HHS Public Access

Author manuscript

J Affect Disord Rep. Author manuscript; available in PMC 2023 January 19.

Published in final edited form as:

J Affect Disord Rep. 2022 December ; 10: . doi:10.1016/j.jadr.2022.100411.

The questionable validity of attention bias variability: Evidence from two conceptually unrelated cognitive tasks

Joshua M. Carlson[*],

Lin Fang,

Dahlia Kassel

Department of Psychological Science, Northern Michigan University, 1401 Presque Isle Avenue, Marquette, MI 49855, USA

Abstract

Background: Attention bias variability is thought to measure fluctuations in attention towards and away from threat-related information and is elevated in affective disorders. However, recent evidence suggests that attention bias variability may quantify general reaction time variability rather than attention bias behavior *per se*.

Methods: The current study calculated "attention bias variability" from two conceptually unrelated cognitive tasks: the dot-probe task (measuring attentional bias) and the arrow flanker task (measuring cognitive control).

Results: Attention bias variability measures were correlated across these unrelated tasks. Yet, when general reaction time variability was controlled, attention bias variability across tasks was no longer correlated. In addition, the reliability of attention bias variability measures decreased when controlling for general reaction time variability. Finally, although attention bias variability calculated from the dot-probe task initially correlated with anxious symptoms, this association was no longer significant when controlling for general reaction time variability.

Limitations: Our sample was comprised of high trait anxious individuals. Replication in clinical samples is warranted.

Conclusions: These findings collectively provide strong empirical evidence that attention bias variability is not a valid measure of attention-related behavior, but reflective of general reaction time variability more broadly.

[*]Corresponding author. joshcarl@nmu.edu (J.M. Carlson).

Author contributions

Conceptualization, funding acquisition, and writing of the original draft was performed by JMC. JMC and LF designed the study methodology. LF, DK, and JMC were involved in the formal analysis of the data. Review and editing of the manuscript was provided by all authors.

Declaration of Competing Interest

The authors have no conflict of interest to declare.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jadr.2022.100411.

Keywords

Attention bias; Attention bias variability; Dot-probe task; Reliability; Validity; Anxiety

1. Introduction

Attention-based mechanisms are necessary to select information from a continuous stream of vast sensory input that cannot be processed in its entirety. Information that is selectively attended, receives prioritized processing at the expense of unselected information (Desimone and Duncan, 1995). Emotional—and in particular threatening—information tends to automatically capture attention, which is referred to as *attentional bias*. Attentional prioritization of threat-related information can prepare an individual for impending danger (Ohman and Mineka, 2001). Yet, heightened attentional bias to threat can become maladaptive and is considered a hallmark of anxiety and other mental health disorders (Bar-Haim et al., 2007; Beck and Clark, 1997; Cisler and Koster, 2010; MacLeod and Mathews, 1988; Mathews and Mackintosh, 1998; Mogg and Bradley, 2018).

A common approach to measuring attentional bias is the dot-probe task (MacLeod et al., 1986) where two stimuli are briefly displayed on a computer screen. One of the stimuli is threat/emotion-relevant and the other is emotionally neutral. Following the presentation of these two stimuli, a target "dot" (or other target stimulus) occurs at the location of one of the previously displayed stimuli. Attentional bias is traditionally measured by the difference in reaction times (RTs) on trials where the target occurs at the location of the threatening stimulus (i.e., congruent trials) compared to the neutral stimulus (i.e., incongruent trials), and this RT-based difference score reflects a given individual's attentional bias to threat. However, these RT difference score measures of attentional bias are now notoriously unreliable and unsuitable for individual differences research (Aday and Carlson, 2019; Chapman et al., 2019; Price et al., 2015; Schmukle, 2005; Staugaard, 2009; Van Bockstaele et al., 2020).

Attention bias variability (ABV) measures—which aim to tap into the possibility that attentional bias is not static, but dynamic with alternating periods of attentional focus towards and away from threat—were introduced (in part) to overcome the low reliability of traditional dot-probe based attentional bias measures (Iacoviello et al., 2014; Zvielli et al., 2015). Most recently, the *trial level bias score* (i.e., the difference between each congruent and incongruent trial and the closest opposing trial type) was introduced to quantify attentional bias on a moment-by-moment (i.e., trial-by-trial) basis and the variability in these trial level bias scores (Zvielli et al., 2015). Initial research using ABV measures found that they were much more reliable than the traditional mean RT difference score approach (Davis et al., 2016; Molloy and Anderson, 2020; Naim et al., 2015; Price et al., 2015; Rodebaugh et al., 2016; Zvielli et al., 2016). In addition, ABV measures have been shown to be elevated in a variety of affective disorders (Davis et al., 2016; Naim et al., 2015; Price et al., 2015; Zvielli et al., 2016) suggesting a common transdiagnostic dysfunction in the allocation of attentional resources towards (and away from) emotional/threat related information in these disorders.

Although much of the field was quick to adopt the usage of ABV measures as a viable replacement for the traditional bias index, there is an unsettled question about what exactly ABV-based measures actually quantify. Initial modeling data found that general RT variability and mean RT speed can influence measures of ABV (Kruijt et al., 2016), suggesting that ABV may reflect more than just dynamic fluctuations in attentional bias. Subsequent empirical research confirmed that ABV measures are correlated with general RT variability (Alon et al., 2019; Carlson and Fang, 2020; Clarke et al., 2020; Swick and Ashley, 2017) and that the superior reliability of ABV-based measures (compared to traditional difference score-based measures) drops considerably when general RT variability (Carlson and Fang, 2020) or general RT speed (Vervoort et al., 2021) are controlled. Additionally, task-based timing parameters such as stimulus onset asynchrony (SOA) influence ABV measures (Carlson et al., 2019). In terms of their clinical relevance, some research suggests that ABV measures maintain their predictive value in clinical samples when controlling for RT variability (Alon et al., 2019), whereas other research suggests that this association is driven by RT variability (Swick and Ashley, 2017).

