2-1-2014

Changing attention to emotion: A biobehavioral study of attention bias modification using event-related potentials

Laura O'Toole

Graduate Center, City University of New York

How does access to this work benefit you? Let us know!

Follow this and additional works at: http://academicworks.cuny.edu/gc_etds

Part of the Psychology Commons

Recommended Citation

O'Toole, Laura, "Changing attention to emotion: A biobehavioral study of attention bias modification using event-related potentials" (2014). CUNY Academic Works.
http://academicworks.cuny.edu/gc_etds/89

This Dissertation is brought to you by CUNY Academic Works. It has been accepted for inclusion in All Dissertations, Theses, and Capstone Projects (2014-Present) by an authorized administrator of CUNY Academic Works. For more information, please contact AcademicWorks@gc.cuny.edu.
CHANGING ATTENTION TO EMOTION: A BIOBEHAVIORAL STUDY OF ATTENTION
BIAS MODIFICATION USING EVENT-RELATED POTENTIALS

by

LAURA J. O’TOOLE

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

2014
This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

Tracy Dennis

Date

Chair of Examining Committee

Maureen O’Connor

Date

Executive Officer

James Gordon

Douglas Mennin

Regina Miranda

Mariann Weierich

Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK
Abstract

CHANGING ATTENTION TO EMOTION: A BIOBEHAVIORAL STUDY OF ATTENTION BIAS MODIFICATION USING EVENT-RELATED POTENTIALS

by

Laura J. O’Toole

Anxiety is characterized by an attentional bias toward threat; that is, anxious individuals will preferentially attend to threatening versus non-threatening information. Recent research has demonstrated that reducing this bias, through attention bias modification (ABMT), leads to reductions in anxious symptoms and stress reactivity. Although these effects are promising for the development of an alternative intervention for anxiety, little is known about the attentional processes underlying ABMT effects. The present research used event-related potentials (ERPs) to investigate the neurocognitive attentional processes altered by ABMT over the course of three studies. In Study 1, non-anxious participants were trained towards and away from threat; findings suggest that training towards threat affects relatively early attentional processing of threat. In Studies 2 and 3, anxious participants were trained away from threat; in addition to collecting neurocognitive measures of the threat bias and threat processing these studies also included an assessment of stress reactivity. Training led to increases in controlled attention to threat and decreases in elaborated threat processing. Additionally, these studies demonstrated the utility of ERPs in tracking both how and for whom ABMT works. Findings suggest that behavioral measures of the threat bias as an outcome measure may be missing important changes in attention following ABMT. Additionally, the present studies raise important questions...
regarding the role of flexibility of the threat bias and administering ABMT to individuals who are avoidant of threat. Taken together, findings from this research have the potential to inform identification of individuals with anxiety and to contribute to future studies assessing the efficacy of ABMT as a viable treatment alternative.
Acknowledgements

I would like to thank my advisor, Dr. Tracy Dennis, for all her guidance and support. I would also like to thank her for opportunities she has provided me with, including the ability to work several projects of interest, present during symposia at our regular conferences, and for connecting me with my potential future F32 mentors. I would also like to thank my committee members – Dr. James Gordon and Dr. Doug Mennin – for their continued support in giving feedback on my research and writing me countless letters of recommendation. Additionally, I would like to thank my supervisory committee – Dr. Regina Miranda and Dr. Mariann Weierich – for their willingness to serve on my committee and provide feedback on this dissertation. Without this team of excellent mentors I would not have been able to achieve all that I have during my time in the doctoral program.

I would also like to thank all of my past and present colleagues in the laboratory. After six years in the lab I often cannot remember who overlapped with whom but you are all my big lab family whether you know each other or not!

Finally, I would like to thank Justin, my family, and my friends for their continued support and understanding during times of “social hibernation” – particularly over the last few months! And of course, I would like to thank Abby for keeping me company during all of my writing and data processing, even if she was fast asleep for most of it.
Table of Contents

List of Tables.................................................................................................................ix
List of Figures................................................................................................................x

Chapter 1: Introduction.................................................................................................1
  I. Background..............................................................................................................1
  II. Cognitive Theories of the Anxiety-Related Threat Bias.........................................2
  III. Measurement of the Threat Bias...........................................................................5
  IV. Attention Bias Modification Training.................................................................7
  V. Using Event-Related Potentials to Measure Attention to Threat.........................9
  VI. The Role of Baseline Attentional Biases.............................................................12
  VII. Aims of the Current Research............................................................................14

Chapter 2: Study 1........................................................................................................16
  I. Introduction............................................................................................................16
  II. Method................................................................................................................18
  III. Results...............................................................................................................23
  IV. Discussion..........................................................................................................30

Chapter 3: Study 2........................................................................................................44
  I. Introduction............................................................................................................44
  II. Method................................................................................................................45
  III. Results...............................................................................................................51
  IV. Discussion..........................................................................................................54

Chapter 4: Study 3........................................................................................................64
  I. Introduction............................................................................................................64
List of Tables

Table 1. Descriptive statistics for behavioral biases for both training groups..................34

Table 2. Descriptive statistics for ERP amplitudes for the train towards threat group........35

Table 3. Descriptive statistics for ERP amplitudes for the train away from threat group......36

Table 4. Descriptive statistics for participants with behavioral biases at 100 ms..................37

Table 5. Descriptive statistics for participants with behavioral biases at 500 ms..................38

Table 6. Participant demographics and baseline anxiety and depression symptoms..........57

Table 7. Threat bias, ERP amplitudes, anxiety, and stress reactivity.............................58

Table 8. Participant demographics and baseline anxiety..............................................76

Table 9. Threat bias, ERP amplitudes, and stress reactivity.........................................77
List of Figures

Figure 1. Sequence of events in the dot probe task for Study 1..........................39

Figure 2. Scalp topographies and waveforms for ERP components (P1, N170, P2, N2) generated to the face pair cues during the pre-training dot probe task...............................40

Figure 3. Attentional bias scores increased for the train toward threat group and decreased for the train away from threat group for participants who showed pre-training biases at 100 ms........41

Figure 4. Vigilance decreased for the train away from threat group for participants who showed pre-training biases at 100 ms.................................................................42

Figure 5. Attentional bias increased for the train toward threat group for participants who showed pre-training biases at 500 ms.................................................................43

Figure 6. Sequence of events in the dot probe task for Study 2...........................59

Figure 7. Scalp topographies and waveforms for ERP components (P1, N1, P2, N2) generated to the face pair cues during the pre-training dot probe task...........................................60

Figure 8. Negative mood following the TSST was reduced for the ABMT versus PT groups, but only for those participants who showed decreased N1 amplitudes to threat from pre- to post-training.................................................................61

Figure 9. Negative mood following the TSST was reduced for the ABMT versus PT groups, but only for those participants who showed enhanced N1 amplitudes to threat versus non-threat at baseline.................................................................62

Figure 10. State anxiety was greater for the ABMT versus PT groups at post training, but only for those participants who showed reduced N2 amplitudes to threat versus non-threat at baseline.................................................................63

Figure 11. Sequence of events in the dot probe task for Study 3...........................78
Figure 12. Scalp topographies and waveforms for ERP components (P1, N170, P2, N2) generated to the face pair cues during the pre-training dot probe task…………………………….79

Figure 13. Scalp topographies and waveforms for ERP components (early and late LPP) generated to the images during the pre-training passive viewing task…………………………….80

Figure 14. Attention bias scores at baseline, pre-training, and post-training……………………81

Figure 15. Stress reactivity was greater (i.e., worse performance) for the ABMT versus PT groups at post-training, but only for those participants who showed reduced N2 amplitudes to threat versus non-threat at baseline…………………………………………………………………….82
Chapter 1: Introduction

I. Background

Anxiety disorders are the most prevalent psychiatric problem, affecting nearly 20% of adults – approximately 90 million in the United States alone (Kessler, Chiu, Demler, & Walters, 2005). Attention, interpretation, and memory processes are all implicated in the vulnerability of developing emotional disorders (Mathews & MacLeod, 2005; Ouimet, Gawronski, & Dozois, 2009). Cognitive-behavioral treatments have been designed to target cognitive disruptions, yet upwards of 50% of individuals with anxiety disorders do not receive treatment (Greenberg et al., 1999; Kessler et al., 2008; Kessler & Wang, 2008) and of those that do nearly half remain symptomatic following treatment (Barlow, Gorman, Shear, & Woods, 2000; Gunter & Whittal, 2010). This crisis in treatment delivery extends beyond mental health implications: individuals with anxiety may develop physical health problems, including gastrointestinal disorders (Spence & Moss-Morris, 2007; Thabane, Kottachchi, & Marshall, 2007) and higher risk for heart attack in individuals with established heart disease (Albert, Chae, Rexrode, Manson, & Kawachi, 2005; Kawachi et al., 1994). By better understanding the disrupted cognitive processes in anxiety, we may be able to develop new treatments that can address barriers to effective mental health intervention delivery.

