Psychological Research (2020) 84:743–756
https://doi.org/10.1007/s00426-018-1081-9

ORIGINAL ARTICLE

Trait anxiety and the alignment of attentional bias with controllability of danger

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Received: 7 May 2018 / Accepted: 17 August 2018 / Published online: 21 August 2018

Abstract

Attentional bias to threat cues is most adaptive when the dangers they signal can readily be controlled by timely action. This study examined whether heightened trait anxiety is associated with impaired alignment between attentional bias to threat and variation in the controllability of danger, and whether this is moderated by executive functioning. Participants completed a task in which threat cues signalled money loss and an aversive noise burst (the danger). In 'high control' blocks, attending to the threat cue offered a high chance of avoiding this danger. In 'low control' blocks, attending to the threat cue offered little control over the danger. The task yielded measures of attentional monitoring for threat, and attentional orienting to threat. Results indicated all participants showed greater attentional orienting to threat cues in high control relative to low control blocks (indicative of proper alignment), however, high trait-anxious participants showed no difference in attentional monitoring for threat between block types, whereas low trait-anxious participants did. This effect was moderated by N-Back scores. These results suggest heightened trait anxiety may be associated with impaired alignment of attentional monitoring for threat cues, and that such alignment deficit may be attenuated by high executive functioning.

Introduction

Heightened trait anxiety is associated with a number of negative outcomes, including an increased risk of developing clinical anxiety disorders (Chambers, Power, & Durham, 2004), diminished performance on cognitive tests (Clarke & MacLeod, 2013), and impaired functioning in academic, occupational, and competitive settings (Owens, Stevenson, Hadwin, & Norgate, 2012; Putwain & Symes, 2011; Wennberg, Pathak, & Autio, 2013; Wilson, Wood, & Vine, 2009). Trait anxiety level is revealed by the frequency with which individuals experience state anxiety symptoms (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). A heightened tendency to experience symptoms of state anxiety can in part be explained by the observation that individuals with heightened trait anxiety tend to show an increased attentional bias to threat. This attentional bias reflects a propensity for high trait-anxious individuals to preferentially allocate attention towards threatening stimuli in the environment, relative to low trait-anxious individuals (Eysenck, MacLeod, & Mathews, 1987; MacLeod, Mathews, & Tata, 1986). Threatening stimuli can be conceptualised as stimuli that signal the prospect of a future negative event (Notebaert, Tilbrook, Clarke, & MacLeod, 2017). It is now well established that individuals with heightened trait anxiety have an increased attentional bias to threat (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Mathews & MacLeod, 2002).

Moreover, there is also evidence that this attentional bias causally contributes to heightened trait anxiety. This evidence has come from studies that have exposed participants to a training contingency designed to systematically induce an attentional bias either away from or towards threatening information, and have observed that the modification of such attentional bias significantly alters trait anxiety, as evidenced for example by the degree to which a lab-based stressor evokes elevated state anxiety (MacLeod & Grafton, 2016; MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002). As such, attentional bias to threat is

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widely considered to be a factor that causally contributes to heightened trait anxiety (Bar-Haim et al., 2007; Mathews & MacLeod, 2002; Van Bockstaele et al., 2014).

Critically, however, theorists have, supported by empirical developments, argued that the attentional processes that functionally underpin heightened trait anxiety may not be stable and consistent processing biases, but rather are processes that fluctuate with an individual's mood state, and across time and context. Some researchers have shown that attentional bias to threat increases when state anxiety increases (Chen, Lewin, & Craske, 1996; MacLeod & Mathews, 1988). Others have proposed that anxiety-linked attentional bias may fluctuate widely from moment-to-moment (Iacoviello et al., 2014; but see Kruijt, Field, & Fox, 2016; Zvielli, Bernstein, & Koster, 2014). Moreover, recent developments have shown that biased attention may vary in response to changing contextual demands (Large, MacLeod, Clarke, & Notebaert, 2016; Notebaert, Clarke, & MacLeod, 2016; Notebaert et al., 2017), and in some contexts, attending to threat cues may, in spite of its effect on anxiety, also have beneficial consequences.

This adaptive function of biased attention to threat is recognised by some researchers and cognitive models who have proposed that attentional bias to threat can be an important neurocognitive function critical for survival (Dolan, 2002; Notebaert et al., 2016; Ohman & Mineka, 2001). Specifically, these models suggest that attentional biases can serve an adaptive function in situations in which individuals have some degree of control over the impending danger through personal action (Dolan, 2002; Notebaert, Crombez, Vogt, et al., 2011; Ohman & Mineka, 2001; Wald et al., 2013). In these situations, if an individual's attention is biased towards threat cues which predict this danger, then this will allow them to quickly engage in appropriate danger mitigation behaviours (Dolan, 2002; Gutiérrez-García & Contreras, 2013). However, attentional bias to threat can clearly also be maladaptive, particularly when threat cues signal dangers over which one has little control. In such situations, allocating attention to threat will not contribute to danger mitigation, and will merely serve to increase levels of state anxiety (Gutiérrez-García & Contreras, 2013). Thus, attentional bias to threat cues can serve both an adaptive and a maladaptive function, and the adaptiveness of this attentional bias will depend on the degree to which the danger signalled by the threat cue can be controlled.

Most research until now has examined attentional bias to threat cues without manipulating within participants the controllability of the dangers signalled by these cues. However, to function adaptively in the complex real-world environment, attentional processes need to be flexibly regulated and calibrated to contextual demands. This alignment of attentional processes is critical to optimise the consequent efficiency of behavioural and cognitive resources (Blanchard, Griebel, Pobbe, & Blanchard, 2011; O'Donovan, Slavich, Epel, & Neylan, 2013; Rothermund, Voss, & Wentura, 2008). Despite the importance of such alignment, no research to date has examined individual differences in the alignment between attentional bias to threat cues and variation in the controllability of the dangers signalled by these threat cues. Proper alignment would consist of greater attentional bias to threat cues in contexts where an individual has more control of the danger signalled by these cues, and reduced attention to threat cues in contexts where the individual has less control of this signalled danger. Such alignment will be adaptive in that it restricts the state anxiety elevations that accompany attentional bias to threat to those situations in which such vigilance for threat enables engagement in effective danger mitigation. For example, for a parent whose child has fallen ill, it is adaptive to show increased attentional vigilance for threat cues that signal potential danger (e.g. fever, rash), despite the fact that this will likely elevate state anxiety, because detection of such threat cues if present will enable swift adaptive action to obtain the appropriate care that will attenuate the danger (escalating illness). However, when the child recovers from their illness, it becomes adaptive for the parent to no longer show such increased vigilance for threat cues, as such a bias would needlessly sustain state anxiety.