Therefore, accumulating research suggests that ABV-based measures may not represent *attention bias* variability *per se*, but rather RT variability more broadly. That is, ABV may not be a valid measure of attentional bias behavior. Given the importance of attentional bias in cognitive models of anxiety and other affective disorders (Beck and Clark, 1997; Cisler and Koster, 2010; MacLeod and Mathews, 1988; Mathews and Mackintosh, 1998; Mogg and Bradley, 2018) as well as the link between ABV-based measures and mental health conditions (Bardeen et al., 2017; Davis et al., 2016; Naim et al., 2015; Price et al., 2015; Todd et al., 2022; Zvielli et al., 2016), it is important to further interrogate the underlying mechanism (and validity) of ABV-based measures. Indeed, the distinction between ABV *per se* and general RT variability has important implications for cognitive theories of affective disorders and cognitive bias modification interventions aimed at treating these disorders.

To address this knowledge gap, the current study utilized an existing sample of highly anxious individuals who completed a fearful face dot-probe task of attentional bias and an unrelated cognitive task (i.e., the arrow flanker task). Trial level bias score “ABV” measures were computed in both tasks and compared. The rationale was that if ABV-based measures quantify ABV *per se*, then the correlation between “ABV” measures from two conceptually unrelated tasks should be weaker than the correlation observed within the same task measuring the same cognitive process (i.e., discriminant validity). On the other hand, if ABV actually quantifies RT variability more broadly, then these ABV-based measures should be correlated across unrelated RT tasks (with a strength comparable to the reliability estimates obtained in a single task). In addition, if a correlation across tasks in ABV measures is found, it should be eliminated/weakened when controlling for general RT variability (if ABV-based measures capture general RT variability). Based on the research reviewed above (e.g., Carlson and Fang, 2020; Kruijt et al., 2016), we hypothesized that ABV-based measures represent RT variability more broadly.

2. Methods

2.1. Participants

Participants included 122 (83 females) adults between the ages of 18 and 42 (M = 21.85, SD = 4.63) years old who were part of a larger clinical trial assessing the effects of attention bias modification on changes in brain structure and function (NCT03092609) (Carlson et al., 2022). For this larger clinical trial, all participants were screened for high levels of trait anxiety (STAI-T scores ≥ 40) and an attentional bias toward threat (dot-probe task incongruent - congruent bias scores ≥7 ms),[1] since previous research indicates that attention bias modification is most effective in highly anxious individuals with a pre-existing attentional bias to threat (Amir et al., 2011; Heeren et al., 2015; Kuckertz et al., 2014; Mogoase et al., 2014). Additional inclusion criteria included the following: (1) right-handed, (2) 18–42 years old, (3) normal (or corrected to normal) vision, (4) no current psychological treatment, (5) no recent history of head injury or loss of consciousness, (6) no current psychoactive medications, (7) not claustrophobic, (8) not pregnant, and (9) no metal in the body or other MRI contraindications. The university's Institutional Review Board approved of this study. Monetary compensation was provided to participants for the completion of the study.

2.2. State-trait anxiety inventory

Trait anxiety scores were obtained for all participants using the Spielberger State-Trait Anxiety Inventory (STAI; Spielberger et al., 1970). There are 20 items on the STAI-T that measure trait anxiety (how anxious one feels in general, as opposed to how one feels in a given moment). The range of STAI-T in the current sample was between 40 and 71 (M = 51.68, SD = 7.37) and the Cronbach's alpha for the STAI-T was 0.83.

2.3. Dot-probe task

A facial dot-probe task (MacLeod et al., 1986) was programmed in E-Prime2 (Psychology Software Tools, Pittsburg, PA). Stimuli included grayscale images of 20 fearful and neutral faces of 10 different actors (half female; Gur et al., 2002; Lundqvist et al., 1998). In order to exclude extraneous features (e.g., hair) in the face stimuli, the images were cropped accordingly. Ratings data from a separate sample showed that the fearful face stimuli were perceived as more negative (M = 3.83, SD = 0.30) than the neutral face stimuli (M = 4.45, SD = 0.52), t(18) 3.23, p = .005.

Each participant was seated 59 cm from the computer screen. A white fixation cue (+) was presented in the center of a black screen at the beginning of each trial for 1000 ms. Following the fixation cue, two faces were presented concurrently on the horizontal axis for 100 ms. Face stimuli were separated by approximately 14° of the visual angle and accounted for approximately 5° × 7° of the visual angle. Immediately after the face stimuli disappeared, the target dot appeared on the left or right side of the screen. A Chronos E-Prime response box was used to record responses. Participants were instructed to use their

[1]Note that previous research indicates that the traditional difference score measure of attentional bias is generally unreliable (Schmukle, 2005) and uncorrelated with RT variability (Carlson and Fang, 2020). Therefore, it is unlikely that selecting participants based on this difference score measure would impact the RT variability analyses included in this report.

right index finger to press the first, leftmost button to indicate left-sided targets and use their middle finger to press the second button to indicate right-sided targets. Participants were told to focus on the central fixation cue throughout the trial and respond to the target dots as quickly as possible.

The dot-probe task consisted of five blocks with 450 total trials. Each block included 30 congruent trials (dot on the same side as the fearful face), 30 incongruent trials (dot on the same side as the neutral face), and 30 baseline trials (two neutral faces) presented in a random order. Participants received feedback at the end of each block that informed them of their overall accuracy and reaction times, which was included to encourage accurate and rapid responses.