The series of studies reported in this dissertation focus on the anxiety-related attentional bias towards threat. While attention to potentially threatening stimuli is an adaptive response that can ensure safety in the face of danger (Le Doux, 1996), preferential attention towards threatening information may create a “vicious cycle” where selective processing becomes maladaptively biased towards threat (Ouimet et al., 2009). Such affect-biased attention occurs reflexively and thus appears to be driven by bottom-up processes; however more top-down
attentional control settings may underlie this habitual responding (Todd, Cunningham, Anderson, & Thompson, 2012). This attentional bias towards threat is thought to emerge during childhood (Puliafico & Kendall, 2006; Roy et al., 2008) and predicts the relationship between social withdrawal and early behavioral inhibition (Perez-Edgar et al., 2010; Perez-Edgar et al., 2011). The development of the threat bias may thus contribute to the development of anxiety disorders (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Eysenck, 1992). Critically, the threat bias is linked to elevated trait anxiety rather than a specific anxiety disorder, suggesting that it may represent a core mechanism underlying anxiety (Bar-Haim et al., 2007; Cisler & Koster, 2010).

II. Cognitive Theories of the Anxiety-Related Threat Bias

Several cognitive models of anxiety have attempted to describe the mechanisms underlying biased attention to threatening information. These models focus on selective information processing (Beck & Clark, 1997; Williams, Watts, MacLeod, & Mathews, 1988, 1997), cognitive-motivational interactions (Mathews & Mackintosh, 1998; Mogg & Bradley, 1998), and attentional control processes (Derakshan & Eysenck, 2009; Eysenck, Derakshan, Santos, & Calvo, 2007) in anxiety, with different models proposing varying contributions of automatic, or bottom-up, and strategic, or top-down, processes.

Williams, Watts, MacLeod, and Mathews’ (1988, 1997) two-component model posits biases in automatic stages of information processing. The affective decision mechanism (ADM) determines the threat value of stimuli at a preconscious level. A high threat appraisal by the ADM triggers the resource allocation mechanism (RAM). Anxious individuals have a lower ADM threshold and will thus show a greater likelihood of activation compared to non-anxious
individuals. In response to an activated RAM, anxious individuals will show facilitated attention towards threat while non-anxious individuals will show attentional avoidance of threat.

Subsequent research, however, demonstrated that non-anxious individuals will show facilitated attention towards severely, but not moderately, threatening stimuli while anxious individuals show facilitated attention to both severely and moderately threatening stimuli (Wilson & MacLeod, 2003). Thus, attentional allocation is biased towards severely threatening (e.g., dangerous) stimuli regardless of anxiety. These findings are inconsistent with the Williams’ et al. (1988, 1997) models that propose attentional avoidance of threat in non-anxious individuals. Subsequent cognitive models have proposed a role for adaptive responses in attentional orienting towards dangerous stimuli that function to ensure safety.

The schema-based information processing model of anxiety proposes a role for both automatic and strategic processes at multiple stages of information processing (Beck & Clark, 1997). According to this model, the automatic allocation of attention is mediated by a stimulus-driven orienting mode. In anxiety, the orienting mode is biased towards threatening stimuli (i.e., the threat bias). Following this relatively automatic initial registration of threat is the activation of a primal mode and metacognitive mode. In anxiety, threat processing becomes increasingly effortful, beginning with a primal threat mode that maximizes safety and minimizes danger. When the primal threat mode is activated, anxious individuals are more likely to show adaptive facilitated attention to subsequent threats. Anxiety may then be exacerbated by a failure to effectively re-evaluate the threatening stimulus in reference to other schemas, either because strategic activation of other schemas is overpowered by the more automatic primal threat mode (e.g., hypervigilance for threat) or because of a failure to activate the metacognitive mode. Failure to activate the metacognitive mode may reflect an avoidant mode of attentional
processing of threat, such that stimuli are not attended to and thus not processed in a more elaborated manner. Beck and Clark (1997) identified the biased orienting mode and tendency to ineffectively activate the metacognitive mode to reappraise threat as targets for treatments of anxiety disorders.

Mogg and Bradley’s (1998) cognitive-motivational model again acknowledges the adaptive nature of attention to threat and proposes two mechanisms through which attention to threat is determined. The valence evaluation system (VES) determines threat value at the preconscious level, similar to the ADM of Williams et al.’s model (1988, 1997). The VES shows heightened sensitivity to threat in anxious versus non-anxious individuals, supporting findings that severe threat is detected regardless of anxiety level while moderate threat is only detected by anxious individuals (Wilson & MacLeod, 2003). The VES then feeds into the goal engagement system (GES) which interrupts current behaviors to allocate attention towards stimuli evaluated as highly threatening, while non-threatening stimuli are ignored in favor of current behavior and goals.

Mathews and Mackintosh’s (1998) cognitive model also proposes an automatic threat detection process, the threat evaluation system (TES), which is similarly modulated by anxiety level. An additional component of this model is the ability to counter the output of the TES via voluntary effort; through such top-down processing attentional allocation towards threat can be avoided or countered.

The Attentional Control Theory proposes that anxiety disrupts central executive functions relevant to attentional processing (Derakshan & Eysenck, 2009; Eysenck et al., 2007). According to this model, anxiety disrupts the balance between stimulus-driven (i.e., saliency of potential threats) and goal-directed (i.e., an individual’s goals, expectations, and knowledge) attentional
control systems. A prioritization of bottom-up processes over top-down processes interferes with inhibitory attentional control, producing facilitated attention towards threat due to a failure in restraining the direction of attention. Conversely, the diminished strength of top-down processes leads to decreased attentional shifting abilities, as reflected by difficulty disengaging from threat once attention is captured.

**Summary.** Taken together, this series of cognitive models for anxiety underscores the role of two distinct attentional processes: bottom-up facilitated attentional capture by threat and top-down disrupted attentional control when disengaging from threat (Bar-Haim et al., 2007; Cisler, Bacon, & Williams, 2009; Cisler & Koster, 2010; Weierich, Treat, & Hollingworth, 2008). Indeed, neuroimaging research links the attention bias to both enhanced bottom-up subcortical activation (i.e., the amygdala) as well as reduced top-down prefrontal activation (i.e., lateral prefrontal cortex, dorsolateral prefrontal cortex) in response to threatening stimuli (Bishop, 2009; Bishop, Jenkins, & Lawrence, 2007; Monk et al., 2006; Monk et al., 2008). Given the role of these complementary processes in the threat bias, the studies reported in this dissertation explored the relative contributions of attentional capture and control in a new treatment alternative for anxiety that targets the threat bias.

**III. Measurement of the Threat Bias**

Empirical studies of the threat bias have used several computerized tasks to assess the threat bias: the emotional Stroop task, the dot probe task, and the emotional spatial cueing task. The *emotional Stroop task* measures the interference caused by threatening stimuli by presenting threat-related and neutral words printed in different colors and response latencies to identify the color are measured. In addition to word stimuli, studies have also used schematic faces with angry or neutral expressions presented in different colors. The threat bias is inferred from longer
response latencies to name colors for the threatening versus non-threatening stimulus (MacLeod, 1991). The *emotional spatial cueing task* was developed to compare cue validity effects for threatening and non-threatening cues to assess attentional engagement with and disengagement from threat (Fox, Russo, Bowles, & Dutton, 2001). A limitation of this paradigm, however, is the lack of competition for attentional resources by threatening and non-threatening stimuli (Mathews & Mackintosh, 1998). The *dot probe task* was developed in response to the ambiguity of cognitive processes underlying results from the emotional Stroop task and to modify the emotional spatial cueing task to include competition (MacLeod, Mathews, & Tata, 1986). The dot probe task simultaneously presents a threatening stimulus and a non-threatening stimulus that compete for attention: faster response latencies to probes appearing in the location of the threatening stimulus suggest that attention has been captured by threat. Such effects have been found when using threat-relevant words (MacLeod et al., 1986), emotional human faces (Bradley, Mogg, & Millar, 2000), and complex emotional images (Yiend & Mathews, 2001). The dot probe task is the most commonly used computerized assessment of the threat bias (Bar-Haim et al., 2007), however, does not distinguish between attentional engagement and disengagement with threat.

