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Review

Attentional bias for threat: Crisis or opportunity?☆

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HIGHLIGHTS

- Attention biases for threat (ABT) often characterize anxiety disorders.
- Methods for measuring ABT have become increasingly precise.
- Yet the reliability of these methods is very poor.

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ABSTRACT

Beginning in the 1980s, experimental psychopathologists increasingly adapted the concepts and paradigms of cognitive science to elucidate information-processing abnormalities that may figure in the etiology and maintenance of anxiety disorders. Assessment and modification of attentional biases for threat has been a major theme in this research program. The field has witnessed the development of progressively more sophisticated approaches for isolating attentional processes from other cognitive processes in the service of accurate assessment and treatment. Yet the field is now in crisis as foundational concerns about the reliability of basic measures of attentional bias for threat (ABT) have emerged. Moreover, recent research points to theoretical revisions deemphasizing ABT as a stable, near-universal feature of anxiety disorders, and stressing deficits in executive control as the primary attentional problem linked to anxiety.

The cognitive perspective on pathological anxiety comprises two distinct, but complementary, methodological approaches (McNally, 2001). The traditional one holds that mistaken beliefs ascertainable through introspective self-report are the basis for pathological anxiety, and hence the chief targets of therapeutic intervention (Beck, Emery, & Greenberg, 1985). Through systematic clinical interviews (e.g., Clark, 1986) and standardized questionnaires (e.g., Reiss, Peterson, Gursky, & McNally, 1986), clinicians identify problematic appraisals and beliefs as a prelude to correcting them via the methods of cognitive-behavior therapy (CBT).

The second approach has its roots in experimental psychology. Its proponents apply the concepts and methods of cognitive science to characterize the information-processing abnormalities implicated in the etiology and maintenance of anxiety and its disorders (Harvey, Watkins, Mansell, & Shafran, 2004; Williams, Watts, MacLeod, & Mathews, 1997). These psychologists favor objective laboratory measures (e.g., reaction times) as the surest route to discovering the dysfunctional mechanisms of the mind.

Opinions vary regarding the compatibility of these approaches. One eminent experimental psychopathologist characterized the traditional one as falling outside "the boundaries of legitimate science" (MacLeod, 1993, p. 170), arguing that its methods do not meet the "standards of scientific acceptability" (MacLeod, 1993, p. 171) of cognitive psychology. Others hold that both have much to offer, chiefly because each addresses different questions about aberrant cognition (McNally, 2001). Hence, reaction time (RT) measures are helpless to disclose the phenomenology of obsessions just as introspective self-report is useless for gauging the magnitude of an attentional bias for threat.

The experimental tradition itself comprises two research programs. One concerns content-dependent cognitive biases, whereas the other concerns content-independent cognitive deficits. The first features studies designed to elucidate biases favoring the processing of threat-related information in paradigms assessing attention, interpretation, and memory. The driving assumption of this work is that people with anxiety disorders suffer repeated episodes of distress because they selectively attend to threat, interpret ambiguity as threatening, and selectively recall threatening experiences. Each bias signifies a dimensional latent variable operative within a person, reflected in diverse observable indicators. For example, an attentional bias for threat may emerge on different tasks (e.g., emotional Stroop, dot probe) just as a

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person's temperature is measurable by a mercury or digital thermometer. Expansion of mercury in a glass tube is not temperature; it reflects temperature. Hence, it is important to distinguish the procedure designed to measure a latent cognitive process from the process itself (MacLeod & Grafton, 2016).

The second program of research rests on the assumption that emotional disorders are associated with cognitive deficits that can operate independently of the emotional valence of the information processed (e.g., Eysenck & Derakshan, 2011). Although the two programs developed in parallel, psychologists have increasingly recognized important connections between them (e.g., Mogg & Bradley, 2018). For example, difficulties in executive control over attention may produce downstream difficulties inhibiting attention to threat.

In keeping with editorial instructions, I will confine my coverage to the anxiety disorders as defined by the current diagnostic manual (American Psychiatric Association, 2013). These syndromes include panic disorder, agoraphobia, social anxiety disorder, generalized anxiety disorder (GAD), and specific phobia. Moreover, I will concentrate on research concerning the assessment and modification of attentional bias for threat (ABT). Without a doubt, this domain of inquiry has dominated cognitive science work on the anxiety disorders. The field has witnessed the development of progressively more sophisticated procedures designed to isolate aberrant attentional processes from other cognitive processes. Insights arising from this work have fostered a canonical instance of translational research whereby alterations in methods of assessing ABT have been transformed into methods for reducing ABT in the service of treating anxiety disorders (MacLeod & Clarke, 2015). Indeed, research on attentional bias modification (ABM) has been the centerpiece of the burgeoning field of cognitive bias modification (CBM; Hallion & Ruscio, 2011; MacLeod & Mathews, 2012).

Yet we are now in the midst of crisis. Theory-driven research on ABT and its modification has undermined the theoretical basis that inspired it. Moreover, serious concerns about measurement reliability are threatening the very foundation of our field (e.g., Rodebaugh et al., 2016). Whether crisis can be converted into opportunity remains to be seen. The purpose of my article is to trace these developments. I do not endeavor to review all of the vast empirical literature as others have done (e.g., Cristea, Kok, & Cuipers, 2015; Heeren, Mogoaşe, Philippot, & McNally, 2015; MacLeod & Grafton, 2016; Van Bockstaele et al., 2014) Rather, I focus on conceptual issues and serious measurement problems hitherto unrecognized until recently, as well as on attempts to solve them. Before doing so, I describe the most common attentional bias paradigms, and review their strengths and limitations prior to considering novel paradigms designed to redress these limitations. I turn next to ABM, and the challenges our field faces.

1. Attentional bias for threat

Limitations in our capacity to process information compel us to attend to only a subset of the input impinging on us at any moment. Hence, a bias for selectively attending to threatening content should heighten one's proclivity to experience episodes of increased anxiety. People characterized by high trait anxiety, especially those with anxiety disorders, should therefore exhibit a bias for selectively attending to threat cues relative to positive or neutral ones.