2.4. Flanker task

An adapted Eriksen flanker task (Eriksen and Eriksen, 1974) was programmed in E-Prime (Psychology Software Tools, Pittsburg, PA). A white fixation cue (+) was presented in the center of a black screen for 1000 ms. Following the fixation cue, five white, centered, and horizontally positioned arrows were presented for 200 ms. Two different types of trials were presented to participants and each trial type had an equal probability of occurring: a compatible trial in which all arrows faced the same direction (e.g., < < < < < or > > > > >) or an incompatible trial in which the center arrow was facing the opposite direction (e.g., < < > < < or > > < > >). After the presentation of the stimuli, participants had 1000–1400 ms to indicate which direction the center arrow faced. The flanker task included a practice block with 20 trials, followed by seven additional blocks of 60 trials. Each block consisted of 15 trials of each stimulus type (the two compatible stimuli options and the two incompatible stimuli options). Participants were instructed to respond as quickly and accurately as possible throughout the task.

In order to encourage participants to respond quickly and accurately, participants were required to maintain an accuracy level between 75 and 90% for each block and were provided feedback based on their accuracy level. If participants had an accuracy above 90%, they were told to respond faster to commit more errors. If they had an accuracy below 75%, they were told to respond slower. If participants had accuracy between 75 and 90%, they were told that they responded appropriately in terms of speed and accuracy. These specific accuracy requirements were maintained in the flanker task due to the collection of EEG data to measure the error-related negativity (ERN) as part of the larger study. While the EEG/ERN data is not relevant for the scope of this manuscript, additional details regarding this component can be found in previous publications (Carlson et al., 2021; Gilbertson et al., 2021; Strand et al., 2021).

2.5. Data reduction and analysis

Bivariate Pearson correlations across all study variables were performed in SPSS 28. To control for the influence of general RT variability, partial correlations were also conducted in SPSS 28. To be included in the analysis, RT measured in flanker task were first filtered to exclude incorrect responses as well as any correct responses with RTs < 200 ms or > 1500 ms (88.30% of the data included; Carlson et al., 2021). Similarly, RT measured in

dot-probe task were filtered to include correct responses between 150 and 750 ms (96.65% of the data included). ABV was calculated using the trial-level bias score method (Zvielli et al., 2015), since it has been shown to be more reliable than other ABV approaches (Molloy and Anderson, 2020). First, each congruent trial was matched with the closest incongruent trial with a maximum distance of 5 trials backward or forward. The same procedure was performed on each incongruent trial. Trial level bias scores were then calculated by subtracting the RT of congruent from incongruent trials for each pair (see Fig. 1). To compute ABV, the summed distance between succeeding trial level bias scores was divided by the total number of trial level bias scores. The standard deviation of the RT (for congruent and incongruent trials) was used as the index of the general RT variability.

3. Results

3.1. Reliability of ABV and RT variability measures

Trial-level bias score ABV indices from each block in the dot-probe task were moderately to highly correlated across the five experimental blocks in the task (*Mean r* (120) = 0.53, $p < .001$, *Range r* = 0.40 to 0.67). However, in partial correlations controlling for general RT variability, the strength of these correlations across blocks was considerably lower and in some instances in the reverse direction (*Mean r* (118) = −0.07, *Range r* = − 0.26 to 0.21; see Table 1). Similarly, ABV calculated from the flanker task was moderately to highly correlated across seven experimental blocks, (*Mean r* (120) = 0.55, $p < .001$, *Range r* = 0.33 to 0.78). When controlling for general RT variability, the correlation between flanker based ABV across blocks was lower (*Mean r* (118) = 0.16, *Range r* = −0.14 to 0.46; see Table 2). Finally, RT variability measures themselves were generally moderately to highly correlated across blocks in the dot-probe (*Mean r* (120) = 0.45, $p < .001$, *Range r* = 0.32 to 0.57) and flanker (*Mean r* (120) = 0.46, $p < .001$, *Range r* = 0.26 to 0.67) tasks, see Tables 1 and 2.

3.2. Correlations across tasks

There was a significant positive correlation between ABV measured in the dot-probe task and ABV measured in the flanker task, $r(120) = 0.62$, $p < .001$. The general RT variability of these two tasks were also significantly correlated with each other, $r(120) = 0.62$, $p < .001$. This general pattern was observed for female and male participants as well as across the age range of our sample (see Supplementary Materials). After controlling for general RT variability in both tasks, the correlation between ABV across tasks was entirely eliminated ($r(118) = -0.07$, p .48).[2]

3.3. Correlations with anxiety

In addition, exploratory analysis indicated that only ABV measured in dot-probe task significantly correlated with trait anxiety, $r(120) = 0.20$, $p = .03$, but after controlling for

[2]Beyond ABV, the trial-level bias score approach can be used to calculate the mean bias towards (i.e., mean of trial level bias scores > 0 ms) or away (i.e., mean of trial level bias scores < 0 ms) from threat (Zvielli et al., 2015). In the dot-probe and flanker tasks, mean toward ($r(120) = 0.88$, $p < .001$ & $r(120) = 0.85$, $p < .001$) and mean away ($r(120) = -0.86$, $p < .001$ & $r(120) = -0.75$, $p < .001$) measures were highly correlated with general RT variability, respectively. Similar to the pattern observed with ABV measures, mean toward ($r(120) = 0.46$, $p < .001$) and away ($r(120) = 0.56$, $p < .001$) measures were correlated across tasks in bivariate correlations, but not in partial correlations controlling for general RT variability (Toward: $r(118) = —0.05$, $p = .63$ & Away: $r(118) = 0.16$, $p = .09$). Therefore, similar to ABV, these additional trial-level bias score measures also appear to capture general RT variability.

general RT variability, the correlation was no longer significant, $r(119) = 0.03$, $p = .78$. No significant correlation was found between flanker task based ABV and trait anxiety, $r(120) = 0.10$, $p = .27$. See Table 3 for the full correlation matrix between ABV, general RT, and anxiety measures.