The dot probe task has been modified to assess attentional engagement and disengagement. By including pairs of two non-threatening stimuli, responses when threatening stimuli are presented can be compared against a baseline response. Faster responding to a valid threat cue than to a baseline trial suggests greater attentional capture by threat, or enhanced *vigilance* toward the location of the threatening stimulus. Slower responding to an invalid threat cue than to a baseline trial suggests reduced attentional control of threat, reflected by *difficulty disengaging* from the location of threatening stimulus. Using this modified task, several studies
have found that the threat bias is driven by difficulty disengaging from threatening stimuli (Koster, Crombez, Verschuere, & De Houwer, 2004, 2006; Salemink, van den Hout, & Kindt, 2007), with a one study documenting enhanced vigilance for threat (Klumpp & Amir, 2009). The studies reported in this dissertation all use this modification to the dot probe task in addition to collecting neurocognitive measures of attentional capture and control when processing threat.

IV. Attention Bias Modification Training

Behavioral studies have shown that an attentional bias to threat can be experimentally induced in non-anxious participants using a modified version of the dot probe task with a systematic contingency between the location of the threatening stimulus and probe. Specifically, participants trained towards threat in this manner show speeded response latencies to probes cued by threat as well as elevations in stress reactivity (i.e., greater mood disruptions in response to a stressful task or challenge), suggesting a causal link between the threat bias and the development of anxiety (Clarke, MacLeod, & Shirazee, 2008; Eldar, Ricon, & Bar-Haim, 2008; MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002).

A direct translational treatment implication of these findings and the threat-related attentional bias literature has been the development of attention bias modification training (ABMT). In ABMT, anxious individuals complete a dot probe task designed to induce a bias away from threat, which leads to reductions in anxiety (Hakamata et al., 2010). Rather than merely exposing anxious individuals to threatening stimuli in order to reduce habitual affect-biased attention, ABMT presents a systematic contingency that targets attentional filters that are tuned towards threat. A recent meta-analysis suggests that assessing anxiety after a stressor or challenge (such as being asked to give an impromptu speech) may produce more evident reductions, as compared to measuring anxiety following the training (Hallion & Ruscio, 2011).
Practically, such training reduces anxiety symptoms across a range of diagnoses including generalized anxiety disorder (Amir, Beard, Burns, & Bomyea, 2009; Vasey, Hazen, & Schmidt, 2002), social anxiety disorder (Amir, Weber, Beard, Bomyea, & Taylor, 2008; Schmidt, Richey, Buckner, & Timpano, 2009), social phobia (Amir, Beard, Taylor, et al., 2009; Heeren, Reese, McNally, & Philippot, 2012), spider phobia (Reese, McNally, Najmi, & Amir, 2010), and obsessive-compulsive disorder (Najmi & Amir, 2010). ABMT also reduces anxiety symptoms in subclinical young adults with impairments including elevated trait anxiety (Eldar & Bar-Haim, 2010), pathological worry (Hayes & Matthes, 2009; Hazen, Vasey, & Schmidt, 2009), and elevated social anxiety (Klumpp & Amir, 2010; Li, Tan, Qian, & Liu, 2008). Thus, the induction of a threat bias via ABMT leads increases in stress reactivity and the reduction of the threat bias via ABMT leads to decreases in stress reactivity, suggesting that ABMT targets an underlying causal factor across the broad spectrum of anxious psychopathology and subclinical anxiety.

Co-existing with the compelling nature of these findings is a lack of clarity concerning the neurocognitive processes that are directly modified by ABMT (Heeren, De Raedt, Koster, & Philippot, 2013), thus limiting direct clinical translation – in particular, understanding of how and for whom ABMT may be most effective. While several studies have demonstrated that changes in threat bias via ABMT predict ABMT efficacy – that is, changes in threat bias mediate the effects of ABMT on anxiety severity (Amir, Beard, Taylor, et al., 2009) and stress reactivity (Amir et al., 2008; Clarke et al., 2008; Heeren et al., 2012; Najmi & Amir, 2010; See, MacLeod, & Bridle, 2009) – others have failed to find such effects (Amir, Beard, Burns, et al., 2009; Eldar, Apter, Lotan, Perez-Edgar, et al., 2012; Waters, Henry, Mogg, Bradley, & Pine, 2010). Even in the case of significant mediation, it is still unclear whether ABMT targets attentional engagement or disengagement with threat.
One potential explanation for these inconsistent findings is that behavioral measure of the threat bias generated from the dot probe task fails to distinguish between two distinct cognitive processes implicated in biased processing of threat: early attention capture by threat, the relatively bottom-up, initial evaluation of stimulus threat value, which is elevated in anxiety (Beck & Clark, 1997; Mogg & Bradley, 2002; Wilson & MacLeod, 2003); and cognitive control, the relatively strategic, top-down control of threat processing and reactivity, which is dampened in anxiety (Bishop, 2009; Derakshan & Eysenck, 2009; Derryberry & Reed, 2002; Eysenck et al., 2007). Thus, ABMT may lead to changes in anxiety by reducing the initial capture of attention by threat, by bolstering attentional control processes to more efficiently disengage from threat, or a combination of both processes (Heeren et al., 2013). In particular, there has been inconsistent evidence for the impact of increased attentional control via ABMT: while several studies suggest that ABMT alters attentional control (Klumpp & Amir, 2010) and the ability to disengage from threat (Bar-Haim, Morag, & Glickman, 2011), a recent randomized control trial of ABMT in anxious youths found no support for increases in attentional control following training suggesting that other cognitive processes, such as relatively automatic attention capture, may be implicated in threat bias and anxiety reduction (Eldar, Apter, Lotan, Perez-Edgar, et al., 2012).

V. Using Event-Related Potentials to Measure Attention to Threat

Scalp-recorded event-related potentials (ERPs) are sensitive to both attentional capture and control processes and can measures changes in bottom-up and top-down cognition on the order of milliseconds. Additionally, ERPs index attention in the absence of a response which allows for the measurement of covert changes in attention to threat that reaction time measures may fail to capture (Banaschewski & Brandeis, 2007).
The P1, N1, and P2 components occur over posterior regions within the first 300 ms after stimulus presentation and reflect relatively automatic attentional capture by and processing of stimuli. The P1 (emerging approximately 80-130 ms after stimulus presentation) reflects activity of the extrastriate area of the visual cortex. Initial orienting of attention is indexed by the P1: amplitudes are larger for attended stimuli (Hillyard & Anllo-Vento, 1998; Luck, Heinze, Mangun, & Hillyard, 1990), with reduced amplitudes at unattended locations possibly reflecting suppression of stimulus processing (Luck & Hillyard, 1995). Enhanced amplitudes are associated with faster response times to stimuli in attended locations (Mangun, 1995; Mangun & Hillyard, 1991). With respect to threat processing, P1 amplitudes are enhanced to threatening (e.g., fearful) versus non-threatening (e.g., neutral) faces (Batty & Taylor, 2003; Holmes, Nielsen, & Simon, 2008; Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Walentowska & Wronka, 2012).