In a comprehensive review of the ABT literature, Bar-Heim, Lamy, Pergamin, Bakermans-Kranenburg, and IJzendoorn (2007) reported that 150+ studies "have established the existence and typical magnitude of the threat-related bias in anxious individuals" (p. 18) with an effect size of $d = 45$. Confident of the robustness of the phenomenon, they said that there are "diminishing returns to be expected from further studies that focus on establishing the presence of a threat-related bias in anxious groups" (Bar-Heim et al., 2007, p. 15). Subsequent meta-analyses have reported similar conclusions, affirming a positive association between anxiety and attention to threat, broadly conceived (Armstrong & Olatunji, 2012; Van Bockstaele et al., 2014). By "broadly conceived," I mean that when differences occur between anxious and nonanxious people it is often unclear what, if any, component of attention (e.g., orienting, disengagement difficulty) is involved, especially when RTs are the basis for inferring an ABT. Hence, an overarching theme has been the progressive refinement of experimental paradigms to isolate the cognitive mechanisms responsible for such behavioral effects.

1.1. The emotional Stroop paradigm

Early studies on ABT employed the emotional Stroop paradigm whereby participants view words that vary in emotional valence and attempt to name the colors in which the words appear while ignoring their meaning (Williams, Mathews, & MacLeod, 1996). Emotional Stroop interference (delayed color-naming) occurs when the meaning of a word captures participants' attention despite their effort to attend to its color and name it as quickly as possible. Investigators have typically used words relevant to the characteristic fears of each diagnostic group (e.g., *boring, stupid* for social anxiety disorder; *suffocate, dizzy* for panic disorder). Relative to healthy comparison participants, people with specific (spider) phobia (Watts, McKenna, Sharrock, & Trezise, 1986), GAD (Mathews & MacLeod, 1985), social anxiety disorder (Hope, Rapee, Heimberg, & Dombeck, 1990; Mattia, Heimberg, & Hope, 1993), and panic disorder (Ehlers, Margraf, Davies, & Roth, 1988; McNally, Riemann, Louro, Lukach, & Kim, 1992) take longer to name the colors of words related to their fears than to name the colors of words having neutral or positive valence.

Emotional Stroop interference vanishes when people recover from spider phobia (Lavy, van den Hout, & Arntz, 1993; Watts et al., 1986), and GAD (Mathews, Mogg, Kentish, & Eysenck, 1995; Mogg, Bradley, Millar, & White, 1995). Mattia et al. (1993) reported that patients with social anxiety disorder who had recovered following either group CBT or phenelzine no longer exhibited interference on the emotional Stroop paradigm, whereas those who failed to recover continued to exhibit interference.

Despite its apparent robustness as a marker of clinical status, the emotional Stroop paradigm is not an unambiguous measure of ABT (Williams et al., 1996). For example, attempts to avoid processing the content of threat words might slow color-naming of them. Another possibility is that threat words may trigger anxiety, briefly "freezing" participants and delaying their color-naming response. Hence, it was unclear whether the emotional Stroop interference effect was solely or even primarily attributable to an *attentional* bias for threat. Keen to identify the component of attention responsible for the link between anxiety and ABT, researchers devised new procedures to isolate the operative mechanism.

1.2. The dot probe paradigm

The interpretive limitations of the emotional Stroop task motivated the development of the dot probe paradigm as an improved measure of ABT (MacLeod, Mathews, & Tata, 1986). In this paradigm, participants view pairs of words that appear simultaneously for 500 ms, one above and one below the center of a computer screen. One some trials, one word is threatening (e.g., *cancer*, *humiliated*), whereas the other is neutral. Immediately thereafter, a dot appears in the location vacated by the threat word or the neutral word. Participants are told to push a button once they detect the dot. ABT occurs when participants are faster to respond to dots that replace threat words (congruent trials) than to those that replace neutral words (incongruent trials).

Researchers have used variants of this task. In one version, photographs of people expressing neutral and threatening facial expressions (e.g., anger or contemptuous disgust) substitute for valenced neutral and threat words. In the probe discrimination version, participants press a button as quickly as possible to indicate the identity of the probe

(e.g., F or E) that replaces one of two facial expressions (e.g., contemptuous disgust versus neutral). This version involves two consecutive processes: probe detection and probe discrimination. In summary, an ABT is inferred from the speeding of a motor response (button or key press) to an emotionally neutral probe that appears in the location vacated by a threat stimulus (facial expression or word) relative to RTs to a neutral probe that appears in the location vacated by an emotionally neutral or positive stimulus. Variants of the dot probe paradigm have provided evidence for ABT in social anxiety disorder (e.g., Mogg, Philippot, & Bradley, 2004), panic disorder (e.g., Asmundson, Sandler, Wilson, & Walker, 1992), spider fear (e.g., Mogg & Bradley, 2006), and GAD (e.g., MacLeod et al., 1986).

Most studies on ABT have involved inference from RTs to probes replacing threat cues. Some investigators have used eye-tracking methods to measure overt visual attentional shifts. For example, Mogg, Millar, and Bradley (2000) found that people with GAD, but without comorbid depression, were more likely to direct their attention to angry than to neutral faces, and more likely to direct it more rapidly to angry faces than away from them. Using both RT and eye-tracking measures, other investigators found that pictures of spiders capture the attention of those with spider phobia relative to those without spider phobia, but only when these pictures were part of a background context they had been told to ignore (Miltner, Krieschel, Hecht, Trippe, & Weiss, 2004). Eye-tracking measures register overt, not covert, attentional shifts. In other words, one can shift attention without moving one's eyes as well move one's eyes without shifting one's attention.

Tracking the time course of attentional vigilance and avoidance has been done in two ways. In one approach, the duration of threat stimuli varies (e.g., 200 ms, 500 ms, 1500 ms) such that short durations tap attentional capture, whereas longer ones enable detection of subsequent attentional avoidance (Mogg & Bradley, 2004). In the other approach, eye-tracking studies have documented attentional vigilance followed by attentional avoidance in people with subclinical spider phobia (Pflugshaupt et al., 2005; Rinck & Becker, 2006) and people with subclinical blood phobia (Mogg, Bradley, Miles, & Dixon, 2004). Prompt avoidance of threat cues following detection would impede habituation of fear to these stimuli.