4. Discussion

We aimed to test the validity of attention bias variability (ABV) as a measure of attention-related behavior. To meet this end, we calculated "ABV" and general RT variability measures across two conceptually unrelated cognitive tasks: (1) the dot-probe task (MacLeod et al., 1986), which is commonly used to assess attentional bias (and ABV) as well as (2) the arrow flanker task (Eriksen and Eriksen, 1974), which is commonly used to assess cognitive/inhibitory control. Within both the dot-probe and flanker tasks, ABV measures were initially moderately to strongly correlated across task blocks. However, when the effect of general RT variability was controlled, the strength of these correlations decreased to nonsignificant or weak levels (see Tables 1 and 2). ABV and general RT variability (i.e., SD) measures were highly correlated across the two unrelated tasks. Critically, however, when general RT variability was controlled, ABV measures were no longer correlated across tasks. In addition, although dot-probe task based ABV was initially correlated with trait anxiety, this association was no longer significant after controlling for general RT variability. Collectively, these findings—across two unrelated tasks—present strong empirical evidence that ABV may not be a valid measure of attention-related behavior, but reflective of general RT variability more broadly.

Ever since the development and introduction of ABV-based measures (Iacoviello et al., 2014; Zvielli et al., 2015), they have been widely accepted as (more) reliable measures of attentional bias to threat (e.g., Rodebaugh et al., 2016). Given the perceived reliability and validity of ABV as a measure of attentional bias, research linking ABV to psychopathology has been plentiful and only continues to grow. Although empirical data indicate that ABV measures offer stronger reliability compared to traditional attention bias measures (Davis et al., 2016; Molloy and Anderson, 2020; Naim et al., 2015; Price et al., 2015; Rodebaugh et al., 2016; Zvielli et al., 2016), much of the existing research has not controlled for RT-based variability. When general RT variability is controlled, ABV-based reliability estimates drop considerably (Carlson and Fang, 2020).[3] Indeed, this was true in the current data set for ABV measures calculated from both the dot-probe and flanker tasks.

The results presented here provide further evidence that ABV is not a valid construct of attention bias behavior. "ABV" values calculated across two unrelated cognitive tasks were strongly correlated with each other ($r = 0.62$) and strongly correlated with general RT variability ($r \geq 0.88$). Furthermore, the correlation between these unrelated measures was comparable in strength to the correlation of dot-probe *(Mean* $r = 0.53$) and flanker *(Mean*

[3]Note that another approach that has been taken is to compute "fake" trial level bias scores with trials containing two neutral stimuli and compare the predictive nature of these measures to the standard trial level bias scores computed from incongruent and congruent trials (with threatening and neutral stimuli; e.g., Zvielli et al., 2015). However, these "fake" trial level bias score measures are typically computed from a smaller number of trials (usually half as many) and are therefore likely to contain more noise/error in capturing RT variability.

$r = 0.55$) based ABV measures observed across blocks within the same task. In other words, ABV-based measures do not provide discriminate validity. This finding suggests that ABV taps into a cognitive process that is not unique to the dot-probe task of attentional bias, but rather common across conceptually unrelated cognitive tasks. We propose that this shared cognitive process can be operationalized by RT variability. Additionally—as would be expected if these measures reflect RT variability—the strong relationship between ABV measures completely disappeared when controlling for general RT variability. In addition, we observed that the strength of ABV-based reliability estimates observed dropped when controlling for general RT variability. Collectively, such findings cast serious doubt on the validity of ABV as a measure of attention-related behavior *per se*. We strongly encourage future research utilizing the ABV approach to include general RT as a control variable.

Given that ABV appears to be an unsuitable substitute for traditional attentional bias measures, further research into establishing a reliable (and valid) measure of attentional bias is warranted. Initial research in this domain has provided promising accuracy-based (Grafton et al., 2021) and psychophysiology-based alternatives (Blanco et al., 2021; Kappenman et al., 2014; Reutter et al., 2017).

Although the findings here question the validity of ABV as a measure of selective attention to emotional information, previous research using the ABV approach may still provide important insight into psychopathology. Here, we provide evidence that ABV is not, in fact, shifts in attentional bias to threat, but something more general that can be captured in unrelated cognitive tasks and related to general RT variability. Previous research indicates that general RT variability might be driven (at least in part) by cognitive control (Ode et al., 2011), which may indicate that ABV measures tap into more general cognitive control processes that are present in other clinical populations such as attention deficit hyperactivity disorder (Tamm et al., 2012). Yet, further research will be needed to clarify the cognitive processes captured by variability measures.

One reason that it is important to continue research on RT variability measures is the number of studies suggesting that ABV (measures) are heightened in a number of clinical populations (e.g., Bardeen et al., 2017; Davis et al., 2016; Iacoviello et al., 2014; Naim et al., 2015; Price et al., 2015; Todd et al., 2022; Zvielli et al., 2015, 2016). Indeed, in our initial analysis, we found that dot-probe task ABV was positively correlated with anxiety. Although it should also be noted that a correlation of comparable strength was also observed between general RT variability and anxiety, suggesting a link between anxiety and RT variability more broadly. Indeed, the association between ABV and anxiety vanished when general RT variability was controlled. Thus, ABV appears to be elevated in clinical samples, but at the same time does not actually measure shifts in attention to threatening/emotional stimuli. If the field is interested in understanding why ABV is elevated in clinical populations, further research is needed to determine the underlying aberration in behavior. This will require a reevaluation and reinterpretation of the elevated levels of ABV measures observed in clinical populations. For example, elevated RT variability has been linked to impaired cognitive control processes in post-traumatic stress disorder (PTSD; Swick et al., 2013). PTSD is also commonly linked to elevated levels of ABV (Iacoviello et al., 2014; Mazidi et al., 2019; Naim et al., 2015; Swick and Ashley, 2017). Given what we now

know about ABV, it seems likely that both sets of results capture broader abnormalities in cognitive control within PTSD (Swick and Ashley, 2017).