Following the P1 is a series of negative deflections, collectively referred to as the N1 (emerging approximately 140-200 ms after stimulus presentation). In terms of automatic attentional processing, the N1 is linked with the P1 (termed the P1/N1 complex) and is similarly modulated by spatial attention (Hillyard & Anllo-Vento, 1998; Luck et al., 1990; Luck & Hillyard, 1995; Mangun, 1995; Mangun & Hillyard, 1991). When processing facial stimuli, this first negative deflection is referred to as the N170. The N170 reflects activity of the posterior superior temporal sulcus (Itier & Taylor, 2004b). N170 amplitudes are larger when processing faces versus objects (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000; Itier & Taylor, 2004a) or face-specific components such as eyes or noses (Eimer, Kiss, & Nicholas, 2010). Despite debate regarding the emotional sensitivity of the N170 (Batty & Taylor, 2006; Eimer & Holmes, 2002), a growing number of studies demonstrate that N170 amplitudes are larger to emotional versus neutral faces (Bentin et al., 1996; Blau, Maurer, Tottenham, &
McCandliss, 2007; Eger, Jedynak, Iwaki, & Skrandies, 2003; Wronka & Walentowska, 2011). In children, N170 amplitudes to threatening versus non-threatening faces predict the stability of elevated anxiety (O'Toole, DeCicco, Berthod, & Dennis, 2013) suggesting that the N170 to threatening faces may be a useful marker in tracking the etiology of anxiety disorders.

Following the P1 and N1 components is the P2 (emerging around 200 ms after stimulus presentation). The P2 is associated with early attentional capture by and processing of emotional information, reflected by larger amplitudes to negative versus neutral stimuli in non-anxious participants (Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Carretié, Mercado, Tapia, & Hinojosa, 2001; Eldar, Yankelevitch, Lamy, & Bar-Haim, 2010). Additionally, high trait anxious participants have greater P2 amplitudes as compared to low trait anxious participants (Bar-Haim, Lamy, & Glickman, 2005; Dennis & Chen, 2007).

Following these visual-processing ERPs is the N2 component (emerging approximately 300 ms after stimulus presentation) which is thought to reflect more strategic and controlled attentional processing. While some accounts suggest that reduced amplitudes are indicative of greater neural efficiency (Gray, Braver, & Raichle, 2002), enhanced N2 amplitudes occur in response to conflicting stimuli or in response to tasks that require inhibition of default responding (Folstein & Van Petten, 2008; Kopp, Rist, & Mattler, 1996; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; Van Veen & Carter, 2002). Given that competition between threatening and non-threatening stimuli is needed for the threat bias to emerge (Mathews & Mackintosh, 1998), the sensitivity of the N2 to conflict makes it well-suited for tracking controlled and strategic attentional processing underlying the threat bias.

The temporal and functional sensitivity of ERPs makes them ideal candidate neural measures of discrete neurocognitive operations underlying the anxiety-related attentional bias to
threat and its remediation through ABMT (Eldar & Bar-Haim, 2010; Suway et al., 2012). Taken together, these ERP components can help to determine whether the threat bias is driven by early and automatic attentional capture by threatening versus non-threatening stimuli (P1, N1/N170, P2) or by later and possibly more controlled recruitment of attentional resources in processing threatening versus non-threatening stimuli (N2). A growing body of research is incorporating the use of ERPs in studies of the threat bias and ABMT. Using ERPs, two studies have found evidence for enhanced early spatial attention towards threat: P1 amplitudes are greater to angry-neutral face pairs in socially anxious versus non-anxious individuals (Helfinstein, White, Bar-Haim, & Fox, 2008) and greater to angry-neutral versus happy-neutral face pairs in participants with social anxiety disorder (Mueller et al., 2009). Eldar et al. (2010) used the dot probe task with angry-neutral, happy-neutral, and neutral-neutral face pairs. Anxious individuals showed greater P2 amplitudes to all face pairs relative to controls suggesting greater early processing of emotional faces (P2) in anxious individuals. These studies suggest that the threat bias is driven by early attentional capture (P1) and relatively automatic processing of threatening stimuli (P2).

To date, one study (Eldar & Bar-Haim, 2010) has incorporated the use of ERPs to examine changes in neural responses to threat following ABMT in highly trait anxious participants. Specifically, this study found that anxious individuals trained away from threat showed increased N2 amplitudes and decreased P2 amplitudes to both threat-relevant and neutral faces. This suggests that ABMT successfully reduced early emotional evaluation of threat (P2) and increased later controlled (N2) attention when threat and non-threat compete for attentional resources. Notably, although P2 amplitudes were reduced following ABMT there were no effects on ERP components reflecting very early and relatively automatic attention capture by threat (P1, N1). Additionally, increases in P2 amplitudes to threat are associated with the induction of
the threat bias in non-anxious individuals (Suway et al., 2012). These findings illustrate that the temporal and functional sensitivity of ERPs make it possible to distinguish between attention capture and control, and even distinguish among very early-emerging, bottom-up cognitive processes that are differentially sensitive to ABMT.

Critically, however, no studies to date have reported whether individual differences in neurocognitive responses to threat predict ABMT response. That is, it is unknown whether neural changes following ABMT predict whether ABMT successfully remediates anxiety, stress reactivity, or attentional biases in anxious participants, and whether baseline individual differences in threat processing influence the efficacy of ABMT (Eldar, Apter, Lotan, Edgar, et al., 2012; Salum et al., 2012). For example, ABMT may be most effective for individuals who show disrupted attention to threat at baseline, either through enhanced vigilance or difficulty disengaging from threat. Such an understanding would allow us to identify who will benefit most from ABMT and to clarify whether ABMT has broad application for anxious individuals in general or only for those with specific patterns of threat responsivity.

VI. The Role of Baseline Attentional Biases

While there is robust evidence that anxious compared to non-anxious individuals have an exaggerated threat bias (Bar-Haim, 2010), there remains significant variability in the degree to which any one anxious person evidences threat bias depending on the nature of anxiety symptoms (Salum et al., 2012) and on the context in which threat bias is measured (Bar-Haim et al., 2010; Shechner, Pelc, Pine, Fox, & Bar-Haim, 2012). In the only randomized controlled trial of ABMT in anxious youth, for example, fully 50% of clinically diagnosed anxious children who were screened for the study did not show a bias towards threat using the dot-probe task (Eldar, Apter, Lotan, Perez-Edgar, et al., 2012). Additionally, the flexibility with which a threat bias can
be induced in non-anxious individuals is related to both positive and negative outcomes: individuals who show greater ease of threat bias induction show greater increases in anxiety in response to a prolonged mild stressor (Clarke et al., 2008) but also, in contrast, greater reductions in anxiety following CBT (Clarke, Chen, & Guastella, 2012). Thus, both baseline levels of the threat bias as well as the ability to induce or reduce the bias may represent individual differences relevant to other training effects.

Yet, neuroscience research documents disruptions in neural responses to threat across anxiety disorders (Etkin & Wager, 2007; Sylvester, 2012). One possibility is that an individual who shows high neural reactivity to threat may begin to employ behavioral avoidance strategies in order to cope with and regulate these threat responses (Hofman, 2007; Weierich et al., 2008), evidencing as attentional avoidance of threat. In other words, avoidance becomes a habitual way of dampening or preventing exaggerated reactivity to threat. Moreover, because behavioral measures of threat bias are imprecise in terms of the relative contribution of disruptions in early attention capture versus cognitive control, they may fail to correspond to more direct and discrete measures of neurocognitive responses to threat (Clarke, MacLeod, & Guastella, 2013). ERPs may thus be ideal neurocognitive measures for disentangling the roles of attentional capture and control in ABMT effects along with predicting for whom ABMT will work best.

VII. Aims of the Current Research

Thus, while there is considerable evidence for the efficacy of ABMT in reducing anxiety and stress reactivity, less is known about the attentional processes underlying such effects. The use of neurocognitive measures of attention to threat, such as ERPs, can provide insight into ABMT effects that behavioral measures may miss. In addition to providing a better understanding of how ABMT works, ERPs measures may also be able to identify individual
differences that influence ABMT efficacy. Over the course of three studies, the current research addresses two overarching aims: 1) To investigate how ABMT changes neurocognitive measures of attention to threat and 2) To investigate whether neurocognitive responses to threat, both in response to ABMT and at baseline, predict the efficacy of ABMT in reducing anxiety and stress reactivity (i.e., how and for whom ABMT works).
Chapter 2: Study 1 (adapted from O’Toole & Dennis, 2012)

I. Introduction

The goal of Study 1 was to demonstrate the plasticity of the threat bias in non-anxious individuals by conducting an initial investigation of how ERPs can track changes in attention in response to attention training. We examined the neurocognitive effects of inducing or reducing the threat bias in non-anxious adults using the dot probe task, by training participants to develop either an attentional bias towards angry faces (train toward threat group) or away from angry faces (train away from threat group). Additionally, we incorporated two modifications to the dot probe task, in order to assess changes in attentional capture and hold: (1) we included baseline trials (with two non-threatening stimuli, happy faces) in order to distinguish between vigilance for threat and difficulty disengaging from threat in the attentional bias; and (2) we included two presentation durations to assess changes in the threat bias in short and long exposure conditions. Last, we examined the neural processes underlying ABMT by analyzing whether ABMT influenced ERPs reflecting early and later stages of attentional processing.