1.3. The visual search paradigm

This procedure requires participants to locate a target stimulus embedded in a matrix comprising distracting visual stimuli, and to respond to it as quickly as possible (e.g., Öhman, Flykt, & Esteves, 2001; Van Bockstaele et al., 2014). On some trials, participants aim to locate a threatening picture (e.g., snake, angry face) among a diversity of nonthreatening images, whereas on other trials they aim to locate a nonthreatening picture among a diversity of threatening images. Faster RTs to threat targets relative to nonthreat targets constitutes an ABT.

Although this paradigm has been used with participants high or low in social anxiety (e.g., Wieser, Hambach, & Weynar, 2018), investigators have often used it test whether people in general are faster to detect angry faces versus happy faces. To make sense of a wildly inconsistent literature confirming an attentional bias for angry faces in many experiments, and confirming an attentional bias for happy faces in many others, Lundqvist, Juth, and Öhman (2014) reanalyzed the data from these studies. They discovered that the driving factor behind attentional bias effects in the visual search paradigm is the level of arousal conveyed by the faces in an experiment, not the valence of their expressions. Hence, when happy faces depict more arousal than angry ones, attentional bias for the former occurs. When angry faces convey greater arousal than happy ones, an attentional bias for angry faces occurs. Because ABT concerns (negative) valence, not arousal, it is doubtful whether the standard visual search paradigm is suitable for assessing ABT. However, Zsido, Bernath, Labadi, and Deak (2018) introduced a variant of the visual search paradigm enabling researchers to disentangle valence and arousal. For example, one can detect an ABT if one controls for arousal.

1.4. The emotional spatial cueing paradigm

The dot probe paradigm has been the dominant procedure for measuring ABT. Yet it leaves uncertain whether ABT is attributable to rapid attentional capture by threat cues, as often assumed, difficulty disengaging attention from them, or both (Fox, Russo, Bowles, & Dutton, 2001).

Inspired by Posner and Petersen (1990) work on the components of attention, Fox et al. (2001) developed an emotional spatial cueing paradigm to distinguish attentional engagement (capture) from attentional disengagement by threat cues. Following the brief appearance of a fixation cross at center screen, a cue appears on either the left or right side of the screen. The cue is either threatening (e.g., angry face) or nonthreatening (e.g., neutral face). The cue vanishes and a neutral probe appears near the location vacated by the cue (i.e., valid trials) or on the opposite side of the screen (i.e., invalid trials). Typically, about 75% of the trials are valid. Participants are told to respond to the location of the probe (e.g., a dot) as quickly and as accurately as possible. A variant requires participants to discriminate between two types of probe (e.g., two vertical dots versus two horizontal ones; Yiend & Mathews, 2001).

Fox et al. (2001) found that participants high on state anxiety, relative to nonanxious participants, were especially slow to respond to probes on invalidly cued threat trials than on invalidly cued neutral trials. That is, once their attention was fixed on the threat cue, anxious participants appeared to have difficulty disengaging it and shifting it to the location of the probe on the opposite side of the screen. However, they were no faster than nonanxious participants in responding to probes on validly cued threat trials versus validly cued neutral trials. Taken together, these findings suggest that anxiety appears characterized by difficulty disengaging attention from threat rather than having attention swiftly captured by it.

Subsequent studies provided additional evidence consistent with the disengagement difficulty interpretation of ABT (e.g., social anxiety disorder: Amir, Elias, Klumpp, & Przeworski, 2003; Yiend & Mathews, 2001). For example, Amir et al. (2003) replicated Fox et al.'s findings in patients with social anxiety disorder, extending it by showing that patients exhibited difficulty disengaging from social threat words, not emotionally positive or neutral ones. As they remarked (Amir et al., 2003, pp. 1331–1332), patients with social anxiety disorder do not complain about detecting "an extraordinary number of threat cues in their environment (e.g., seeing many angry faces), but rather that they have difficulty dismissing such threat cues once they have been detected (i.e., not thinking about a negative social interaction)."

However, Mogg, Holmes, Garner, and Bradley (2008) noted that the emotional spatial cuing paradigm does not provide unambiguous evidence for the disengagement difficulty hypothesis. They suggested that threat cues may trigger a freezing response (e.g., Algom, Chajut, & Lev, 2004), thereby beclouding interpretation of RT data in this paradigm. To investigate this, Mogg et al. had high and low state anxious participants complete a central cuing task assessing threat-related RT slowing as a function of cue valence (angry, happy, or neutral face). That is, a valenced cue appeared briefly at center screen, and was replaced by a probe (an arrow pointing either up or down). Participants were told to perform the probe discrimination task as quickly and as accurately as possible. The results indicated that high anxiety participants were slower to discriminate probes that followed threat cues relative to those that followed neutral cues, whereas low anxiety participants did not exhibit this response "freezing" slowdown. Mogg et al. also had participants perform the emotional spatial cueing task, replicating Fox et al.'s disengagement difficulty effect.

However, the results reversed when they used RTs from the central cueing task to correct for the freezing effect in the emotional spatial cueing paradigm. The anxious participants now exhibited faster

attentional capture by threat cues relative to nonanxious participants, but no disengagement difficulty.

Few psychologists have used the central cueing task to correct RTs in the emotional spatial cueing paradigm (e.g., Cisler & Olatunji, 2010). However, Mogg and Bradley (2016) have identified a more serious problem with this paradigm: the scientists who once distinguished among subcomponents of an attentional orienting system (i.e., shifting, engagement, and disengagement) have recently abandoned this conceptualization in favor of one distinguishing between top-down orienting and stimulus-driven orienting (Petersen & Posner, 2012). Neuroimaging findings motivated this reformulation.

What are the implications of this reconceptualization for ABT? It suggests that ABT may arise from stimulus-driven capture of attention either with or without a corresponding difficulty in top-down executive control of attention. For example, threat cues may capture the attention of people with spider phobia, and deficits in executive control may render them especially vulnerable to stimulus-driven capture, to difficulties disengaging their attention from threat, or both.

1.5. The attentional response to distal versus proximal emotional information paradigm

MacLeod's team has devised a new method for distinguishing between attentional engagement (i.e., capture) versus delayed disengagement from threat (e.g., Grafton & MacLeod, 2014; Rudaizky, Basanovic, & MacLeod, 2014). They have dubbed this probe variant the Attentional Response to Distal versus Proximal Emotional Information (ARDPEI) paradigm. It works as follows. First, a cue anchors attention in one of two locations (left side or right side) on a computer screen. Second, a pair of stimuli – one threatening, one neutral - appears proximally or distally from the locus of attention. This arrangement enables researchers to assess how strongly attention is held by proximal threat stimuli relative to neutral stimuli, thereby furnishing an index of disengagement bias. It also enables researchers to assess how strongly attention is captured by distal threat stimuli relative to neutral ones, thereby furnishing an index of engagement bias.