A number of cognitive models of anxiety include impairments in top-down cognitive control (Eysenck et al., 2007; Mogg and Bradley, 2018), which can lead to elevated threat biases and anxiety. Additionally, recent research suggests that cognitive control mediates the relationship between ABV and anxiety symptoms (Clarke et al., 2020). Future research should continue to explore the relationship between cognitive control, general RT variability, and clinical symptoms.

5. Limitations and conclusions

In conclusion, the evidence presented here indicates that ABV measures are correlated across conceptually unrelated tasks—an effect that is driven by a consistent correlation between general RT variability measures across these tasks. These findings were observed in a sample of individuals selected for high levels of trait anxiety and therefore should be assessed in other populations to determine the generalizability of these effect. In particular, it should be noted that although our sample was selected for high trait anxiety, this was not a clinical sample and therefore replication in a clinical sample is warranted. We suspect that there are many existing dot-probe datasets from published research that included additional cognitive tasks. We encourage the reanalysis of such datasets to determine the generalizability of the results observed here to other populations. Racial/ethnic, cultural/geographic, income, education, or socioeconomic status data was not collected and is a limitation. Regardless, the results presented here strongly question the validity of ABV as a measure of attention-related behavior.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We would like to thank the students in the Cognitive × Affective Behavior & Integrative Neuroscience (CABIN) Lab at Northern Michigan University for assisting in the collection of this data.

Funding

Research reported in this publication was supported by the National Institute of Mental Health of the National Institutes of Health under Award Number R15MH110951. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Data availability

The data for this project are available on the Open Science Framework (OSF) at https://osf.io/zh7xq/.

References

Aday JS, Carlson JM, 2019. Extended testing with the dot-probe task increases test–retest reliability and validity. Cogn. Process 20, 65–72. 10.1007/s10339-018-0886-1. [PubMed: 30171401]

Alon Y, Naim R, Pine DS, Bliese PD, Bar-Haim Y, 2019. Validity of attention bias variability indices for posttraumatic stress disorder research: evidence from patient data. J. Trauma Stress 32 (5), 791–798. [PubMed: 31461560]

Amir N, Taylor CT, & Donohue MC (2011). Predictors of response to an attention modification program in generalized social phobia. J. Consult. Clin. Psychol, 79(4), 533–541. 10.1037/a0023808/2011-13209-001[pii]. [PubMed: 21707134]

Bar-Haim Y, Lamy D, Pergamin L, Bakermans-Kranenburg MJ, van Ijzendoorn MH, 2007. Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. Psychol. Bull 133 (1), 1–24. 10.1037/0033-2909.133.1.1. [PubMed: 17201568]

Bardeen JR, Daniel TA, Hinnant JB, Orcutt HK, 2017. Emotion dysregulation and threat-related attention bias variability. Motiv. Emot 41 (3), 402–409.

Beck AT, Clark DA, 1997. An information processing model of anxiety: automatic and strategic processes. Behav. Res. Ther 35 (1), 49–58. 10.1016/S0005-7967(96)00069-1. [PubMed: 9009043]

Blanco I, Boemo T, Sanchez-Lopez A, 2021. The role of cognitive biases and emotion regulation strategies when facing major stressors: ecological evidence during the COVID-19 lockdown of 2020 using a novel online cognitive bias assessment. JMIR Ment. Health 8 (11), e30961. 10.2196/30961. [PubMed: 34517337]

Carlson JM, Aday JS, Rubin D, 2019. Temporal dynamics in attention bias: effects of sex differences, task timing parameters, and stimulus valence. Cogn. Emot 33 (6), 1271–1276. 10.1080/02699931.2018.1536648. [PubMed: 30336735]

Carlson JM, Fang L, 2020. The stability and reliability of attentional bias measures in the dot-probe task: evidence from both traditional mean bias scores and trial-level bias scores. Motiv. Emot 44, 657–669. [PubMed: 33551518]

Carlson JM, Fang L, Andrzejewski JA, 2021. No change in electrocortical measures of performance monitoring in high trait anxious individuals following multi-session attention bias modification training. Neuroimage Rep. 1 (4), 100067.

Carlson JM, Fang L, Koster EH, Andrzejewski JA, Gilbertson H, Elwell KA, Zuidema TR, 2022. Neuroplastic changes in anterior cingulate cortex gray matter volume and functional connectivity following attention bias modification in high trait anxious individuals. Biol. Psychol, 108353 [PubMed: 35569575]

Chapman A, Devue C, Grimshaw GM, 2019. Fleeting reliability in the dot-probe task. Psychol. Res 83 (2), 308–320. [PubMed: 29159699]

Cisler JM, Koster EH, 2010. Mechanisms of attentional biases towards threat in anxiety disorders: an integrative review. Clin. Psychol. Rev 30 (2), 203–216. [PubMed: 20005616]

Clarke PJ, Marinovic W, Todd J, Basanovic J, Chen NT, Notebaert L, 2020. What is attention bias variability? Examining the potential roles of attention control and response time variability in its relationship with anxiety. Behav. Res. Ther 135, 103751. [PubMed: 33070010]