We tested the following predictions for behavioral and ERP effects. We predicted that individuals in the train away from threat versus train toward threat group will show decreased attentional bias scores (attentional bias, vigilance, difficulty disengaging) and anxiety. Using neurocognitive measures we predicted reduced attentional capture by threat as indicated by reduced ERP amplitudes reflecting relatively automatic processing (P1, N170, P2) and more elaborated and controlled processing (N2) of threatening versus non-threatening cues and probe locations. Additionally, we examined whether relationships exist between ERP and behavioral biases following ABMT. We predicted that greater neural processing of threat relative to non-
threat at post-training will correlate with greater behavioral biases to threat, whereas greater neural processing of non-threat will correlate with reduced behavioral biases.

We also explored the effect of varying cue exposures durations on ABMT effects. Several studies have demonstrated that the pattern of bias toward or avoidance of threat depends on the duration of exposure to stimuli. Using both highly threatening (HT) and moderately threatening (MT) stimuli, Koster, Verschuere, Crombez, and Van Damme (2005) demonstrated that both anxious and non-anxious individuals show a bias toward HT at 100 ms and 500 ms, but only anxious individuals show a bias toward MT at 500 ms. Among just non-anxious individuals, the threat bias is found at 100 ms but not at 500 ms (Koster, Crombez, Verschuere, Vanvolsem, & De Houwer, 2007; Mogg, Bradley, De Bono, & Painter, 1997). However, in another study the threat bias was found at 100 ms and an avoidance of threat at 500 ms for non-anxious participants (Cooper & Langton, 2006). Taken together, these studies suggest for non-anxious individuals that at shorter durations the threat bias is present while at longer durations it is either absent or reversed. However, a more recent study varied cue duration and the effects of ABMT did not appear for the non-anxious sample of participants at shorter durations (i.e., 30 and 100 ms) (Koster, Baert, Bockstaele, & De Raedt, 2008). The vast majority of ABMT research thus far has employed a longer (500 ms) cue duration (Hakamata et al., 2010). A recent study demonstrated that ABMT using subliminal cues is effective in reducing stress reactivity but only for socially anxious individuals who show baseline attentional biases towards threat (Maoz, Abend, Fox, Pine, & Bar-Haim, 2013). The current study explored the effects of varying cue duration (100 ms versus 500 ms) on ABMT effects in non-anxious participants.

Additionally, because the threat bias is more prevalent among anxious individuals (Bar-Haim et al., 2007), we expected that in this non-clinical sample attention training effects may
only occur for those participants who already show a bias towards threat at baseline (for the train away from threat group) or a bias away from threat at baseline (for the train toward threat group), due to ceiling and floor effects, respectively. However, despite expected variability in the threat bias (Salum et al., 2012; Shechner et al., 2013) it is unclear how this variability affects ABMT effects on anxiety or neurocognitive measures of threat processing.

II. Method

Participants. Participants were 61 non-diagnosed adults recruited through the psychology participant research pool at Hunter College, The City University of New York. Prior to completing the tasks, participants were screened for psychological impairments (anxiety, depression) via self-report questionnaires. Twelve participants were excluded from analyses for the following reasons: participant refusal ($f = 1$), experimenter error during EEG recording ($f = 2$), too many incorrect responses during the dot probe task ($f = 3$), heavily artifacted EEG recording ($f = 6$). The final sample consisted of 49 non-diagnosed adults (20 males, 29 females) aged 18 to 38 ($M = 20.92$, $SD = 4.30$). Self-reported race/ethnicity was as follows: 18 White, 9 Hispanic, 15 Asian or Pacific Islander, 5 African American, and 2 self-reported other race/ethnicity.

Procedure. Participants spent approximately three hours in the laboratory. After a brief questionnaire period, an elasticized nylon cap was fitted on the participants and scalp electrodes were applied. Participants were seated 65 cm from a 17 in monitor and instructed to remain still and not blink when the stimuli appeared on the screen to reduce the occurrence of muscle or ocular artifacts in the EEG recording. After passively viewing all faces used in the dot probe procedures (a procedure analyzed separately from the present study) participants completed the
pre-training dot probe assessment, the dot probe training task, a brief mood questionnaire, the
post-training dot probe assessment, and a brief mood questionnaire.¹

**Questionnaires.** The State-Trait Anxiety Inventory is an 40-item questionnaire that
measures participants’ perceptions of their current (state) and general (trait) level of nervousness,
anxiety, and shyness (STAI; Spielberger, 1983). The sample average for state \( (M = 34.82, \text{SD} =
8.40) \) and trait \( (M = 40.18, \text{SD} = 7.57) \) anxiety were within the normative range before attention
training. State anxiety was assessed two more times: immediately after the training task and
approximately 30 minutes after training.

**Emotional face stimuli.** Stimuli were 24 black-and-white photographs of angry and
happy faces (Tottenham et al., 2009)². Faces were paired during the dot probe task so that angry-
happy or happy-happy pairs were of the same person. There were equal numbers of males and
females, as well as White and African American faces.

**The dot probe task.** Stimuli were programmed using E-Prime version 1.1 (Schneider,
Eschman, & Zuccolotto, 2002). Figure 1 displays the sequence of events for a trial of the dot
probe task. Each trial begins with a fixation cross presented for 1000 ms, followed by a pair of
cue stimuli (emotional faces) for either 100 or 500 ms. Face pairs were either angry-happy faces,
happy-angry faces, or happy-happy faces. Each type of pair was presented an equal number of
times so that angry and happy faces were equally presented on either side of the screen. An angry
face probe is when the target replaces the angry face from a pair of angry and happy faces, while
a happy face probe is when the target replaces the happy face from a pair of angry and happy

¹ Because participants first passively viewed all faces before the dot probe and ABMT tasks there may be potential
habituation effects. However, other studies have successfully employed the same task with a similar number of
stimuli (Eldar & Bar-Haim, 2010; Eldar et al., 2008).

faces. A baseline probe is when the target replaces either face from a pair of two happy faces. Face images subtended 7 cm x 10 cm and were presented equal distance to the right and left of the fixation cross. After the faces were removed a 500 ms delay occurred, followed by a probe (arrow) in the location previously occupied by one of the faces. Participants were asked to respond as quickly and as accurately as possible whether the arrow was pointing to the left or the right by clicking on the mouse. The inter-trial interval was 1000 ms.

Reaction times (RT) were filtered by removing responses that were faster than -3SD from an individual’s mean and slower than +3SD from an individual’s mean. Following removal of these trials, mean RTs for each condition were either normally distributed across the sample or slightly positively skewed, as expected for RTs. Using correct trials only, the dot probe task yields three threat bias scores (attentional bias, vigilance, disengagement) by comparing reaction times (RT) following the different cues. The attentional bias score is calculated as RT happy probe – RT angry probe. Higher scores indicate an attentional bias toward threatening information, such that participants respond faster when the probe appears in the location of the angry face versus the happy face. Such a bias can be driven by the speed of attentional capture by threat (vigilance) or the length of attentional hold by threat (disengagement). The vigilance score is calculated as RT baseline probe – RT angry probe. Higher scores indicate greater attentional capture by threat, such that participants respond faster when the probe appears in the location of the angry face versus when no threatening face is presented. The disengagement score is calculated as RT happy probe – RT baseline probe. Higher scores indicate greater attentional hold by threat, such that participants are faster to respond when no threat is presented versus when they have to disengage and shift attention to the location of the happy face.
Participants received an equal number of angry, happy, and baseline probe trials during the pre- and post-training dot probe task, with a total of 288 trials each. The ABMT task was a dot probe designed to either induce or reduce a bias toward threat. Half of the participants ($n = 25$) were randomly assigned to train toward threat group and the other half ($n = 24$) to the train away from threat group. The train toward threat group consisted of angry probes only while the train away from threat group consisted of happy probes only, with a total of 480 trials in each.