Such flexible altering of attentional processing in line with changing situational demands requires efficient executive functioning (Kashdan & Rottenberg, 2010). Executive functions are cognitive control capabilities that enable people to process information, plan actions that will facilitate attainment of goals, and modify behaviour in response to environmental changes (Diamond, 2013). Thus, aligning attentional bias to threat cues with variation in the controllability of the danger signalled by such cues is likely to require efficient executive functioning. Several cognitive processes fall under the umbrella of executive functions, including more specific processes such as interference control and response inhibition, and higher order processes such as fluid intelligence and planning (Diamond, 2013; Miyake et al., 2000). While multiple executive processes may contribute to proper alignment, one prime candidate is fluid intelligence. Fluid intelligence refers to the capacity to solve novel problems and adapt to new situations, and is a non-verbal process encompassing both reasoning and problem solving (Engle, Tuholski, Laughlin, & Conway, 1999). This ability to adapt to changing contexts could be an important contributor to an individual's capacity to change patterns of biased attention in response to changes in the controllability of dangers signalled by threat cues. Therefore, individuals with lower levels of fluid intelligence may be especially vulnerable to show impairment in such alignment.

The hypothesis under test in the present study is that heightened trait anxiety is associated with impaired alignment between attentional bias to threat cues and variation in the controllability of the danger signalled by these threat cues, and that this impairment will be most severe when executive functioning is poor. By going beyond examination of attentional bias in a single context to instead investigate individual differences in the degree to which attentional bias does or does not change adaptively as a function of context, testing this novel hypothesis will advance our understanding of the attentional factors that differentiate high and low trait-anxious individuals. Such understanding is vital for researchers seeking to explain, predict, and reduce levels of trait anxiety through addressing its attentional underpinnings.

The aim of the current study was thus to evaluate our novel hypothesis, and test it in relation to two manifestations of attentional bias distinguished in the literature (Jefferies, Enns, & Di Lollo, 2017; Richards, Benson, Donnelly, & Hadwin, 2014). One manifestation, attentional orienting to threat, operates in the presence of threat cues and is often examined using tasks in which threat cues are presented as peripheral information while participants perform some central task. Attentional orienting to threat cues is inferred when performance on this central task is impaired in the presence of these peripheral threat cues, relative to when such threat cues are absent (e.g. Schmidt, Belopolsky, & Theeuwes, 2015). In contrast, attentional monitoring for threat involves excessively scanning the environment to determine whether or not threat cues are present (Richards et al., 2014), and this is often assessed using tasks in which threat cues can appear in a predictable location. Attentional monitoring for threat is then inferred when individuals allocate attention to this location even in the absence of threat (e.g. Notebaert, Crombez, Van Damme, De Houwer, & Theeuwes, 2010).

These two manifestations of attentional bias to threat may each serve a different purpose, with attentional orienting serving to narrow attention onto threat cues present in the environment to ensure they receive processing priority, and attentional monitoring serving to ensure that the cognitive system quickly detects threat cues when they appear (Richards et al., 2014). However, importantly, both manifestations of attentional bias will be adaptive when threat cues signal more controllable dangers, as each bias then allows fast execution of the action that will mitigate these dangers. In contrast, while it may be adaptive to monitor for threat cues and to narrow attention onto presented threat cues when the dangers signalled by these threat cues are more controllable, it is less adaptive to do so when these dangers less controllable, as this would result in the pervasive elevation of state anxiety without any attendant benefit in terms of enhancing the prospect of danger reduction. In the present study, we aimed to test whether heightened trait anxiety is associated with impaired attentional bias alignment in either or both of these manifestations of attentional bias.

To test our hypothesis, a novel attentional bias alignment assessment task (ABAAT) was developed. In this task, the display consisted of a central grey circle, sometimes surrounded by a peripheral ring of differently coloured circles, with each circle (including the central one) containing a unique digit. Correctly identifying the digit displayed in the central grey circle allowed participants to gain 3 cents per trial. To assess attentional bias alignment, several critical features were implemented. The task contained a threat cue (on particular colour) that signalled a genuine negative event (the danger: loss of money and a loud noise burst), and we manipulated the degree to which participants were able to control this danger (Notebaert et al., 2011). ‘Control’ was implemented as the ability to avoid the danger by making a response that required information embedded within the threat cue. The level of controllability was varied across blocks, with some block (high control blocks) offering a high degree of control, and other blocks (low control blocks) offering a low degree of control.

Measures of attentional bias alignment were derived by contrasting the patterns of attentional bias to the threat cue observed in high control versus low control blocks. Good alignment would be evidenced by a greater attentional bias to the threat cue in the high control as compared to low control blocks. Our hypothesis predicts that high trait-anxious participants relative to low trait-anxious participants will show a reduced difference in attentional bias between these two block types. Our hypothesis further states that this negative relationship between trait anxiety and attentional bias alignment will be moderated by executive functioning. As such, participants also completed an N-Back task (Kirchner, 1958), which can be used to index fluid intelligence (Jaeggi et al., 2010). It is predicted that the strongest negative relationship between trait anxiety and attentional bias alignment will be observed in participants with the lowest N-Back scores. The ABAAT was designed such that both a measure of attentional monitoring for threat (when no threat cue was actually present), and attentional orienting to threat (when a threat cue was present) could be computed. This allowed us to examine whether any anxiety-linked reduction in attentional bias alignment was evident in either or both of these manifestations of attentional bias.