Davis ML, Rosenfield D, Bernstein A, Zvielli A, Reinecke A, Beevers CG, Koster EH, Smits JA, 2016. Attention bias dynamics and symptom severity during and following CBT for social anxiety disorder. J. Consult. Clin. Psychol 84 (9), 795–802. 10.1037/ccp0000125. [PubMed: 27362791]

Desimone R, Duncan J, 1995. Neural mechanisms of selective visual attention. Annu. Rev. Neurosci 18, 193–222. 10.1146/annurev.ne.18.030195.001205. [PubMed: 7605061]

Eriksen BA, Eriksen CW, 1974. Effects of noise letters upon the identification of a target letter in a nonsearch task. Percept. Psychophys 16 (1), 143–149.

Eysenck MW, Derakshan N, Santos R, Calvo MG, 2007. Anxiety and cognitive performance: attentional control theory. Emotion 7 (2), 336. [PubMed: 17516812]

Gilbertson H, Fang L, Andrzejewski JA, Carlson JM, 2021. Dorsal anterior cingulate cortex intrinsic functional connectivity linked to electrocortical measures of error monitoring. Psychophysiology 58 (5), e13794. 10.1111/psyp.13794. [PubMed: 33624288]

Grafton B, Teng S, MacLeod C, 2021. Two probes and better than one: development of a psychometrically reliable variant of the attentional probe task. Behav. Res. Ther 138, 103805. [PubMed: 33485106]

Gur RC, Sara R, Hagendoorn M, Marom O, Hughett P, Macy L, Turner T, Bajcsy R, Posner A, Gur RE, 2002. A method for obtaining 3-dimensional facial expressions and its standardization for use in neurocognitive studies. J. Neurosci. Methods 115 (2), 137–143. [PubMed: 11992665]

Heeren A, Philippot P, Koster EH, 2015. Impact of the temporal stability of preexistent attentional bias for threat on its alteration through attention bias modification. J. Behav. Ther. Exp. Psychiatry 49 (Pt A), 69–75. 10.1016/j.jbtep.2014.10.012. [PubMed: 25468203]

Iacoviello BM, Wu G, Abend R, Murrough JW, Feder A, Fruchter E, Levinstein Y, Wald I, Bailey CR, Pine DS, Neumeister A, Bar-Haim Y, Charney DS, 2014. Attention bias variability and symptoms of posttraumatic stress disorder. J. Trauma Stress 27 (2), 232–239. 10.1002/jts.21899. [PubMed: 24604631]

Kappenman ES, Farrens JL, Luck SJ, Proudfit GH, 2014. Behavioral and ERP measures of attentional bias to threat in the dot-probe task: poor reliability and lack of correlation with anxiety. Front. Psychol 5, 1368. 10.3389/fpsyg.2014.01368. [PubMed: 25538644]

Kruijt A-W, Field AP, Fox E, 2016. Capturing dynamics of biased attention: new attention bias variability measures the way forward? PLoS One 11 (11), e0166600. 10.1371/journal.pone.0166600. [PubMed: 27875536]

Kuckertz JM, Gildebrant E, Liliequist B, Karlstrom P, Vappling C, Bodlund O, Stenlund T, Hofmann SG, Andersson G, Amir N, Carlbring P, 2014. Moderation and mediation of the effect of attention training in social anxiety disorder. Behav. Res. Ther 53, 30–40. 10.1016/j.brat.2013.12.003. [PubMed: 24373984]

Lundqvist D, Flykt A, & Öhman A.(1998). The Karolinska directed emotional faces (KDEF). CD ROM from Department of Clinical Neuroscience, Psychology section, Karolinska Institutet, 91–630.

MacLeod C, Mathews A, 1988. Anxiety and the allocation of attention to threat. Q. J. Exp. Psychol. A 40 (4), 653–670. [PubMed: 3212208]

MacLeod C, Mathews A, Tata P, 1986. Attentional bias in emotional disorders. J. Abnorm. Psychol 95 (1), 15–20. 10.1037/0021-843X.95.1.15. [PubMed: 3700842]

Mathews A, Mackintosh B, 1998. A cognitive model of selective processing in anxiety. Cognit. Ther. Res 22 (6), 539–560. 10.1023/A:1018738019346.

Mazidi M, Vig K, Ranjbar S, Ebrahimi MR, Khatibi A, 2019. Attentional bias and its temporal dynamics among war veterans suffering from chronic pain: investigating the contribution of post-traumatic stress symptoms. J. Anxiety Disord 66, 102115 10.1016/j.janxdis.2019.102115. [PubMed: 31394483]

Mogg K, Bradley BP, 2018. Anxiety and threat-related attention: cognitive-motivational framework and treatment. Trends Cogn. Sci 22 (3), 225–240. 10.1016/j.tics.2018.01.001. [PubMed: 29402737]

Mogoase C, David D, Koster EH, 2014. Clinical efficacy of attentional bias modification procedures: an updated meta-analysis [meta-analysis]. J. Clin. Psychol 70 (12), 1133–1157. 10.1002/jclp.22081. [PubMed: 24652823]

Molloy A, Anderson PL, 2020. Evaluating the reliability of attention bias and attention bias variability measures in the dot-probe task among people with social anxiety disorder. Psychol. Assess 32 (9), 883. [PubMed: 32525343]

Naim R, Abend R, Wald I, Eldar S, Levi O, Fruchter E, Ginat K, Halpern P, Sipos ML, Adler AB, Bliese PD, Quartana PJ, Pine DS, Bar-Haim Y, 2015. Threat-related attention bias variability and posttraumatic stress. Am. J. Psychiatry 10.1176/appi.ajp.2015.14121579appiajp201514121579.