**Electrophysiological recording and data reduction.** A Biosemi system (BioSemi; Amsterdam, NL), was used to record EEG activity continuously using 64 Ag/AgCl scalp electrodes. Electrodes in this EEG system are fixed into an elasticized nylon cap and arranged according to the international 10/20 system. Eye movements were monitored by electro-oculogram (EOG) signals from electrodes placed 1 cm above and below the left eye (to measure vertical eye movements) and 1 cm on the outer edge of each eye (to measure horizontal eye movements). Preamplification of the EEG signal occurs at each electrode which improves the signal-to-noise ratio. During data acquisition, EEG was recorded at a sampling rate of 512 Hz and amplified with a band pass of 0.16 – 100 Hz. The voltage from each of the 64 electrodes from which data was collected was referenced online with respect to the common mode sense active electrode and driven right leg electrode (located adjacent to PO3 and PO4, respectively), which produces a monopolar (nondifferential) channel. Brain Vision Analyzer (Version 2.2, GmbH; Munich, DE) was used to prepare the data. Offline, all data were re-referenced to the average of the scalp and digitally filtered with a high pass frequency of .1 Hz and a low pass frequency of 30 Hz and a 24 dB/octave roll off. The Gratton & Coles (1983) ocular correction was used to correct all data for blinks. Data was then segmented 200 ms prior to stimulus onset.
and continued for 600 ms. The 200 ms portion of segmented data prior to stimulus onset was used for baseline correction.

Artifacts were identified using the following criteria and removed from analyses: data with voltage steps exceeding 75 µV, maximum changes exceeding 100 µV (within a given segment), maximum and minimum differences within a segment ±105 µV, and activity lower than 1 µV per 100 ms were excluded from analyses. In addition to this semi-automatic identification of artifacts, trials were also visually inspected for any further artifacts and were removed on a trial-by-trial-basis.

Electrodes were chosen via visual inspection of the topographical distribution of the pre-training dot probe task data, grand averaged across all stimulus conditions and participants (see Figure 2). Peak amplitudes were generated to the face cues during the dot probe task separately for angry-happy and happy-angry pairs (threat face pairs) and happy-happy pairs (non-threat face pairs and averaged over clusters of electrodes: between 100 and 300 ms for P1 (maximal at approximately 120 ms) over PO7/O1/PO8/O2; N170 (maximal at approximately 170 ms) over PO7/P7/PO8/P8, and P2 (maximal at approximately 230 ms) over PO7/O1/PO8/O2; and between 200 and 400 ms for N2 (maximal at approximately 310 ms) over Fz/FCz.

Trial counts were grand averaged across all stimulus conditions and participants. The average trial count for P1 was 43.75 ($SD = 3.54$), for N170 was 44.11 ($SD = 2.70$), for P2 was 43.75 ($SD = 3.54$), and for N2 was 43.75 ($SD = 3.55$). There were no significant differences in the average trial counts between the train toward and train away from threat groups, all $ts < 1.5$, $ps > .10$. 
III. Results

**Descriptive statistics.** See Tables 1, 2, and 3 for descriptive statistics of behavioral biases and ERP amplitudes at pre- and post-training. There were no differences between the train toward and train away from threat groups on either state anxiety [\( t(47) = -0.25, p = .80 \)] or trait anxiety [\( t(47) = 1.07, p = .28 \)]. Below are separate analyses for behavioral threat bias, subjective anxiety, and ERP outcome variables for the sample as a whole. Following that, we conduct the identical analyses for behavioral threat bias and subjective anxiety only for those participants showing a pre-training attention bias towards or away from threat prior to training. Additionally, we examine correlations between ERPs and behavioral bias scores on the post-training assessment for the entire sample, to explore associations between neural and behavioral biases following ABMT.

**Effect of ABMT on behavioral threat bias.** We first tested the predictions that participants in the train away versus train toward threat group would show decreased behavioral attentional biases following ABMT, and that these effects would be more prominent at 100 versus 500 ms. For each behavioral threat bias score (attentional bias, vigilance, disengagement), a 2(ABMT Group: train toward threat, train away from threat) x 2(Test: pre-training, post-training) x 2(Duration: 100 ms, 500 ms) mixed design factorial ANOVA was conducted, with ABMT Group as a between-subjects factor and Test and Duration as within-subjects factors. No significant effects on any behavioral threat bias scores emerged.

**Effect of ABMT on state anxiety.** Next, we tested the prediction that participants in the train away versus train toward threat group would show reduced subjective anxiety following ABMT. A 2(Test: pre-training, post-training) x 2(ABMT Group: train toward threat, train away from threat) mixed design factorial ANOVA was conducted on state anxiety scores, with ABMT
Group as a between-subjects factor and Test as a within-subjects factor. The main effect of Test revealed that state anxiety scores decreased from pre-training \((M = 38.98, SD = 10.57)\) to post training \((M = 36.94, SD = 10.13)\) for all participants, \(F(1, 47) = 6.45, p = .01\), partial \(\eta^2 = .12\). Thus, state anxiety decreased following training, regardless of training group.

**Effects of ABMT on participants with pre-training attentional biases.** This non-anxious sample of participants showed a wide range in attentional bias scores on the pre-training assessment (100 ms: -52.59 to 110.54; 500 ms: -87.17 to 75.20). As such, analyses examining effects of ABMT on behavioral bias scores and anxiety were repeated using only participants with a bias away from threat (negative attention bias score) in the train toward threat group and a bias toward threat (positive attention bias score) in the train away from threat group. This prevents ceiling effects from occurring in the case of the train toward threat group (i.e., if participants already show an attentional bias toward threat) and floor effects from occurring in the train away from threat group (i.e., if participants already show an attentional bias away from threat). This method is also analogous to studies with anxious participants – who are presumed to have a pre-training threat bias – who are trained away from threat. Because some participants showed a bias toward threat at 100 ms and a bias away from threat at 500 ms, all subsequent analyses were performed separately for the two durations.

For the 100 ms condition there were 26 participants (train toward threat: \(n = 14\), attentional bias range: -48.37 to -1.87; train away from threat: \(n = 12\), attentional bias range: 4.32 to 110.54). There were no differences between the two groups at 100 ms on either state anxiety \([t(24) = -1.03, p = .32]\) or trait anxiety \([t(24) = 0.46, p = .65]\). Consistent with our group selection procedure in which only those participants with pre-training attentional biases were included in the train away from threat group, and vice versa for the train toward threat group, on the pre-
training assessment, participants in the train away versus train toward threat group had greater attentional bias scores ($M = 30.63, SD = 29.82$ versus $M = -17.73, SD = 13.97$), $t(24) = -5.43, p < .001$. Additionally, participants in the train away versus train toward threat group also had greater vigilance scores ($M = 15.54, SD = 26.67$ versus $M = -2.80, SD = 16.70$), $t(24) = -2.14, p = .04$. There were no differences in disengaging scores at 100 ms between the two ABMT groups on the pre-training assessment.

For the 500 ms condition there were 24 participants (train toward threat: $n = 11$, attentional bias range: -23.98 to -3.25; train away from threat: $n = 13$, attentional bias range: 2.02 to 36.76). There were no differences between the two groups at 500 ms on either state anxiety [$t(22) = -0.73, p = .47$] or trait anxiety [$t(22) = -0.04, p = .97$]. Again, consistent with our group selection procedure, on the pre-training assessment the train away from threat group had greater attentional bias ($M = 14.33, SD = 9.84$) than the train toward threat group ($M = -9.70, SD = 7.13$), $t(22) = -6.73, p < .001$.

**Behavioral threat bias.** See Tables 4 and 5 for descriptive statistics of behavioral threat biases for the two samples of participants at the two durations. We again tested the prediction that participants in the train away versus train toward threat group would show decreased behavioral attentional bias following ABMT. Since analyses were conducted separately for the two durations, we further predicted that these effects may only emerge for the shorter duration. For each behavioral threat bias score, a 2(ABMT Group: train toward threat, train away from threat) x 2(Test: pre-training, post-training) mixed design factorial ANOVA was conducted, with ABMT Group as a between-subjects factor and Test as a within-subjects factor.