Method

Participants

To obtain a group of participants high in trait anxiety, and a group low in trait anxiety, candidate participants from the University of Western Australia’s School of Psychologyical Science’s undergraduate participant pool completed the Trait subscale of the State Trait Anxiety Inventory (STAI-T, Spielberger et al., 1983). Students who scored in the bottom and top third on this scale (scores < 38 and > 46) were invited to participate via email. As the study involved coloured visual stimuli and auditory stimuli, participants were required to have normal or corrected to normal vision, no colour blindness, or hearing problems. Seventy-nine students participated in the current study in exchange for partial course credit, including 52 females and 27 males, with a mean age of 21.8 years (SD = 5.83). Participants gave their informed consent and had the option to terminate the experiment at any time. The study was approved by the University of Western Australia's Human Research Ethics Committee.

Materials

Spielberger state trait anxiety inventory trait subscale

The Trait subscale of the State Trait Anxiety Inventory (STAI-T; Spielberger et al., 1983) was used to assess participants' trait anxiety levels for screening, and again at the time of testing. The 20-item STAI-T measures the frequency with which an individual generally experiences a range of anxiety symptoms. Total STAI-T scores range from 20 to 80, with higher scores indicating greater trait anxiety levels. The STAI-T is a commonly used measure of trait anxiety with well-established internal consistency, test–retest reliability and validity across a variety of population groups, including undergraduate students (Barnes, Harp, & Jung, 2002; Spielberger et al., 1983). In the current study, Cronbach's alpha was 0.96.

Circle stimuli

The colours for the circle stimuli presented in the ABAAT were generated using the Microsoft Windows 10 PAINT program. The display consisted one central grey circle (hue = 160, luminance = 120), and a peripheral ring of coloured circles. One of these colours (counterbalanced across participants) predicted a noise burst and loss of money, and therefore represented the threat cue. All circle stimuli were of equal size with a radius of 7.5 mm. The peripheral stimuli were spaced equally distant from neighbouring stimuli and the midpoint of the screen (5 cm). Circle stimuli consisted of a colour band (0.5 cm) and a transparent centre to ensure stimuli presented in their centre were equally easy to discriminate from the background, across colours (Notebaert, Crombez, Van Damme, De Houwer, & Theeuwes, 2011). The task required presenting circles in easy-to-discriminate colours. When present, peripheral circles each appeared in a light (luminance 180), medium (luminance 120), or dark shade (luminance 60), of one of the five colours, blue (hue = 159), aqua (hue = 119), green (hue = 72), yellow (hue = 39) and red (hue = 0). For each participant, one of these five colours was designated the threat cue, and circles presented in this colour always appeared in its medium shade, whereas the other peripheral circles each appeared in the dark or light shade of each of the remaining four colours.

Danger

The threat cue signalled the possibility that an aversive event would occur at the end of the trial, and this danger was a loud noise burst coupled with the loss of money (10 cents). The noise burst was a 500 ms 95 decibel white noise burst. Noise bursts presented for this duration and intensity are not physiologically harmful (Hobbs, 1990), but are rated as aversive (Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004). On each trial in which a threat cue was presented, there was a 50% probability the danger would follow (Notebaert et al., 2011).

Tasks

Executive functioning assessment task

Executive functioning was assessed using the single N-Back task described in Jaeggi et al. (2010). In this task, participants are presented with a random sequence of irregular shapes, and asked to press the spacebar when the currently presented shape is the same as the shape that was presented either one ($N = 1$), two ($N = 2$), or three ($N = 3$) trials before. Participants first practised each N level in a 10-trial block, after which they were tested on 1-, 2-, and 3-back levels in that order, with each level presented for three consecutive blocks. The dependent measure was the number of hits (pressing the spacebar when there was indeed a match) minus false alarms (pressing the spacebar when there was no match), averaged over all n-back levels, with a higher score representing better fluid intelligence (Jaeggi et al., 2010).

Attentional bias alignment assessment task

The attentional bias alignment assessment task (ABAAT) was developed to examine the alignment of attentional bias to threat cues, across contexts which varied in the degree to which the occurrence of the danger signalled by these threat cues could be reduced by participant action. Below, the main features of the task are described first, before the details of the implementation of the task.

Central task allowing monetary gain

To mimic the cost that attending to task-irrelevant information has on goal-driven performance, the ABAAT was configured such that participants could gain money by carrying out a central task that involved attending to the central grey circle (meaning that attending to the peripheral locus where threat cues could appear would impair participants' ability to gain this money). Specifically, each trial contained a central grey circle in which a digit probe (the digit 1–9) was briefly presented (see Fig. 1). For every trial in which the participant pressed the key corresponding to the digit probe displayed within the central grey circle, the participant gained 3 cents. The digit probe was presented for only 100 ms, to ensure that this probe would only be detected if attention was kept focussed on this central circle.

Assessment of attentional bias to threat cues

To examine whether participants showed an attentional bias to the threat cue, the central grey circle was sometimes surrounded by a peripheral ring of coloured circles, which sometimes (but not always) included the threat cue. Attentional allocation away from the central grey circle towards the peripheral locations where the outer circles could appear would therefore be reflected by reduced accuracy to identify the central digit. There were three critical experimental conditions, illustrated by the three panels shown in Fig. 1. CentralOnly trials, shown in Panel A, presented only the central grey circle, containing its digit probe. This trial type provides a baseline measure of participants' accuracy on the central task in the absence of distractors. RingNoThreat trials, shown in Panel B, presented the central grey circle together with a peripheral ring of eight non-threat cue circles, each containing a digit probe. On other trials, the outer ring of circles was presented and the threat cue was present in this outer ring. However, with a digit presented both in the threat cue and in the centre circle, it was considered possible, despite the brief exposure duration of the digits, that participants could identify both these digits. On trials in which this was the case there could be individual differences in the choice of which digit to enter. To circumvent this, on half of the trials in which a threat cue was present, only four digits were presented, randomised across the peripheral circles, with the constraint that the threat cue never contained a digit. Thus, these trials provide a cleaner measure of interference by the threat cue as on these trial participants should enter the digit probe from the central circle, but will be unable to do so to the extent that their attention was oriented towards the threat cue. These RingThreat trials which contained the threat cue but no digit within the threat cue, shown in Panel C, therefore provided the data of interest for assessing attentional orienting.