Using this paradigm, this team has discovered that elevated trait anxiety is characterized by attentional engagement by threat cues and by difficulty disengaging from them (Rudaizky et al., 2014). Moreover, the engagement and disengagement bias indices are uncorrelated (Grafton & MacLeod, 2014), yet both linked to elevated trait anxiety. Interestingly, people scoring high on a measure of rumination exhibit difficulty disengaging attention from threat cues, but do not exhibit attentional capture by them (e.g., Grafton, Southworth, Watkins, & MacLeod, 2016; Southworth, Grafton, MacLeod, & Watkins, 2017).

Taken together, these studies suggest that elevated trait anxiety can be characterized by heightened attentional engagement by threat cues, difficulty disengaging attention from them, or both. Hence, independent attentional difficulties are associated with elevated propensity to experience episodes of anxiety.

In summary, ABT research has featured the progressive refinement of experimental procedures. Diverse paradigms have detected differences between groups of people reporting low versus high anxiety, or between healthy people and those with anxiety disorders. Yet it has often been unclear whether attentional bias per se explains these effects. Hence, interpretive ambiguity has been the mother of invention of new paradigms, such as Grafton and MacLeod's (2014) ARDPEI one. I suspect that the mechanisms disclosed by these novel paradigms will be interpreted within the framework of new models formulated by cognitive neuroscientists, such as Petersen and Posner (2012).

2. Attentional bias modification

The importance of ABT arises from its possible causal role in the etiology and maintenance of anxiety disorders (Van Bockstaele et al., 2014). If ABT increases proneness to experience episodes of heightened anxiety, then reducing it would be a worthy clinical goal. If the causal pathway operates both ways – ABT increases anxiety, which, in turn, exacerbates ABT – then therapeutically reducing it would still be worthwhile. Yet if ABT is merely a correlate of anxiety, then targeting it therapeutically would be akin to reaching for a fan rather than a fire extinguisher to expel the smoke of an incipient blaze.

If ABT is a causal contributor to anxiety proneness, then altering the dot probe paradigm so that probes consistently follow nonthreatening cues should diminish ABT and reduce a person's anxiety proneness (MacLeod, 1995). In support of this conjecture, a seminal pair of experiments involving healthy undergraduates demonstrated that training participants to attend to nonthreatening cues reduced their subsequent reactivity to a laboratory stressor, whereas training them to attend to threatening cues increased it (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002).

The pioneering work of MacLeod and his group launched an entire research program testing the efficacy of procedures designed to reduce ABT as a means of diminishing anxiety vulnerability. Initial studies on attentional bias modification (ABM) methods were very promising, especially in people diagnosed with social anxiety disorder (Amir, Beard, Taylor, Klumpp, Elias, Burns, & Chen, 2009; Heeren, Reese, McNally, & Philippot, 2012; Schmidt, Richey, Buckner, & Timpano, 2009). For example, Amir, Beard, Taylor, et al. (2009) found that 50% of people with this syndrome lost their diagnosis after a month of twice-weekly ABM sessions as did 50% of patients with GAD (Amir, Beard, Burns, & Bomyea, 2009). Moreover, a reanalysis of three ABM studies revealed that the greater a patient's ABT at baseline, the more he or she benefited clinically by ABM (Amir, Taylor, & Donohue, 2011). Individuals exposed to a no-contingency control condition consisting of probes replacing threat cues on 50% of trials, and replacing nonthreat cues on the remaining trials did not experience these therapeutic benefits.

Researchers keen to develop portable, scalable interventions began to test the efficacy of ABM on the Internet whereby investigators randomly assigned anxious subjects to ABM versus a control training condition. Participants practiced at home on their computers. In an open trial, Amir and Taylor (2012a) found that such a program combined with CBT modules eliminated the GAD diagnosis in 79% of patients. However, in other studies anxious participants randomly assigned to the control condition experienced reduction in anxiety symptoms that were indistinguishable from the benefits experienced by participants who underwent ABM procedures (e.g., Boettcher, Berger, & Renneberg, 2012; Carlbring et al., 2012). Enock, Hofmann, and McNally (2014) randomized 429 socially anxious participants to ABM, control, and wait-list; those in the first two groups performed three brief daily sessions of training for four weeks on their smartphones. Both the ABM and control groups exhibited significant and statistically indistinguishable reductions in social anxiety symptoms, whereas the wait-list group did not.

It has become increasingly clear that ABM interventions delivered remotely (e.g., over the Internet or via smartphone) are rarely more efficacious than control procedures (Linetzky, Pergamin-Hight, Pine, & Bar-Haim, 2015; Mogg & Bradley, 2018). In one especially surprising Internet-based study, investigators randomly assigned people with social anxiety disorder to attend to threat, attend to positive, or to a control condition (Boettcher et al., 2013). Interestingly, participants on average did not exhibit ABT. Social anxiety diminished in all three conditions, and especially so in the group trained to attend to threat cues.

These findings are truly a major disappointment for those who championed remote ABM as a means of treating countless people with anxiety disorders for whom evidence-based treatment is geographically or financially inaccessible (e.g., Enock & McNally, 2013)

When ABM does diminish anxiety vulnerability or anxiety disorders, it usually occurs in the highly controlled settings of laboratories and research clinics. Yet recent reviews of ABM have arrived at diverse

conclusions about its efficacy. They have ranged from optimistic (Price et al., 2016) to bluntly dismissive (Cristea et al., 2015). Cristea et al.'s meta-analysis incited a lively debate regarding how to interpret the results of randomized controlled trials (RCTs) testing ABM for anxiety disorders. Critics of Cristea et al. argued that meta-analysts need to distinguish between studies in which the ABM procedure worked as intended – that is, actually reduced ABT – from studies in which it failed to do so (MacLeod & Clarke, 2015; MacLeod & Grafton, 2016). A fair test of ABM, they said, requires that one first determine whether it reduced ABT. If it did, then one can ask whether participants whose ABT diminished also exhibited a reduction in anxiety symptoms or stress reactivity. Hence, MacLeod and Grafton (2016) emphasized the distinction between *procedures* designed to reduce ABT and the *process* of successfully reducing it. Unfortunately, as they observed, one phrase – *attentional bias modification* – has confusingly denoted both procedure and process.