**100 ms.** The two-way ABMT Group x Test interaction was significant for attentional bias, $F(1, 24) = 21.72, p < .001$, partial $\eta^2 = .48$. Consistent with predictions, the train toward
threat group showed increases in attentional bias from pre-training ($M = -17.73, SD = 13.97$) to post-training ($M = 4.72, SD = 28.33$), $t(13) = -2.47, p = .03$, while the attend non-threat group showed decreases in attentional bias from pre-training ($M = 30.63, SD = 29.82$) to post-training ($M = -6.43, SD = 18.02$), $t(11) = 4.20, p = .001$ (see Figure 3).

The two-way ABMT Group x Test interaction was also significant for vigilance, $F(1, 24) = 9.69, p = .005$, partial $\eta^2 = .29$. Consistent with predictions, the train away from threat group showed decreases in vigilance from pre-training ($M = 15.54, SD = 26.67$) to post-training ($M = -10.49, SD = 13.55$), $t(11) = 3.16, p = .009$. Additionally, on the post-training assessment, the train toward threat group had greater vigilance ($M = 6.86, SD = 26.07$) than the train away from threat group ($M = -10.49, SD = 13.55$), $t(24) = 2.07, p = .049$ (see Figure 4). There were no significant effects for difficulty disengaging.

$500 \text{ ms.}$ The two-way ABMT Group x Test interaction was significant for attentional bias, $F(1, 22) = 7.84, p = .01$, partial $\eta^2 = .26$. Partially consistent with predictions, the train toward threat group showed increases in attentional bias from pre-training ($M = -9.70, SD = 7.13$) to post-training ($M = 3.79, SD = 13.60$), $t(10) = -2.56, p = .03$. There were no changes in attentional bias for the train away from threat group (see Figure 5). There were no significant effects for vigilance or difficulty disengaging.

In summary, when participants were selected based on having a pre-training attentional bias toward or away from threat, we found that, as predicted, the train toward threat group showed increases in attention bias at 100 ms and 500 ms while the train away from threat group showed decreases in attentional bias and vigilance at 100 ms only.

**State anxiety.** Last, we tested the prediction that participants in the train away versus train toward threat group would show reduced subjective anxiety following ABMT, and that this
effect would occur only at 100 ms. A 2(Test: pre-training, post-training) x 2(ABMT Group: train toward threat, train away from threat) mixed design factorial ANOVA was conducted on state anxiety scores, with ABMT Group as a between-subjects factor and Test as a within-subjects factor.

100 ms. The main effect of Test revealed that state anxiety scores decreased from pre-training ($M = 40.62, SD = 11.19$) to post training ($M = 39.00, SD = 10.58$) for all participants, $F(1, 24) = 4.37$, $p = .047$, partial $\eta^2 = .15$.

500 ms. There were no significant effects.

**Summary.** In summary, when the sample was reduced such that only participants with attentional biases (away from threat for the train toward threat group and toward threat for the train away from threat group) were examined, behavioral effects consistent with predictions emerged. The train toward threat group showed increases in attentional bias at both 100 and 500 ms, while the train away from threat group showed decreases in attentional bias and vigilance at 100 ms only. Additionally, state anxiety again decreased following training, regardless of training group, but consistent with predictions this effect was limited to 100 ms.

**Effect of ABMT on ERPs to face pairs.** Next, we tested the predictions that participants in the train away versus train toward threat group would show decreased ERP amplitudes to threat following ABMT, and that these effects would be more prominent at 100 versus 500 ms. For each ERP time-locked to face pairs (P1, N170, P2, N2) a 2(ABMT Group: train toward threat, train away from threat) x 2(Test: pre-training, post-training) x 2(Duration: 100 ms, 500 ms) x 2(Face Pair: threat, non-threat) mixed-design factorial ANOVA was conducted on ERP amplitudes, with ABMT Group as a between-subjects factor and Test, Duration, and Face Pair as within-subjects factors. Bonferroni corrections were used for all follow-up t-test comparisons.
P1. The significant main effects of Test \( F(1, 47) = 7.51, p = .009, \text{partial } \eta^2 = .14 \) and Duration \( F(1, 47) = 4.63, p = .04, \text{partial } \eta^2 = .09 \) were subsumed under the significant ABMT Group x Test x Duration interaction, \( F(1, 47) = 7.23, p = .01, \text{partial } \eta^2 = .13 \). Participants in the train away from threat group showed pre- to post-training decreases in P1 amplitudes to all face pairs presented for 100 ms \( (\text{pre-training } M = 5.11, SD = 2.12; \text{post-training } M = 4.28, SD = 1.88), t(23) = 4.55, p < .001 \).

The three-way ABMT Group x Test x Stimulus interaction was also significant, \( F(1, 47) = 4.19, p = .046, \text{partial } \eta^2 = .08 \). Contrary to predictions, participants in the train away from threat group showed decreases in P1 amplitudes to non-threatening face pairs from pre-training \( (M = 4.94, SD = 2.15) \) to post-training \( (M = 4.26, SD = 1.77), t(23) = 2.95, p = .007 \).

N170. A significant main effect of Test revealed that N170 amplitudes decreased from pre-training \( (M = -3.07, SD = 2.20) \) to post-training \( (M = -2.23, SD = 2.03), F(1, 47) = 31.14, p < .001, \text{partial } \eta^2 = .40 \). There was also a significant main effect of Duration, such that N170 amplitudes were greater to face pairs presented for 500 ms \( (M = -2.80, SD = 2.00) \) versus 100 ms \( (M = -2.49, SD = 2.14), F(1, 47) = 12.44, p = .001, \text{partial } \eta^2 = .21 \).

P2. In contrast to the effects for N170, a significant main effect of Test revealed that P2 amplitudes increased from pre-training \( (M = 4.57, SD = 2.52) \) to post-training \( (M = 5.07, SD = 2.58), F(1, 47) = 7.58, p = .008, \text{partial } \eta^2 = .14 \).

N2. Effects for N2 amplitudes were similar to those for N170 amplitudes. A significant main effect of Test revealed that N2 amplitudes decreased from pre-training \( (M = -4.05, SD = 1.22) \) to post-training \( (M = -3.50, SD = 1.33), F(1, 47) = 24.00, p < .001, \text{partial } \eta^2 = .34 \). There was also a significant main effect of Duration, such that N2 amplitudes were greater to face pairs
presented for 500 ms ($M = -3.94$, $SD = 1.37$) versus 100 ms ($M = -3.61$, $SD = 1.20$), $F(1, 47) = 7.25, p = .01$, partial $\eta^2 = .13$. No other effects reached significance.

In summary, counter to predictions, no training group differences in ERPs to face cues emerged. P1 amplitudes to face cues, however, were affected by training condition. Somewhat consistent with predictions, participants in the train away from threat group showed reductions in P1 amplitudes to all cues presented for 100 ms after training, regardless of stimulus type, and greater P1 amplitudes to non-threatening versus threatening face cues before training, regardless of duration. Additionally, N170 and N2 amplitudes were greater to cues presented for 500 versus 100 ms; however, these effects were across stimulus type and do not reflect any attentional biases as predicted.

**Correlations.** Correlations were conducted on post-training data separately for the two training groups. We predicted that greater ERP processing of threat relative to non-threat would be associated with greater behavioral biases on the post-training assessment for the train toward threat group, and vice versa for the train away from threat group. Effects emerged only for the train toward threat group at 100 ms. Consistent with predictions, greater P2 amplitudes to threat versus non-threat were associated with greater attentional bias ($r = .50, p = .01$) and vigilance ($r = .47, p = .02$) on the post-training assessment. Counter to predictions, however, greater N170 amplitudes to threat versus non-threat were associated with reduced attentional bias ($r = -.57, p = .003$) and vigilance ($r = -.43, p = .03$) on the post-training assessment. Thus, while there were no direct effects of ABMT on behavioral biases, post-training correlations revealed associations between ERP amplitudes (i.e., P2 and N170) and behavioral biases.
IV. Discussion

The goal of Study 1 was to explore whether ERPs could contribute to a greater understanding of the early and late attentional processes altered by ABMT in non-anxious individuals. Results suggest training-related changes in the behavioral threat bias only emerged among a subset of participants who showed pre-training attention biases towards and away from threat. In addition, ABMT also influenced ERP measures of early spatial attention to emotional face cues. Finally, post-training ERPs were correlated with behavioral threat biases – in particular, greater P2 amplitudes and reduced N170 amplitudes to threatening versus non-threatening cues were associated with greater attentional bias and vigilance for the group trained toward threat.