Attentional monitoring bias index

To the extent participants monitor the visual display for potential threat cues, by scanning the outer ring of circles when this is presented even if no threat cues actually appear within this outer ring, accuracy on the central task will be impaired when peripheral circles are present, as compared to when no peripheral circles are present. Thus, an Attentional Monitoring Bias index was computed for each participant by subtracting their accuracy identifying the digit probe presented in the central grey circle on RingNoThreat trials from their accuracy on CentralOnly trials. Higher Attentional Monitoring Bias index scores are indicative of greater attentional monitoring for threat cues.

Attentional orienting bias index

To the extent participants' attention was oriented towards threat cues presented within this outer ring of circles, participants' accuracy on the central task will be more greatly impaired on those trials presenting an outer ring of circles when this ring contains the threat cue, compared to those trials in which the outer ring of circles does not contain the threat cue. Thus, an Attentional Orienting Bias index was computed for each participant by subtracting their accuracy identifying the digit probe presented in the central grey circle on RingThreat trials from their accuracy on RingNoThreat

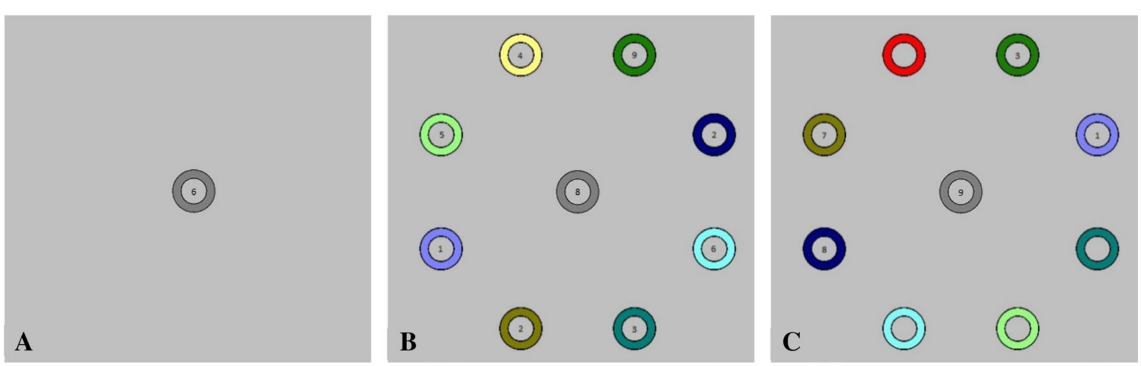

Fig. 1 Attentional bias alignment assessment task trial types. Where red is the threat cue, **a** CentralOnly trials, **b** RingNoThreat trial, and **c** RingThreat trials

trials. Higher Attentional Bias Orienting index scores are indicative of greater attentional orienting to threat cues.

Manipulation of danger controllability

To examine individual differences in the alignment of attentional bias to variation in the controllability of danger, the level of danger controllability was manipulated across blocks. In 'high control' blocks, participants had a high degree of control over the occurrence of the danger, whereas in 'low control' blocks, participants had little control over the occurrence of the danger. Specifically, in high control blocks, if participants entered the digit presented in the threat cue, they had a 87.5% chance of avoiding the danger (corresponding to successful danger avoidance on a random 7 out of 8 trials). In low control blocks, doing so gave them only a 12.5% chance of successfully avoiding the danger (corresponding to a random 1 out of 8 trials). As will be explained further in the next section, the task was configured such that in high control blocks, it was adaptive to monitor the peripheral ring of circles and/or orient attention towards the threat cue, as the total monetary loss that would be avoided by exerting control over the danger was more than the money that would be gained by attending to the central grey circle and entering the digit probe it contained. By contrast, in low control blocks, it was maladaptive to monitor the peripheral ring of circles and/or have orient attention towards the threat cue, as the total monetary loss that could be successfully avoided by attempting to exert control over the danger was less than the money that could be gained by attending to the central grey circle and entering the digit probe it contained.

Task implementation details

The task consisted of 8 blocks of 48 trials, totalling 384 trials. There were four high control blocks and four low control blocks, which alternated, with the condition of the starting block being counterbalanced across participants. Each block of trials contained 16 CentralOnly trials, 16 RingNoThreat trials, and 16 RingThreat trials (with half of them only presented digit probes in four peripheral circles). Within each block, the threat cue was presented twice in every possible peripheral location, once with a digit probe and once without.

In each trial, the circle stimuli appeared on screen first, without digit probes. After 250 ms, a unique digit probe was presented in each circle for 100 ms. The display was then cleared, and participants were required to enter a digit on the numerical part of the keyboard. Following this response, a screen showed the amount of money gained (e.g. "+ 3"), or lost (e.g. "− 10") on that trial, and the noise burst was delivered depending on the trial configuration and digit response. The inter-trial-interval was 1000 ms.

Given the number of trials, in each block type (high control and low control) participants had the ability to gain 576 cents overall by consistently attending to and entering the digit probes within the central grey circle (48 trials × 4 blocks × 3 cents). However, they also stood to lose 320 cents per block type (16 trials with threat cue present × 4 blocks of each block type × 50% probability of danger occurring). In high control blocks, participants could avoid losing 140 cents through consistently monitoring for and attending to threat cues, and entering the digit probes presented within the threat cue (which would require them to forego gaining the 96 cents they would have earned by attending to entering the digit probe presented within the central grey circle). Monitoring for and attending to the threat cues was, therefore, adaptive in the high control condition. In low control blocks, monitoring for attending to threat cues, and entering the digit probes within them, could enable participants to avoid losing 20 cents (which still would require them to forego gaining the 96 cents they would have earned by attending to entering the digit probe presented within the central grey circle). Monitoring for and attending to the threat cues was, therefore, maladaptive in the low control condition.

