{RT-Var} \rightarrow \text{Anxiety}$) and the total effect (sum of all specific indirect effects) overlapped with zero and were therefore not statistically significant. This pattern of effects therefore provides support for the hypothesis that attention control underpins the relationship between $AB\text{-}Var_{TLBS}$ and anxiety, but does not support the role of RT-Var, nor the sequential mediation of attention control via RT-Var in this relationship.

Figure 3. Mediation model

Mediation paths between trial-level bias score measure of attention bias variability ($AB\text{-}Var_{TLBS}$) and anxiety, via attention control and response time variability (RT-Variability) showing path coefficients, t values, and significance.

Table 2. Indirect pathways. Standardised indirect effects for mediation model with trial-level bias score measure of attention bias variability (AB-Var_{TLBS}), showing mediation coefficient, standard error, and 95% confidence intervals.

	Coefficient	Standard Error	95% CI lower	95% CI Upper
AB-Var _{TLBS} → Attn Control → Anxiety	.0513	.0292	.0008	.1148
AB-Var _{TLBS} → RT-Var → Anxiety	-.0078	.0498	-.1103	.0843
AB-Var _{TLBS} → Attn Control → RT-Var → Anxiety	-.0007	.0046	-.0078	.0109
Total effect	.0429	.0566	-.0731	.1484

The identical mediation model was also performed for AB-Var_{Mov}. Significance and path coefficients are shown in the full mediation model depicted in Figure 4, with indirect effects summarised in Table 3. As with the pattern of effects in the previous model, paths a, c, b, e, and F, were all significant, while d was not significant. However, unlike the previous analysis, the direct effect of AB-Var_{Mov} on Anxiety after accounting for the effect of mediator variables remained significant (path f'), suggesting that full mediation was not present. Indeed, as summarised in Table 3, the confidence limits of all mediation pathways overlapped with zero, indicating that there were no significant mediation effects. These findings therefore provide no support for the hypotheses that attention control or RT-Var, either alone or combined underpin the relationship between AB-Var_{Mov} and anxiety.

Table 3. Indirect pathways. Standardised indirect effects for mediation model with moving average measure of attention bias variability (AB-Var_{Mov}), showing mediation coefficient, standard error, and 95% confidence intervals.

	Coefficient	Standard Error	95% CI lower	95% CI Upper
AB _{Variability} → Attn Control → Anxiety	.0270	.0184	-.0008	.0693
AB _{Variability} → RT-Var → Anxiety	-.0142	.0351	-.0917	.0477
AB _{Variability} → Attn Control → RT-Var → Anxiety	-.0014	.0037	-.0099	.0057
Total effect	.0114	.0367	-.0680	.0760

Figure 4. Mediation model

Mediation pathways between 10 trial moving average measure of attention bias variability (AB-Var_{Mov}) and anxiety, via attention control and response time variability (RT-Variability) showing path coefficients, t values, and significance.

Discussion

The current study sought to examine whether response time variability and/or attention control underpin the relationship between measures of attention bias variability and anxiety using two consistently employed approaches to the computation of attention bias variability. Reliability data indicated that AB-VAR_{TLBS} showed moderate split-half reliability, while both AB-VAT_{TLBS}, and AB-Ave showed significant, though low reliability. Both measures of AB-Var and the standard AB-Ave index showed small significant relationships with anxiety in the predicted direction, with higher average attention bias toward threat, and higher attention bias variability being associated with higher levels of anxiety. Furthermore, AB-Var measures (but not AB-Ave) shared significant variance with both the proposed mediators of response time variability and attention control. In examining the roles of these mediators, attention control was found to be the only statistically significant mediator of the relationship between AB-Var_{TLBS} and anxiety. This is consistent with the underlying

role of attention control in this relationship. For the AB-Var_{Mov} measure, neither RT-Var, nor attention control significantly mediated the relationship between AB-Var_{Mov} and anxiety. Indeed, no support was found for the role of either RT-Var in isolation, or via attention control, in the relationship between either measure of AB-Var and anxiety.

The absence of any mediation effect involving RT-Var is clearly inconsistent with the hypothesis that response time variability (either alone, or as a product of attention control) underlies the relationship between AB-Var and anxiety. Thus, while RT-Var and AB-Var showed clear evidence of shared variance, this shared variance does not explain the relationship between AB-Var and anxiety in the current study. However, the sizable variance shared between AB-Var and RT-Var highlights the potential importance for future research to establish whether RT-Var explains the relationship between AB-Var and other symptoms of psychopathology.

It is relevant to consider the pattern of effects observed in the current study in light of predictions generated by Kruijt et al.'s (2016) findings using modelled data. There were some consistencies between the present findings and Kruijt et al.'s (2016). Specifically, both measures of AB-Var shared significance with RT-Var. Furthermore, as with Kruijt's findings showing that changes in averaged attention bias did not influence measures of AB-Var, we found no evidence of an association between average attention bias and measures of either AB-Var or RT-Var. As to the most substantive point posed by Kruijt et al.: that findings showing a relationship between AB-Var and emotional vulnerability may be due to either genuine attention bias variability, or due to response time variability, the present findings clearly suggest that despite significant shared variance, RT-Var did not mediate the relationship between AB-Var and anxiety. While this does not directly speak to relationships with other forms of psychopathology, the current data clearly suggest that error variance associated with RT-Var did not primarily drive the observed relationships between measures of AB-Var and anxiety. The present findings clearly highlight the importance of following-up modelled data with behavioural observation to directly assess predictions with real-world samples.