In fact, when Grafton et al. (2017) redid the meta-analysis of Cristea et al. (2015), they found that studies where investigators successfully reduced ABT ($n = 3$), ABM procedures markedly reduced anxiety symptoms or reactivity, Hedges' $g = 0.602$, whereas such an effect was nonexistent when the ABM procedure failed to reduce ABT ($n = 9$), Hedges' $g = -0.01$.

In their reply, Cristea, Kok, and Cuipers (2017) objected to Grafton et al.'s selecting for reanalysis only those studies where ABT declined, arguing that post hoc selection of RCTs based on postulated process measures is a "pernicious practice" (p. 272) that violates standard meta-analytic practice for the evaluation of psychotherapies. For example, they said, no one requires that dysfunctional thinking diminish as a precondition for including an RCT in a meta-analysis of CBT efficacy. They further argued that process and outcome measures are often confounded and difficult to disentangle, and that even when a process measure does change, one cannot be sure that it is the mechanism of change, theory notwithstanding. Citing Koster and Bernstein (2015), Cristea et al. observed that it is by no means clear that reduction in ABT accounts for the effectiveness of ABM when clinical improvement does occur.

Although Grafton et al. (2017) argued that reduction in ABT predicts reduction on clinical measures and stress reactivity, exceptions do exist, suggesting a boundary condition for ABM's efficacy. For example, two studies indicated that it reduced ABT in people with intense fears of spiders, but did not significantly affect clinical measures of spider phobia (Reese, McNally, Najmi, & Amir, 2010; Van Bockstaele et al., 2011). This phobia seems driven by observable, external features of spiders, such as their unpredictable movement and discrepancy from the human form (McNally, 2016). It differs from the quasi-ruminative, self-referential cognitive processing characteristic of people with social anxiety disorder who seem especially likely to benefit from ABM, at least when it diminishes their ABT. Indeed, a meta-analysis focusing on ABM for social anxiety revealed that the magnitude of reduction in ABT was strongly predictive of the reduction in stress reactivity ($r = 0.90$; Heeren, Mogoaşe, Philippot, & McNally, 2015).[1]

The aforementioned reviews suggest that when ABM reduces ABT, clinical improvement can occur. Although one cannot conclude that the correlation between reduction in ABT and clinical improvement signifies that the former causes the latter, it is at least consistent with this interpretation. However, other interpretations are plausible. For example, ABM may bolster executive control over attention, thereby enabling people to improve their emotion regulation skills and diminish their anxiety proneness.

Consider studies whereby ABM failed to outperform theoretically inert control procedures. It is not so much that participants do not enjoy statistically significant reduction in symptoms; rather, the improvement in ABM and control groups is indistinguishable. Although such disappointing results are common in RCTs done over the Internet, similar results occur in controlled laboratory experiments, too. For example one ABM experiment revealed strikingly similar improvement in socially anxious participants on self-report, behavioral, and physiological measures of speech phobia, including a control condition whereby participants were trained to attend to threatening faces (e.g., McNally, Enock, Tsai, & Tousian, 2013). Interestingly, the greater the pretest to posttest improvement on a self-report measure of attentional control (Derryberry & Reed, 2002), the greater the improvement on a self-report measure of social phobia symptoms ($r = 0.506$; Liebowitz, 1987) irrespective of training condition. This finding suggests that even theoretically-inert control procedures as well as ABM are associated with improved attentional control.

For two reasons, the 50/50 control condition may be suboptimal. It may inadvertently foster adaptive attentional flexibility rather than functioning as a purely inert procedure. Alternatively, it may constitute a diluted ABM intervention for some individuals. Consider anxious participants prone to attend to threat 90% of the time. Exposure to a condition whereby probes follow threat "only" 50% of the trials might diminish their ABT. Acknowledging that ABM procedures can fail to reduce ABT, MacLeod and Clarke (2015) called for improving extant methods. Because "traditional" ABM methods are very tedious, investigators have explored gamified versions of attentional training designed to engage, motivate, and challenge participants such that larger reductions in ABT occur in the service of fostering clinical recovery.

Dennis and O'Toole (2014) randomly assigned participants to a single session of a game-like mobile app involving an ABM procedure designed to foster avoidance of cartoon threat faces or to a control version. They found that participants who played the ABM version for 45 min exhibited a reduction in ABT and less anxiety and reactivity during a stressful speech in the lab relative to those in the control condition.

On the other hand, Enock's (2015) ABM game reduced ABT, but did not reduce anticipatory anxiety in response to a speech threat, relative to a control procedure. Using Enock's ABM game, Pieters et al. (2017) found equally disappointing results in two studies, one involving multiple sessions. Although participants became increasingly proficient at the game, their improved skill did not transfer to a novel measure of attentional bias. However, these experiments did not involve high-anxiety participants, and Enock's was done over the Internet. In summary, it is too early to pronounce a verdict on gamified ABM procedures.

Others have reported promising results by having anxious participants attend to positive cues in the service of avoiding threat in variants of the visual search paradigm (e.g., De Voogd, Wiers, Prins, & Salemink, 2014; Waters, Pittaway, Mogg, Bradley, & Pine, 2013). De Voogd et al. (2014) found that measures of social anxiety significantly declined after adolescents underwent two sessions of a visual search paradigm where they detected smiling faces among negatives. Notably, participants received the intervention remotely by logging on to computers at school.

In yet another innovative approach, Lazarov, Pine, and Bar-Heim (2017) developed a gaze-contingent positive reinforcement paradigm whereby patients with social anxiety disorder heard their favored music as long as they diverted their attention toward neutral faces and away from threatening ones in a matrix containing 16 faces (half neutral). Relative to the control condition, eight sessions of gaze-contingent music reward therapy produced significant improvement on self-report and clinician-rated measures of social anxiety.