Procedure

Participants were tested in individual cubicles in a quiet laboratory setting, positioned approximately 60 cm from the computer screen. Participants first provided demographic information, and then completed the STAI-T and N-Back tasks. Next, they were provided with the instructions for the ABAAT, and it was emphasised that they could earn real money in this task. The task started with a staged practice component, first requiring participants to complete ten trials (five CentralOnly and five RingNoThreat) which allowed them to rehearse entering the digit presented in the central circle and gaining money. Next, participants were instructed which colour predicted a loss of 10 cents and the delivery of a noise burst at the end of the trial. Participants then completed another 16 practice trials, in which the threat cue was present on eight trials, four of which were followed by the money loss and noise burst. This phase was designed to have participants experience the threat cue predicting the money loss and noise burst within the practice phase. Following these practice trials, participants were informed about their ability to avoid the danger by entering the digit presented within the threat cue, and were also told about the difference in controllability of this danger across block types. No exact probabilities were conveyed to participants, rather instructions referenced a "high chance" or "low chance" of being able to avoid the danger. At the start of each block, participants were informed whether, in the upcoming block, there was a high or low chance of avoiding the money loss and noise burst by entering the digit presented in the threat cue. At the end of each block, participants were shown how much they earned in that block. Following completion of the 384 trials, participants were debriefed and received the money they had gained in the task.

Results

Participant characteristics

Descriptive statistics for age, gender, trait anxiety, executive functioning scores, and the amount of money earned in the attentional bias alignment assessment task are presented in Table 1. STAI-T scores obtained at the time of testing were used to divide participants into a low and a high trait-anxious group using a median split (cut-off score of 45). There were no significant differences between groups on demographic measures or N-Back score measures, all $p > 0.05$. As expected, there was a significant group difference in STAI-T scores, $p < 0.001$. Furthermore, high trait-anxious participants on average ended up earning significantly less money than did low trait-anxious individuals, $t(77) = 2.85$, $p = 0.006$, $d = 0.643$.

Table 1 Trait anxiety scores (STAI-T), mean (SD) age, gender distribution, executive functioning (N-Back) scores, and amount of money earned in the attentional bias alignment task (M, SD) for the high and low trait-anxious groups

	Low trait anxious ($N = 40$)	High trait anxious ($N = 39$)
STAI-T	35.30 (5.98)	54.36 (5.21)
Age	22.20 (7.18)	19.92 (3.78)
Gender (F/M)	24/16	28/11
N-Back score	3.09 (1.14)	2.97 (1.68)
Money earned	$3.62 (0.92)	$2.96 (1.12)

Attentional bias alignment

Participants' rates of accuracy in identifying and entering the digit contained within the central grey circle, on each trial type and block condition, are presented in Table 2, which also shows the two attentional bias index scores derived from these data.

Examining anxiety-linked impaired alignment in attentional monitoring bias

Our hypothesis predicts that heightened trait anxiety will be characterised by impaired alignment between attentional bias to threat cues and variation in the controllability of the danger signalled by these threat cues. To test this hypothesis in relation to attentional monitoring for threat, Monitoring Bias index scores were subjected to a 2×2 mixed design ANOVA, considering Block Type (high control versus low control) as a within subjects factor, and Anxiety Group (high trait anxious versus low trait anxious) as a between subjects factor. There was no significant main effect of either Block Type, $F < 1$, or Anxiety Group, $F < 1$. However, there was a significant interaction between these two factors, $F(1,77) = 6.643$, $p = 0.012$, $\eta_p^2 = 0.079$. Follow-up paired sample t test revealed this interaction to reflect the fact that only the low trait-anxious participants demonstrated alignment of attentional monitoring bias for threat cues with controllability of the signalled danger, showing significantly greater monitoring bias index bias scores in the high control blocks as compared to low control blocks, $t(39) = 2.164$, $p = 0.037$, $d = 0.441$. In contrast, for the high trait-anxious participants, the difference in monitoring bias between these block types was in the reverse direction, though this difference was not significant, $t(38) = 1.581$, $p = 0.112$, $d = 0.365$. Thus, the high trait-anxious participants displayed no evidence that their attentional monitoring bias for threat cues was aligned with the controllability of the danger.

Table 2 Central digit identification accuracy on the different trial types, and resulting attentional monitoring bias and orienting bias scores, shown by high and low trait-anxious participants on high and low control blocks

	Low trait anxious				High trait anxious			
	High control blocks		Low control blocks		High control blocks		Low control blocks	
	M	SD	*M*	SD	*M*	SD	*M*	SD
CentralOnly	0.995	0.015	0.994	0.011	0.986	0.022	0.991	0.018
RingNoThreat	0.982	0.034	0.992	0.023	0.984	0.023	0.977	0.045
RingThreat	0.783	0.148	0.905	0.111	0.708	0.176	0.821	0.169
Monitoring Bias Index Score	0.014	0.032	0.002	0.019	0.002	0.019	0.013	0.040
Orienting Bias Index Score	0.199	0.142	0.087	0.108	0.276	0.177	0.157	0.168

The moderating influence of executive functioning on anxiety-linked differences in alignment of attentional monitoring bias

To examine whether executive functioning moderated the relationship between trait anxiety and alignment in attentional monitoring, a moderation analysis was performed according to the guidelines provided by Hayes (2013), using PROCESS (Hayes, 2012). This method uses an ordinary least squares regression approach to estimate moderation effects. First, a Monitoring Alignment Index was created for each participant by subtracting the Monitoring Bias Score in low control blocks from the Monitoring Bias Score in high control blocks. As it is more adaptive to monitor for threat in high control blocks than in low control blocks, a higher Monitoring Alignment Index indicates better alignment of biased attentional monitoring for threat cues with the controllability of the danger signalled by these threat cues. The split-half reliability of this Monitoring Alignment Index was significant but moderate, $r=0.626$, $p<0.001$ (reliability was calculated using an odd/even trial number split and applying the Spearman–Brown formula, as in Kappenman, Farrens, Luck, & Hajcak Proudfit, 2014). This Monitoring Alignment Index served as the outcome variable in the moderation analysis, while continuous STAI-T scores were used as predictor and continuous N-back scores as moderator. The predictor and moderator were mean centred to create the interaction variable.