Ode S, Robinson MD, Hanson DM, 2011. Cognitive-emotional dysfunction among noisy minds: predictions from individual differences in reaction time variability. Cognit. Emot 25 (2), 307–327. [PubMed: 21432673]

Ohman A, Mineka S, 2001. Fears, phobias, and preparedness: toward an evolved module of fear and fear learning. Psychol. Rev 108 (3), 483–522. [PubMed: 11488376]

Price RB, Kuckertz JM, Siegle GJ, Ladouceur CD, Silk JS, Ryan ND, Dahl RE, Amir N, 2015. Empirical recommendations for improving the stability of the dot-probe task in clinical research. Psychol. Assess 27 (2), 365–376. 10.1037/pas0000036. [PubMed: 25419646]

Reutter M, Hewig J, Wieser MJ, Osinsky R, 2017. The N2pc component reliably captures attentional bias in social anxiety. Psychophysiology 54 (4), 519–527. 10.1111/psyp.12809. [PubMed: 28111770]

Rodebaugh TL, Scullin RB, Langer JK, Dixon DJ, Huppert JD, Bernstein A, Zvielli A, Lenze EJ, 2016. Unreliability as a threat to understanding psychopathology: the cautionary tale of attentional bias. J. Abnorm. Psychol 125 (6), 840. [PubMed: 27322741]

Schmukle SC, 2005. Unreliability of the dot probe task. Eur. J. Person 19 (7), 595–605. 10.1002/per.554.

Spielberger CD, Gorsuch RL, Lushene RE, 1970. Manual for the State-Trait Axiety Inventory (Self-Evaluation Questionnaire). Consulating Psychology Press.

Staugaard SR, 2009. Reliability of two versions of the dot-probe task using photographic faces. Psychol. Sci. Q 51 (3), 339–350.

Strand N, Fang L, Carlson JM, 2021. Sex differences in anxiety: an investigation of the moderating role of sex in performance monitoring and attentional bias to threat in high trait anxious individuals. Front. Hum. Neurosci 15 10.3389/fnhum.2021.627589.

Swick D, Ashley V, 2017. Enhanced attentional bias variability in post-traumatic stress disorder and its relationship to more general impairments in cognitive control. Sci. Rep 7 (1), 14559. 10.1038/s41598-017-15226-7. [PubMed: 29109521]

Swick D, Honzel N, Larsen J, Ashley V, 2013. Increased response variability as a marker of executive dysfunction in veterans with post-traumatic stress disorder. Neuropsychologia 51 (14), 3033–3040. [PubMed: 24157540]

Tamm L, Narad ME, Antonini TN, O'Brien KM, Hawk LW, Epstein JN, 2012. Reaction time variability in ADHD: a review. Neurotherapeutics 9 (3), 500–508. [PubMed: 22930417]

Todd J, Wilson E, Coutts-Bain D, Clarke PJ, 2022. Attentional bias variability and its association with psychological and health symptoms: a meta-analysis. Neurosci. Biobehav. Rev 140, 104812. [PubMed: 35931220]

Van Bockstaele B, Lamens L, Salemink E, Wiers RW, Bögels SM, Nikolaou K, 2020. Reliability and validity of measures of attentional bias towards threat in unselected student samples: seek, but will you find? Cognit. Emot 34 (2), 217–228. [PubMed: 31044648]

Vervoort L, Braun M, De Schryver M, Naets T, Koster EH, Braet C, 2021. A pictorial dot probe task to assess food-related attentional bias in youth with and without obesity: overview of indices and evaluation of their reliability. Front. Psychol 12, 561.

Zvielli A, Bernstein A, Koster EH, 2015. Temporal dynamics of attentional bias. Clin. Psychol. Sci 3 (5), 772–788.

Zvielli A, Vrijsen JN, Koster EH, Bernstein A, 2016. Attentional bias temporal dynamics in remitted depression. J. Abnorm. Psychol 125 (6), 768–776. 10.1037/abn0000190. [PubMed: 27505407]