In summary, cognitive science has proved useful in guiding the progressive development of novel clinical interventions for anxiety. Initial studies indicated very impressive results for ABM, sometimes moving 50% of patients out of the diagnostic range with only eight, brief training sessions. Attempts to scale up ABM to deliver it remotely via smartphones and the Internet have proved largely disappointing in

[1] This value is based on the five studies suitable for computing this specific correlation among the 15 studies otherwise qualifying for the meta-analysis. A recent study complicates this picture by showing that ABM successfully moved socially anxious participants from not having an ABT to having a bias away from facial threat cues, but had minimal impact on measures of anxiety (Yao, Yu, Qian, & Li, 2015).

that ABM often failed to outperform theoretically inert control procedures. However failures to replicate the most encouraging early clinical trials have spurred the development of variants of ABM that show promise. Yet a crisis has arisen concerning the statistical reliability of the foundational attentional bias indices.

3. The reliability crisis

Cronbach (1957) observed that psychology comprises two disciplinary traditions, one experimental and the other correlational. Research on attentional bias is squarely in the first tradition. Issues that preoccupy the psychometricians who dominate the second tradition seldom trouble the sleep of the experimentalists. Accordingly, whether measures of attentional bias are reliable has rarely been addressed until recently. An early study of inpatient Vietnam veterans with PTSD revealed that the emotional Stroop interference effect was stable over two weeks ($r = 0.80$; McNally, English, & Lipke, 1993). This finding dovetailed with the assumption that attentional bias is a stable attribute of individuals, albeit one subject to change under certain circumstances, such as effective treatment. However, this study involved threat words appearing blocked on a single card as in the original emotional Stroop (Mathews & MacLeod, 1985).

Over a decade later, a personality psychologist working in the second of Cronbach's two disciplines conducted two studies showing that the dot-probe paradigm "is a completely unreliable measure of attentional allocation in non-clinical samples" (Schmukle, 2005, p. 595) over one week, on both test-retest and internal consistency measures. Years later, clinical researchers began evaluating the reliability of ABT indices derived from versions of the dot-probe task. The results were not encouraging. For example, split-half reliabilities ranged from $r = 0.035$ to $r = 0.074$ in one study (McNally et al., 2013).

Waechter and her colleagues have conducted seminal studies on the reliability of ABT indices (Waechter, Nelson, Wright, Hyatt, & Oakman, 2014; Waechter & Stolz, 2015). For example, in one study they selected participants high and low on social anxiety, asking them to complete a dot probe task and an eye-movement tracking task where stimuli were faces displaying anger, disgust, happiness, or neutral emotion. Following Koster, Crombez, Verschuere, and De Houwer (2004), they computed three bias scores from the dot probe task. The overall attentional bias for threat score was computed by subtracting the mean RT for congruent trials (when the probe followed the emotional face) from the mean RT for incongruent trials (when it followed the neutral face). They calculated a facilitation bias score by subtracting the mean RT for congruent trials from the mean RT for trials involving two neutral faces. Finally, they calculated a disengagement bias score by subtracting the mean RT for the neutral-neutral trials from those for the incongruent trials. Using eye-tracking equipment for the other task, Waechter et al. measured the proportion of first fixations, latency of these fixations, proportion of fixation frequency, and proportion of time fixating on the emotional faces versus the neutral ones. The results indicated that none of the dot probe bias scores provided "a reliable index of individual differences in attention to threat" (Waechter et al., 2014, p. 326).

Price et al. (2015) endeavored to solve the reliability problem by reanalyzing three of their dot probe data sets in various ways. They found that reliability could be improved somewhat by using trials when the probes appeared on the bottom half of the computer screen. Rescaling outliers rather than removing them also helped as did multiple dot probe assessments.

It is impossible to see how any scientific field can survive in the absence of reliable measurement. The assessment and modification of ABT is no exception. Indeed, we have an emerging crisis, arising as a mathematical consequence of the logic of difference scores (Miller & Ulrich, 2013; Rodebaugh et al., 2016; Salthouse & Hedden, 2002; Waechter et al., 2014).[2]

The problem arises as follows. First, a common process – speed of probe detection or discrimination – purportedly drives RT measures. Second, mean RT measures are highly reliable (e.g., rs = 0.85–0.96; Waechter et al., 2014). In fact, reliabilities usually exceed 0.85 with 20 trials, and exceed 0.95 with 100 trials (Miller & Ulrich, 2013). Third, mean RTs for congruent and incongruent trials are highly correlated (e.g., for disgust faces, $r = 0.87$; for angry faces, $r = 0.93$; Waechter et al., 2014). Indeed, fast participants have shorter RTs overall, whereas slow participants have longer RTs overall, irrespective of valence and congruency. Fourth, the reliability of a linear composite score is a function of the reliability of each component score plus the magnitude of the correlation between the components. The reliability of the components always fosters the reliability of the composite, but the magnitude of the correlation between the components either increases or decreases the reliability of the composite depending on whether one adds or subtracts the components to create the composite. When one *adds* the components, the resultant composite has greater reliability than does either component alone. That is, the larger the correlation between the components, the greater the reliability of the composite. However, when one *subtracts* the components, the larger the correlation between the components, the smaller is the reliability of the composite. Fifth, attentional bias indices are composites created via subtraction. Therefore, large positive correlations between the component RTs nearly guarantee that the resultant indices will be very unreliable.

The logic of difference scores will render it extremely difficult for ABT measures to achieve even modest reliability if component RTs are highly correlated, which is usually the case. Reliability of the index can improve if the effect size is substantial, or if hundreds, if not thousands, of trials occur (Miller & Ulrich, 2013). For example, the reliability of ABT indices went from nil to 0.53 across repeated ABT assessments and thousands of ABM trials over the course of four weeks in Enock et al.'s (2014) study. Yet 0.53 falls far short of the 0.90 that Rodebaugh et al. (2016) recommend for making clinical decisions about individual clients.

Given the logic of difference scores and the findings regarding unreliability of ABT measures, how can we make sense of the oft-replicated association between ABT and anxiety (e.g., Bar-Heim et al., 2007)? Several factors likely contribute to resolving this apparent paradox, none mutually exclusive.

First, anything that reduces the correlation between components that figure in a subtractive composite will foster an increase in its reliability. Hence, although the correlation between RTs for congruent and incongruent trials is usually quite high, it is conceivable that extraneous factors (e.g., variation in state anxiety, fatigue, or motivation) may diminish the correlation.