The overall moderation model was significant, explaining 25.5% of the variance in Monitoring Alignment, $F(3, 74)=8.452$, $p<0.001$, MSE = 0.001. Of greatest importance to the hypothesis under test, the interaction term was a significant predictor of monitoring alignment, $p<0.001$, with this predictor explaining an additional 11.1% of the variance over and above the main effects, $F(1,74)=11.038$, $p=0.001$. The nature of this moderating effect is depicted in Fig. 2. This figure plots Monitoring Alignment scores for individuals with low trait anxiety scores (1 SD below the mean), average trait anxiety scores (the mean), and high trait anxiety scores (1 SD above the mean), as a function of their N-Back scores. For each level of the predictor, three data points are represented for the moderator, corresponding to N-Back scores 1 SD below the mean, average N-Back scores, and N-Back scores 1 SD above the mean. As can be seen, the negative relationship between trait anxiety and monitoring alignment is strongest for those with the lowest executive functioning scores, effect = −0.003, $t=4.412$, $p<0.001$, was attenuated but still significant in those with average executive functioning scores, effect = −0.001, $t=3.256$, $p=0.002$, but was not evident at all in those with high executive functioning scores, effect = 0.000, $t<1$.

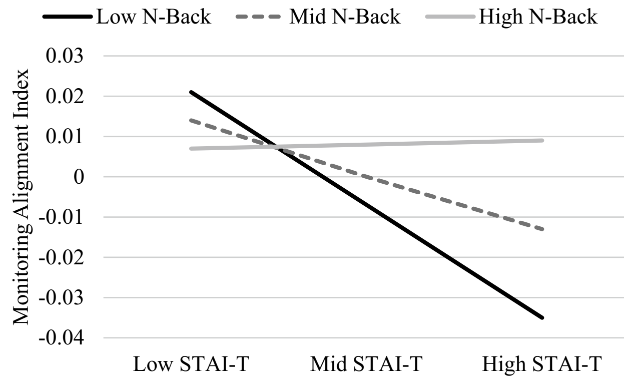

Fig. 2 The moderating influence of executive functioning (N-Back scores) on the relationship between trait anxiety (STAI-T scores) and alignment of attentional monitoring bias

Examining anxiety-linked impaired alignment in attentional orienting

To test our central hypothesis in relation to attentional orienting to threat, Orienting Bias Scores were subjected to a 2 × 2 mixed design ANOVA including Block Type (high control versus low control) as a within subjects factor, and Anxiety Group (high trait anxious versus low trait anxious) as a between subjects factor. There was a significant main effect of Anxiety Group, $F(1,77)=5.796$, $p=0.18$, $eta_p^2=0.070$, indicating that high trait-anxious participants showed more attentional orienting to the threat cues ($M=0.217$, SD = 0.137) than did low trait-anxious participants ($M=0.143$, SD = 0.133). There was also a large main effect of Block Type, $F(1,77)=61.493$, $p<0.001$, $eta_p^2=0.444$, indicating that participants generally showed alignment of attentional orienting to threat cues with controllability of the danger, evidenced by the fact that these Orienting Bias scores were higher in the high control blocks ($M=0.237$, SD = 0.164) than in the low control blocks ($M=0.121$, SD = 0.144). However, the interaction between Block Type and Anxiety Group was not significant, $F<1$, indicating that the alignment of attentional orienting with danger controllability was not reduced in the high trait-anxious participants, compared to the low trait-anxious participants.

The moderating influence of executive functioning on anxiety-linked differences in alignment of attentional orienting bias

To examine whether executive functioning moderated the relationship between trait anxiety and alignment in attentional orienting bias, again a moderation analysis was performed. First, an Orienting Alignment Index was created for each participant by subtracting the Orienting Bias Score in low control blocks from the Orienting Bias Score in high control blocks, with a higher Orienting Alignment Index indicating better alignment of biased attentional orienting to threat cues with the controllability of the danger signalled by these threat cues. The split-half reliability of this Orienting Alignment Index was also significant but moderate, $r = 0.573$, $p < 0.001$. This Orienting Alignment Index served as the outcome variable in the moderation analysis, while STAI-T scores were used as predictor and N-back scores as moderator. This time, however, the overall moderation model was not significant, explaining only 4.0% of the variance in Orienting Alignment, $F(3, 74) = 1.029$, $p = 0.385$, MSE = 0.017.

Discussion

The aim of the current study was to empirically test the hypothesis that heightened trait anxiety is characterised by impaired alignment between attentional bias to threat cues and the controllability of the danger signalled by these threat cues, and that this relationship is moderated by executive functioning. We examined two manifestations of attentional bias to threat. The first was attentional orienting to threat cues present in the stimulus display, which serves to narrow attention to these threat cues to give them processing priority. The second was attentional monitoring for threat cues, which can occur in the absence of threat cues and serves to increase the prospect of quickly detecting such cues should they be presented.

With regards to attentional orienting, results revealed that participants' attention was oriented towards threat cues to a greater extent when the danger predicted by these threat cues was more controllable (in high control blocks), relative to when the danger was less controllable (in low control blocks). This alignment of attentional orienting to the threat cue with the controllability of the danger represents an adaptive pattern of attentional responding, as attentional orienting to the threat cue in high control blocks provided a high chance of avoiding the 10 cents loss and the aversive noise burst. Specifically, if participants attended to and entered the digit presented within the threat cue in these high control blocks, they had an 87.5% chance of avoiding the danger. In contrast, attentional allocation to the threat cue in the low control blocks was not adaptive, as attending to and entering the digit presented within the threat cue on these low control blocks would seldom eliminate danger (12.5% chance), and would instead result in the participant forfeiting the substantially greater amount of money they would have gained across the block by attending to and entering the digit presented within the central grey circle.