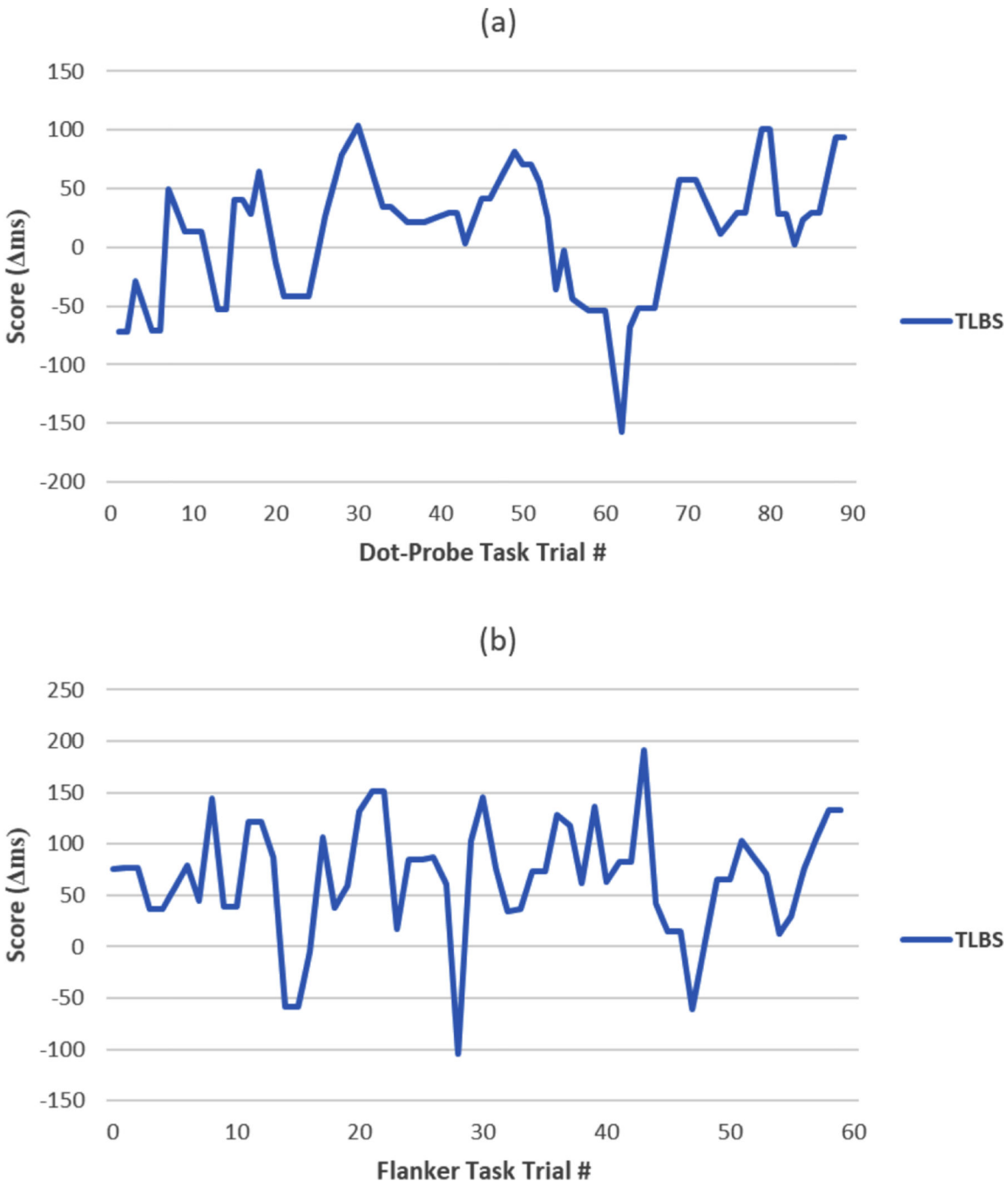

Fig. 1.

For demonstration purposes, an example of trial level bias scores (TLBS) of one block in the (a) dot-probe task and (b) flanker task are depicted. The TLBS indices plotted here were from a single subject. Both the dot-probe and flanker task TLBSs similarly fluctuate across the entirety of the task block demonstrating that the concept of the TLBS can generalize across tasks. Note that the exact pattern of variation varies from block to block

and individual to individual (and task to task). What is consistent are peaks and troughs thought to represent shifts in attention (towards and away).

Table 1

Correlations across blocks in the dot-probe task.

Reaction Time Variability	**Block 1**	**Block 2**	**Block 3**	**Block 4**	**Block 5**
Block 1		0.51***	0.40***	0.32***	0.44***
Block 2			0.52***	0.34***	0.39***
Block 3				0.57***	0.45***
Block 4					0.56***
Block 5					
Attention bias variability	**Block 1**	**Block 2**	**Block 3**	**Block 4**	**Block 5**
Block 1		0.48***	0.43***	0.40***	0.45***
Block 2	−0.07		0.67***	0.56***	0.53***
Block 3	−0.23*	0.21*		0.66***	0.55***
Block 4	−0.26**	−0.04	0.15		0.57***
Block 5	−0.17	−0.12	−0.14	−0.06	

* $p < .05$,

** $p < .01$,

*** $p < .001$.

The region on the bottom of the attention bias variability correlation matrix reflects partial correlations controlling for reaction time variability.

Table 2

Correlations across blocks in the flanker task.

Reaction Time variability	**Block 1**	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**	**Block 7**
Block 1		0.45***	0.56***	0.50***	0.45***	0.39***	0.52***
Block 2			0.26**	0.43***	0.45***	0.36***	0.30***
Block 3				0.44***	0.35***	0.33***	0.49***
Block 4					0.67***	0.44***	0.55***
Block 5						0.57***	0.65***
Block 6							0.55***
Block 7							
Attention bias variability	**Block 1**	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**	**Block 7**
Block 1		0.55***	0.40***	0.43***	0.39***	0.33***	0.42***
Block 2	0.28**		0.42***	0.64***	0.59***	0.56***	0.59***
Block 3	0.02	0.12		0.55***	0.59***	0.57***	0.49***
Block 4	−0.02	0.25**	0.28**		0.65***	0.63***	0.62***
Block 5	−0.13	0.15	0.34***	0.23*		0.72***	0.69***
Block 6	−0.14	0.08	0.33***	0.17	0.39***		0.78***
Block 7	−0.03	0.09	0.16	0.06	0.25**	0.46***	

*$p < .05$,

**$p < .01$,

***$p < .001$.

The region on the bottom of the attention bias variability correlation matrix reflects partial correlations controlling for reaction time variability.

Table 3

Pearson correlations between ABV, general RT variability, and anxiety across two tasks (n = 122).

Measure	ABV_{DT}	ABV_{FT}	General variability $_{DT}$	General variability $_{FT}$	Trait anxiety
ABV_{DT}		0.62***	0.95***	0.59***	0.20*
ABV_{FT}			0.66***	0.88***	0.10
General $Variability_{DT}$				0.62***	0.20*
General $Variability_{FT}$					0.17

Note: ABV, attentional bias variability; DT, dot-probe task; FT, flanker task.

*$p < .05$,

**$p < .01$,

***$p < .001$.