Second, as Thomas L. Rodebaugh suggested, it is conceivable that group differences in ABT might appear if a subset of healthy control participants routinely avoid attending to threat cues, whereas anxious participants exhibit more variability in their deployment of attention (Personal communication, February 10, 2018). Such patterns could give the impression of an ABT in the latter group in the presence of another factor (e.g., file drawer effect).

Third, some version of the "winner's curse" may play a role whereby early studies of a phenomenon tends to feature large effects that diminish (or disappear) in subsequent replication attempts (Ioannidis, 2008). For example, early studies on ABM for social anxiety had

[2] This problem is not confined to ABT. Any measure based on difference scores is vulnerable to this problem (Cronbach & Furby, 1970), including other cognitive tasks (e.g., assessing executive functioning; Paap & Sawi, 2016). Yet difference scores are not invariably unreliable. For example, we obtained Spearman-Brown split-half reliability values of 0.80 and 0.76 for Fan, McCandliss, Sommer, Raz, and Posner's (2002) attentional conflict index at pretest and posttest, respectively (McNally et al., 2013). Yet the corresponding reliabilities for the ABT indices were approximately zero.

significantly larger effect sizes than those published later (Heeren, Mogoaşe, McNally, Schmitz, & Philippot, 2015).

Fourth, as Stephanie Waechter noted, sometimes the reliability of ABT indices can reach moderate levels (i.e., 0.30–0.50). Although psychometrically unacceptable, she noted that such levels might permit group differences to appear (Personal communication, February 11, 2018).

4. Conceptual crisis or opportunity?

A fundamental assumption behind research on the assessment and reduction of ABT is that it is a stable feature of individuals – "trait-like" – at least in people who have not undergone training programs designed to abolish it. Perhaps this assumption is incorrect.

Indeed, one research team has reconceptualized the attentional abnormalities that presumably characterize people with anxiety disorders, and they have devised novel methods of analyzing dot probe RT data as a means of testing their views (e.g., Bernstein & Zvielli, 2014; Zvielli, Amir, Goldstein, & Bernstein, 2016; Zvielli, Bernstein, & Koster, 2015). Another group has likewise converged on similar intuitions and methods (Iacoviello et al., 2014). They do not view the primary attentional abnormality associated with elevated anxiety to be a stable propensity to selectively attend to threat (cf. MacLeod et al., 1986). Rather, they view it as a dynamic process unfolding over time, characterized by fluctuating attention toward threat, away from threat, increased temporal variability, and increased amplitude of responses.

To test these conjectures, they developed measures derivable from standard dot probe tasks. Zvielli et al.'s (2015) Trial Level Bias Score (TL-BS) method works as follows. Each incongruent trial is paired with a congruent one that is temporally as proximal as possible to it, but no further than five trials away either before or after the incongruent one. Researchers then compute a bias index (BI) for each trial pair by subtracting the RT for the congruent trial from the RT for the incongruent trial. The same procedure is used to pair each congruent trial to its incongruent trial neighbor. This procedure yields a long series of TL-BSs that indicate how attention is allocated over to time to threat and nonthreat stimuli. These data furnish the basis for calculation of five indices. The peak and average values are computed separately for negative and positive TL-BSs, constituting the first four indices. The fifth index, TL-BS variability, is the mean absolute distance over the series of TL-BSs.

In an experiment comparing participants with and without spider phobia, Zvielli et al. (2015) found that levels of TL-BS toward spider cues, peak levels of TL-BS away from spider cues, and greater variability in attentional bias distinguished participants with spider phobia from healthy participants. Moreover, these measures of temporal dynamics distinguished phobic from nonphobic participants better than the traditional attention bias index did. In a second experiment, they found that the traditional attentional bias for threat index had extremely low split-half reliability, whereas estimates of the TL-BS parameters had significant, but still modest, levels of reliability.

However, a voice of caution was expressed by Kruijt, Field, and Fox (2016). They ran simulations to investigate the behavior of the attentional indices proposed by Zvielli and colleagues. Across simulations, they systematically manipulated the settings for different variables (e.g., mean RTs on congruent and incongruent trials, standard deviations for congruent and incongruent trials) for one "group," while leaving them unchanged in the other "group" thereby establishing the ground truth to evaluate the results of their simulations. Unfortunately, the results indicated that group differences can occur even in the absence of bias. Although very supportive of the efforts to devise dynamic measures of attentional bias, interpreting their results, they said "This renders the new indices in their current form unfit for empirical purposes" (p. 1). However, as one anonymous reviewer of this article observed, Kruijt et al.'s simulations presuppose that RTs are normally distributed when they are usually positively skewed. Their normality assumption, in turn, enabled them to treat RT and standard deviation as independent whereas they are not. Finally, this reviewer remarked that although group differences can emerge without a bias being present, it does not rule out the possibility that variability in AB may predict unique variance in symptoms.

If the evolved function of anxiety is to motivate defense against danger, the capacity to detect danger cannot per se be deemed pathological. What, then, constitutes the psychopathology of attentional bias for threat in anxiety disorders? One possibility is that people with anxiety disorders have a low threshold for responding to cues as if they were seriously threatening (Mathews & Mackintosh, 1998; Mogg & Bradley, 1998).

Consistent with this possibility, Wilson and MacLeod (2003) reported that participants scoring low as well as high on a measure of trait anxiety exhibited attentional avoidance for morphed faces displaying minimal anger as well as exhibiting attentional vigilance for those displaying intense anger. Importantly, the groups differed when it came to responding to probes that replaced faces displaying moderate anger: only participants with high trait anxiety exhibited attentional vigilance. These individuals responded to moderate threat as if it signified intense threat.

If this is the case, then perhaps our efforts should be devoted to the assessment and modification of interpretation biases for threat. If so, then attentional bias for threat may be parasitic on a more fundamental interpretive bias for threat. As Mogg and Bradley (2004) observed, "biases in the evaluation of threat cues, rather than attentional biases, underlie vulnerability to anxiety" (p. 71). For example, Amir and Taylor (2012b) reported that such a program resulted in 65% of patients with generalized social anxiety disorder no longer qualifying for the diagnosis at the end of the program relative to 13% of those who had undergone a control training that did not involve fostering benign interpretations of ambiguous material.