High trait-anxious individuals showed greater attentional orienting to the threat cue relative to low trait-anxious individuals, which is consistent with the previous literature (Bar-Haim et al., 2007; Notebaert et al., 2017). However, contrary to our hypothesis, there was no significant difference between high and low trait-anxious individuals in the degree to which attentional orienting to threat was aligned with the controllability of the danger. Rather, danger controllability had an equivalent impact on patterns of attentional orienting in high and low trait-anxious participants. While our findings did not support the hypothesis that heightened trait anxiety is characterised by reduced alignment of biased attentional orienting to threat cues with variation in the controllability of the danger signalled by these cues, support for this hypothesis was obtained when we instead considered biased attentional monitoring for threat cues.

Specifically, high trait-anxious individuals did show a significant impairment in alignment of attentional monitoring for threat cues with variation in the controllability of the danger. The results showed that low trait-anxious participants demonstrated such alignment, with scores indexing attentional monitoring for threat cues being higher in the high control blocks than in the low control blocks. However, for high trait-anxious participants, there was no significant difference between attentional monitoring scores in high control blocks and low control blocks. These results indicate that consistent with our hypothesis, high trait-anxious participants displayed equivalent attentional monitoring for threat cues regardless of whether the danger signalled by these threat cues was more or less controllable. This impaired attentional monitoring alignment in high trait-anxious individuals would result in these individuals monitoring for threat cues in situations where there is no functional advantage to doing so.

It is important to note that participants' performance on the trial types that contributed to the measure of attentional monitoring (CentralOnly and RingNoThreat), was relatively high. In all conditions and participant groups, accuracy was above 97%, which means that the computation of the attentional monitoring indices is based on a limited number of data points. This high accuracy rate may decrease the amount of variability present in the data. Therefore, caution is needed when interpreting these effects, and replication is warranted before firm conclusions about the relationship between trait anxiety and alignment in attentional monitoring can be made. In such a replication, modifications could be made to the paradigm to increase the error rate on the CentralOnly and RingNoThreat trial types, to allow for more variability in the attentional monitoring indices. This could be done, for example, by reducing the presentation duration of the digits, or increasing the diameter of the peripheral circle. However, when implementing these modifications, it will be important to ensure the conceptual features of the task remain unchanged. It was important in the current task to ensure a balance between providing a clear incentive for attending to the central circle location (i.e. gaining three cents per trials), and implementing a cost or benefit (in low control and high control blocks, respectively) of attending to the peripheral ring of circles. If it is made too hard for participants to accurately report the information in the central circle, this may alter responses in a way that may reduce the capacity to measure attentional bias alignment (for example, if participants ignore the peripheral information altogether in an effort to focus on the central task). Nevertheless, it will be important for future research to conduct a conceptual replication of this design, to examine whether this would provide converging evidence for an anxiety-linked impairment in attentional monitoring alignment.

If such converging evidence is obtained, it would be interesting to consider whether such maladaptive attentional monitoring for threat cues signalling poorly controllable dangers could account in part for the reduced emotional well-being as well as the compromised productivity associated with heightened trait anxiety. The likely emotional consequence of impaired monitoring would be increased state anxiety, as attentional bias to threat is known to elevate anxiety reactivity to stressor (Price et al., 2016; Van Bockstaele et al., 2014). If high trait-anxious individuals monitor for threat in contexts where low trait-anxious individuals do not, then this could contribute to their increased experience of anxiety symptoms. This novel line of research examining whether heightened trait anxiety is characterised by an attentional insensitivity to contextual variables that determine the extent to which threat cues signal danger that can be controlled, may thus represent an important avenue for future research aiming to understand and ameliorate the maladaptive expressions of attentional bias to threat that underpin heightened trait anxiety.

Such future research could, for example, examine whether impaired attentional bias alignment makes a causal contribution to anxiety vulnerability (e.g. Notebaert et al., 2016). Such studies could implement extended versions of our attentional bias alignment task, combined with feedback encouraging participant to attend to the threat cue more in high control blocks, and less in low control blocks. The effectiveness of this training in changing attentional bias alignment can then be assessed relative to a control group in which the reverse pattern of attentional allocation is encouraged, thereby decreasing alignment. The impact on bias alignment can be examined in a second alignment assessment task which shares the capacity to assess patterns of attentional bias to threat cues signalling more and less controllable dangers, but employs different threat and non-threat cues, and different danger stimuli. Subsequently, participants can be exposed to a stressor (aspects of which are controllable but containing other aspects which are uncontrollable), with measures of state anxiety taken before and after this stressor. If impaired attentional bias alignment causally contributes to anxiety vulnerability, then if the attentional training is successful the group trained to increase attentional bias alignment should show reduced elevations in state anxiety in response to the stressor as compared to the group trained to reduce attentional bias alignment.

Given that impaired attention monitoring alignment is a sub-optimal pattern of attentional allocation, it may negatively impact on individuals' functioning in ways that impede the pursuit of other important goals. In the current task, monitoring for threat cues in low control blocks was maladaptive, as monitoring for such threat cues compromised success on the central task, thereby imposing performance costs without yielding benefits. Results showed that high trait-anxious participants on average did end up earning significantly less money than did low trait-anxious individuals. Future research may therefore further investigate whether poorly aligned attentional bias to threat indeed contributes to detrimental situational outcomes, in addition to increasing levels of state anxiety, as this may represent one avenue through which heightened trait anxiety contributes to functional impairments such as diminished performance in academic, occupational, and competitive settings (Chambers et al., 2004; Clarke et al., 2017; Owens et al., 2012).

Our results further showed that the relationship between trait anxiety and alignment of attentional monitoring appeared to be moderated by executive functioning. Specifically, heightened trait anxiety was significantly associated with impaired alignment of attentional monitoring for threat in those participants with low or moderate n-back scores, but was not apparent in participants with high n-back scores. The N-back task can be considered to be a measure of fluid intelligence (Jaeggi et al., 2010), and previous research has shown that fluid intelligence is important for the flexible regulation of attentional processes (Stankov, 1988). Our results suggest that high levels of fluid intelligence may protect against the association between trait anxiety and impaired alignment of attentional monitoring. In contrast, poor levels of fluid intelligence may further compromise an individual's ability to align attentional monitoring for threat with variation in the controllability of danger.