The present study did however, find evidence regarding an outstanding question flagged but not directly addressed by Kruijt et al. (2016) in relation to the potential role of cognitive control processes in measures of AB-Var. The significant mediating role of antisaccade performance in the relationship between AB-Var_{TLBS} and anxiety suggests that higher order cognitive processes such as inhibitory attention control could potentially explain effects observed with this measure of attention bias variability. Indeed, this finding highlights the possibility that relationships involving the trial-level bias score measure of attention bias in particular, may reflect the measure's sensitivity to attention control processes. As such, future studies may wish to incorporate measures of attention control to determine if effects are due to attention bias variability, or more broadly associated with attention control processes.

It is also important to acknowledge within the context of the current cross-sectional design that the mediation effects could, in principle, be influenced by general shared variance between variables examined. For example, it is possible that methodological artefacts common to multiple tasks, such as response-time variability, or degree of task engagement, could potentially contribute to shared variance observed between attention control and AB-Var_{TLBS}. The specific pattern of findings observed, however, does not necessarily support this possibility as attention control was not simply related to AB-Var_{TLBS} in general, but was specifically related to the component of attention bias variability that is also associated with anxiety, thus accounting for the relationship. Nevertheless, it is possible that other sources shared of variance could be influential in this relationship, such as general response time variability. Although, it is relevant to note that the attention control measure employed in the present design potentially decreases the probability of this. The specific antisaccade task adopted is calibrated to assess inhibitory attention control via accuracy, thus avoiding speed-accuracy trade-offs in response registration and reducing the potential influence of response-time variability in the measure of attention control. Thus, having the measure of attention control derived from accuracy and measures of attention bias derived from response times reduces (though does not eliminate) the potential for common task factors to be a

source of shared variance. An additional possibility is that general motivation could have contributed to shared variance. This would also lead to the expectation that high/low motivation on the attention probe and antisaccade tasks would contribute to a degree of corresponding high/low accuracy on both. However accuracy on the attention probe task was not related to accuracy on the antisaccade task ($r = .051$, $p = .475$).

While these task features and pattern of effects provide some reassurance for the voracity of the present findings, it will be critical for future research to further validate the outcomes of the current study. This will also be important to substantiate the mediation models examined. In particular, while the tested models were theoretically informed, it is also possible to envisage other variants of mediation models involving these same variables that could be theoretically defensible and potentially significant. In order to support the specific models examined in the current study it will be essential to replicate and extend the present findings (e.g. using additional attention control measures). More importantly, manipulation designs (e.g. targeted attention control training, neurostimulation) will be necessary to further validate of the current cross-sectional findings implicating the role of attention control in the relationship between AB-Var_{TLBS} and anxiety.

It should also be acknowledged that, while both AB-Var_{TLBS} and AB-Var_{MOV} showed similar correlations with attention control, lower levels of reliability observed for the AB-Var_{MOV} measure could have reduced the likelihood of detecting a mediation effect involving this measure and attention control. Thus it will be important for future research to confirm that the absent mediation effect for the AB-Var_{MOV} measure represents the genuine absence of an effect rather than a false negative. However, if attention control mediation is found to be restricted to the AB-Var_{TLBS} measure, it is be relevant to consider why the AB-Var_{TLBS} measure in particular may be more sensitive to effects associated with attention control as compared to the AB-Var_{MOV} measure. Given that both are derived from the same task, this difference must relate to the alternative methods used to compute these measures. One possibility is that the method of computing sequential differences between attention bias index scores used in the AB-Var_{TLBS} measure is more likely to

capture processes associated with attention control. For example, brief lapses or difficulty inhibiting irrelevant distracting information associated with poorer attention control may lead to inflated AB-Var_{TLBS} measures. Alternatively, the moving average methodology may act to smooth effects associated with brief lapses in attention as it captures variance over a broader 10 trial window, and may therefore be less sensitive to effects associated with attention control. It will be important therefore for future studies to replicate the present findings to confirm that effects associated with AB-Var_{TLBS} may actually be due to the association of this measure with attention control, and that AB-Var_{MOV} is not also underpinned by such higher order attention control processes.

In the present study we focused specifically on the relationship between measures of attention bias variability and anxiety. However, it is important to acknowledge that effects may differ when considering alternative forms of psychopathology where attention control is more or less implicated. For example, effects may be stronger in conditions such as traumatic stress disorders which are associated with diminished attention control (Blair et al., 2013) compared to other psychological disorders where attention control may be less strongly implicated. As such, the relative influence of attention control in the relationship between measures of attention bias variability and various forms of psychopathology may vary across conditions.

It should also be acknowledged that the measure of attention control employed in the current study (inhibitory attention control) is a very specific measure among a number of components of attention control that could be related to measures of attention bias variability. The present findings could therefore represent an under-estimate of the role of attention control in measures of attention bias variability, where the inclusion of measures that capture other aspects, such as switching and updating, could reveal a greater role of attention control in these processes. It will be relevant, therefore, for future studies to examine whether the addition of such measures show associations with measures of AB-Var above those observed with inhibitory attention control in the current study.

In summary, the present study found that measures of attention bias variability share significant variance with attention control and response time variability, though only attention control was observed to significantly mediate the relationship between attention bias variability and anxiety, and only for the trial-level bias score measure of bias variability. This significant mediation effect and shared variance of both bias variability measures with attention control and response time variability underscore the potential importance for future studies to determine whether it is these specific attention bias variability measures or other related cognitive processes that carry observed relationships with various measures of psychopathology.

Declaration of interests

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