At first glance, the aim of training people to avoid mildly threatening cues seemingly violates the time-honored principle of exposure therapy: graduated systematic exposure to feared, but harmless, stimuli reduces the propensity to respond fearfully to them (McNally, 2007). As Foa and Kozak (1986) argued, cognitive as well as behavioral avoidance can maintain pathological anxiety. Accordingly, ABM would seemingly be iatrogenic.

Yet there is likely a distinction between avoiding threat when it is neither severe, nor imminent, nor actionable. Brooding about possible threats in the future, as those with GAD do, surely counts as unnecessary suffering, and learning to disengage from negative material would not count as pathological cognitive avoidance.

Although evidence indicates that people with anxiety disorders, as a group, do exhibit an attentional bias for threat (Bar-Heim et al., 2007), considerable variability exists. Some people with trait anxiety or anxiety disorders exhibit attentional avoidance, whereas others exhibit neither ABT nor avoidance (e.g., Boettcher et al., 2013; Mogg & Bradley, 2016; Zvielli, Bernstein, & Koster, 2014). Clearly, the absence of ABT in people with anxiety disorders indicates that ABT is not a universal casual risk factor (or even correlate) for anxiety disorders.

Further complicating matters, Yiend et al. (2015) reported two experiments where patients with GAD exhibited faster disengagement from threat cues than did healthy participants with either high or low trait anxiety. Such unsettling findings imply that the many studies on college students with elevated trait anxiety are not readily generalizable to GAD.

But even if we pursue programs to reduce ABT, we need to determine who should receive ABM interventions. Amir et al.'s (2011) data suggest that only people who have elevated ABT scores at baseline are likely to benefit clinically from ABM. On the one hand, this makes sense. If an anxious patient does not exhibit a bias for selectively attending to threat, why should a program designed to correct this bias confer any therapeutic benefits? In fact, inconsistent efficacy results in the ABM field may partly be attributable to inclusion of participants

who never had an ABT in the first place, their level of anxiety notwithstanding. Although these data do not confirm that ABT is the pathogenic maintenance factor, they are certainly consistent with this interpretation. However, the very fact that people can acquire an anxiety disorder without exhibiting an ABT suggests that such a bias is not inevitably implicated in the etiology and maintenance of these syndromes. Perhaps ABT signifies only one of multiple pathways to pathological anxiety.

Other studies have revealed pre-post improvements on clinical and attentional control measures after socially anxious participants have undergone ABM, control, or inverse ABM (toward threat) training (e.g., Chen, Clarke, Watson, MacLeod, & Guastella, 2015; Heeren, Mogoaşe, McNally, et al., 2015; McNally et al., 2013). These findings invite the conjecture that any of these training regimens foster enhanced attentional control, thereby enabling people to cope better with anxiety (e.g., Klumpp & Amir, 2010). If so, then perhaps we should focus our efforts on maximizing executive control of attention in our patients rather than doing so indirectly by abolishing an ABT.

In summary, after reviewing the results of 34 RCTs on AMB for anxious participants, Mogg, Waters, and Bradley (2017) concluded that anxiety reduction often occurs following control procedures as well as ABM; not all anxious patients exhibit ABT at pretreatment; and anxiety reduction can occur with or without ABT or reduction in ABT. Accordingly, Mogg et al. argue that we need to move beyond the original theoretical intuitions that inspired research on ABT and its modification, and they suggest ways of doing so.

5. Clinical implications and future directions

Cognitive science has inspired the study of aberrant processes presumably implicated in the maintenance and perhaps the etiology of anxiety disorders (e.g., attentional bias for threat) as well as the development of procedures to correct them. Yet despite their methodological rigor these new interventions seem unlikely to surpass the therapeutic efficacy of traditional CBT. On the other hand, some studies suggest that they can abolish anxiety disorders in 50% of patients in far less time than CBT and with scant therapist involvement (e.g., Amir, Beard, Taylor, et al., 2009). Such results imply the potential of a two-step, cost-effective approach whereby patients are offered ABM first and traditional CBT is offered to those who fail to benefit sufficiently from ABM. The first step might also help prevent anxiety disorders in those at risk for developing them (e.g., people with elevated anxiety sensitivity). However, clinicians must be alert to clients becoming demoralized should they fail to respond adequately to early, cost-effective minimal intervention.

Another clinical implication concerns the potential scalability of ABM. Indeed, the promise of reducing the pointless suffering of people without ready access to CBT inspired attempts to use cutting-edge technology as vehicles to reach hundreds of anxiety-disordered individuals at a time e.g., smartphones; (Enock et al., 2014). Yet the power of ABM seems confined to the highly controlled environment of the laboratory and the research clinic. Delivery via the Internet has yielded disappointing findings (MacLeod & Grafton, 2016), tempering enthusiasm for ABM's potential scalability. However, training biases toward positive cues does show some promise outside the lab and clinic (e.g., De Voogd et al., 2014).

With some exceptions, researchers have seldom examined demographic variables as moderators of the magnitude of ABT or its modification. For example, the magnitude of ABT in anxious children does not differ from that in anxious adults (Bar-Heim et al., 2007). The percentage of female participants did not moderate the effect of ABM in a meta-analysis of studies on social anxiety disorder (Heeren, Mogoaşe, McNally, et al., 2015). However, Amir et al. (2011) found that non-Caucasian participants with social anxiety disorder responded better than Caucasians to ABM, but also to the control procedure. Hence, it remains unknown whether demographic variables such as social class, ethnicity, age, and so forth affect response to ABM.

In sum, cognitive science has had minimal impact on the assessment and diagnosis of anxiety disorders. However, cognitive science has fostered the development of innovative treatment methods designed to target aberrant cognitive processes. But it remains to be seen whether subsequent variations of these interventions can consistently produce marked reductions in symptoms that would justify their widespread dissemination. Finally, we need to solve the reliability problem before we can hope to apply new cognitive science methods to reduce the unnecessary suffering of those with anxiety disorders (Rodebaugh et al., 2016). One possibility would be to devise procedures that capture attentional selectivity to threat cues, but that do not rely on subtractive composite measures of attentional bias that seemed doomed to unreliability.

Conflict of interest

None.

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