Given that fluid intelligence comprises inductive and deductive reasoning, it is possible that low levels of fluid intelligence compromrise an individual's ability to deduce the optimal attentional strategy within a particular block of the attentional bias alignment assessment task. Thus, such individuals may fail to recognise that the most optimal attentional strategy in high control blocks is to attend to the threat cue, while the most optimal strategy in low control blocks is to focus on the central circle. Future research may probe this possibility by questioning strategy use at the end of the task. A second possibility is that individuals with lower levels of fluid intelligence fail to differentiate between contexts in which the signalled danger is more or less controllable. However, this is considered unlikely in the current task, as prior to the start of each block, participants were explicitly instructed whether in the coming block they had a high or low chance of being able to avoid the danger. However, future research that removes this explicit instruction, and instead requires participants to learn about the controllability of the signalled danger through performance on the task, could examine whether heightened trait anxiety and/or poor fluid intelligence is associated with a reduced ability to infer whether dangers are more or less controllable, and whether this contributes to anxiety-linked impairment of attentional bias alignment.

The N-back task is not a process-pure measure of fluid intelligence, and other executive functions such as online monitoring and updating are also known to contribute to N-back performance (Chan, Shum, Toulopoulou, & Chen, 2008). Both these processes may therefore also contribute to individual differences in attentional bias alignment. Indeed, to respond adaptively across changing contexts, the environment needs to be monitored for such change, and information in working memory needs to be updated when any changes occur to represent the latest state of affairs. Impairments in other executive functions may similarly contribute to attentional bias misalignment. For example, attentional control, or the ability to orient attention in accordance with one's goals, is critical to focus attention on particular goal-relevant information, and to inhibit attention to information that is not relevant to current goals (Derakshan & Eysenck, 2009; Müller & Geyer, 2009). Future research may thus seek to determine the specific facets of executive functioning that are most strongly implicated in the moderation of anxiety-linked impairment in attentional bias alignment.

It is relevant to consider why the anxiety-linked alignment impairment was observed in attentional monitoring for threat, and not in attentional orienting to threat. In light of these differential findings, we first examined the internal reliability of both alignment indices. Previous research examining the reliability of attentional bias to threat has revealed that the most commonly used task to index this attentional bias, the dot-probe task (MacLeod et al., 1986) shows poor and often non-significant split-half reliability (Chapman, Devue, & Grimshaw, 2017; Kappenman et al., 2014; MacLeod et al., 1986; Price et al., 2014; Schmukle, 2005; Waechter, Nelson, Wright, Hyatt, & Oakman, 2014). Such reliability can be problematic for correlational research, although it is less of a problem for power and replicability in experimental research (De Schryver, Hughes, Rosseel, & De Houwer, 2016). Given that our attentional bias alignment assessment task is a novel paradigm, it was considered important to examine the reliability of the key measures derived from it, the Monitoring Alignment Index and the Orienting Alignment Index. As reported, the split-half reliability of these indices was moderate, 0.626 and 0.573, respectively, which is higher than traditional attentional bias assessment paradigms. In addition, these results suggest the differential findings obtained for attentional monitoring and attentional orienting alignment are not likely to be due to a substantial difference in the internal reliability of these two measures.

A potential alternative explanation for the differential pattern of findings regarding orienting and monitoring could relate to differences in the relative automaticity of these two manifestations of attentional bias to threat. Previous research has shown that the expression of attentional bias is subject to both bottom-up or automatic influences, and top-down or strategic influences (Cisler & Koster, 2010; Notebaert et al., 2010; Notebaert, Crombez, Van Damme, Durnez, & Theeuwes, 2012). While the current design does not permit discrimination of the degree to which strategic and automatic processes underpin attentional monitoring and orienting, it may be that attentional monitoring for threat is more dependent on strategic processes than is attentional orienting to threat (Beck & Clark, 1997). If the hypothesized anxiety-linked impairments in attentional bias alignment result from anxiety-linked differences in strategic processing, then this may account for why such effects are restricted to our measure of attentional monitoring for threat. Future research could directly test this proposal, for example, by imposing a secondary cognitive load on the task to disrupt strategic processing (Clarke et al., 2017).

Of course, this study is not without its limitations. This is the first study to examine individual differences in the alignment of attentional processes to contextual variation in the controllability of danger. It is therefore important to replicate and extend these findings before firm conclusions are being drawn about the relationship between trait anxiety and attentional bias alignment. Related to this, in addition to making task modifications to increase the error rate, it would be prudent to replicate these findings with different incentive and danger stimuli, to ensure that these present findings are not constrained to the use of money and noise bursts, but remain valid across a variety of tasks employing differing types of threat cues to signal different types of dangers. Second, our measures of attention bias were derived by determining the degree to which different peripheral stimuli interfered with participants' ability to identify the digit presented in the central grey circle. While it is common to assess attentional bias through the use of such interference methodologies, future research could employ eye-tracking to provide a converging measure of attentional monitoring for threat and orienting to threat (Richards et al., 2014). This would also allow eliminating the trials in which no digit was presented in the threat cue, which would increase the overall level of danger controllability. Third, participants in the present study varied in trait anxiety, but were not selected on the basis of anxiety pathology, and so the current findings cannot be generalised to clinical populations.

Nevertheless, the present findings suggest that heightened trait anxiety, especially in combination with poor executive functioning, may be associated with impaired alignment between attentional monitoring for threat cues, and variation in the controllability of the danger signalled by these threat cues. The current study is the first to investigate individual differences in calibrating attentional bias to contextual variation in the adaptiveness of attending to threat. We hope that these findings and the novel methodology introduced in this study will be of value to future work seeking to illuminate the processes that contribute to anxiety-linked impairment in the alignment of attentional bias, and its contribution to maladaptive emotional and behavioural functioning.

Funding Preparation of this paper was supported by Australian Research Council Grants FL170100167 and DP170104533. EF and SP were supported by the European Research Council (ERC) under the European Union's Seventh Framework Programme (FP7/2007–2013)/ERC Grant agreement no: [324176]. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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