For the sample as a whole, ABMT did not result in significant modification in behavioral attentional biases. When the sample was selected to only include those participants in each ABMT condition with pre-training attentional biases, the predicted behavioral effects emerged. Specifically, participants in the train away from threat group showed reductions in attentional bias and vigilance, or attentional capture, at 100 ms. Furthermore, participants in the train toward threat condition showed increases in attentional bias at both 100 and 500 ms. Results underscore the importance of taking baseline threat bias into account when using the ABMT task. It is likely that in this non-anxious sample no behavioral effects were found because of the wide range of biases present before attention training - selecting a sub-sample of those participants showing a pre-training bias reduced the potential for ceiling and floor effects.

In addition to these behavioral effects, ABMT affected early spatial attention in this group of non-anxious individuals: Participants in the train away from threat group showed decreases in P1 amplitudes to all face pairs presented for 100 ms after training and decreases in
P1 amplitudes to non-threatening face pairs after training. This pattern of reduced P1 suggests habituation effects such that training attention away from threat (and towards non-threat) in a normative group of participants actually serves to reduce early, automatic capture of attention of face cues – even to non-threatening ones. These effects are also interesting because, in contrast to the Eldar and Bar-Haim (2010) study with anxious participants, we found that ABMT influences early spatial attention (P1) rather than more elaborated attentional processes (N2) in non-anxious individuals. This hints at the possibility that anxious participants may need to recruit more effortful attentional processes to modify attention biases, whereas in non-anxious individuals shifts in more automatic and early attention are influenced by ABMT.

Correlational analyses, however, suggest that for participants trained to attend to threat the degree to which post-training attention to threat at 100 ms is enhanced (P2) is associated with greater behavioral measures of attention bias. Contrary to this pattern, enhanced processing of threatening versus non-threatening faces as measured by the N170 (at 100 ms) was associated with reduced behavioral attentional bias. This interesting dissociation may speak to the distinct processes reflected by the N170 and P2. While the N170 is thought to reflect structural encoding of faces (Bentin et al., 1996; Holmes, Vuilleumier, & Eimer, 2003) it may also reflect expertise with a particular type of stimulus (Roisson, Curran, & Gauthier, 2002; Tanaka & Curran, 2001). In contrast, the P2 has been linked to relatively more attentional processing of emotion (Carretié, Martín-Loeches, et al., 2001; Carretié, Mercado, et al., 2001; Eldar et al., 2010). Thus, enhanced face-specific processing of threat may actually hinder the effects of attention training toward threat, whereas the P2, which is more specific to emotion, may reflect greater attentional capture by threat due to attention training.
State anxiety scores were reduced following ABMT regardless of training condition. This effect should perhaps not be surprising, however, since previous research suggests that emotional vulnerability, or stress reactivity, is altered by ABMT rather than mood (Eldar et al., 2008; MacLeod et al., 2002). Indeed, it appeared that taking part in the dot probe task had general anxiety-reducing effects, perhaps due to its predictable and repetitive nature. Future research should include a measure of emotional vulnerability before and after ABMT such as stress reactivity; including this measurement along with ERPs would allow for examination of how changes in stress reactivity are related to changes in physiological measures of the threat bias following attention training.

Results also underscore the importance of stimulus duration when considering the effects of ABMT on behavior and ERP measures of attention. Although behavioral studies suggest that non-anxious individuals show an attentional bias to threat at shorter stimulus durations such as 100 ms (Cooper & Langton, 2006; Koster et al., 2007; Koster et al., 2005; Mogg et al., 1997), the present study suggests that non-anxious individuals show sensitivity to a range of stimulus durations. For example, at 100 ms both the train toward and away from threat conditions were successful in altering behavioral biases, while at 500 ms only the train toward threat condition had an effect. ERP amplitudes to both face cues and probes were sensitive to presentation duration: N170 and N2 amplitudes were greater to face cues presented for 500 versus 100 ms. Many of these duration effects, however, are independent of stimulus type (i.e., threatening versus non-threatening). Thus, it appears that both early- and later-developing attentional processes are implicated in threat processing in non-anxious individuals. Further research is required to track the time course of attention to threatening versus non-threatening stimuli presented for brief versus longer durations (O'Toole, DeCicco, Hong, & Dennis, 2011).
Limitations of Study 1 include the duration of the ISI between cues and probes and the use of happy faces instead of neutral faces. First, the somewhat long duration of the ISI (500 ms) between cues and probes may have allowed effects of the cues to extinguish before probes appeared. In future studies a shorter ISI should be employed, such as a jittered duration between 100 and 300 (Mueller et al., 2009). Second, the use of happy faces rather than neutral faces may have altered the interpretation of the vigilance and disengagement scores – although the inclusion of happy faces strengthens the inference that effects are specific to threat rather than emotionally arousing stimuli (Mathews & MacLeod, 2002).

In summary, identifying neurocognitive changes following ABMT can inform the processes underlying both the induction and reduction of the threat bias. Furthermore, the current results suggest that ABMT may only be effective for non-anxious participants who show biases before training. Findings set the stage for the next study to use ERPs to track changes in attention following ABMT and to predict ABMT effects on anxiety and stress reactivity in highly trait anxious participants.
Table 1

*Descriptive Statistics for Behavioral Biases for both Training Groups*

<table>
<thead>
<tr>
<th></th>
<th>Pre-Training</th>
<th></th>
<th>Post-Training</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 ms</td>
<td>500 ms</td>
<td>100 ms</td>
<td>500 ms</td>
</tr>
<tr>
<td>Train Toward Threat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>2.66 (29.87)</td>
<td>7.21 (22.10)</td>
<td>5.60 (25.47)</td>
<td>9.76 (22.74)</td>
</tr>
<tr>
<td>V</td>
<td>5.80 (24.36)</td>
<td>1.34 (23.82)</td>
<td>5.99 (25.18)</td>
<td>-3.62 (31.96)</td>
</tr>
<tr>
<td>D</td>
<td>-3.14 (23.83)</td>
<td>5.87 (26.20)</td>
<td>-0.38 (22.60)</td>
<td>13.38 (41.44)</td>
</tr>
<tr>
<td>Train Away from Threat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>6.06 (34.39)</td>
<td>-4.47 (28.50)</td>
<td>-9.35 (29.42)</td>
<td>12.38 (52.20)</td>
</tr>
<tr>
<td>V</td>
<td>0.74 (30.23)</td>
<td>-18.47 (89.84)</td>
<td>-11.28 (36.18)</td>
<td>6.41 (31.09)</td>
</tr>
<tr>
<td>D</td>
<td>5.32 (21.80)</td>
<td>14.00 (71.95)</td>
<td>1.93 (22.57)</td>
<td>5.97 (51.49)</td>
</tr>
</tbody>
</table>

*Note. Difference scores of response times are presented as mean difference scores of reaction times (ms) with standard deviations in parentheses. AB = Attentional Bias, V = Vigilance, D = Disengagement.*
<table>
<thead>
<tr>
<th></th>
<th>Pre-Training</th>
<th></th>
<th>Post-Training</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 ms</td>
<td>500 ms</td>
<td>100 ms</td>
<td>500 ms</td>
</tr>
<tr>
<td><strong>ERPs to Cues</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat</td>
<td>5.58 (2.40)</td>
<td>6.09 (2.88)</td>
<td>5.29 (2.61)</td>
<td>4.81 (2.38)</td>
</tr>
<tr>
<td>Non-Threat</td>
<td>5.70 (2.49)</td>
<td>5.47 (2.58)</td>
<td>5.46 (2.84)</td>
<td>5.24 (2.87)</td>
</tr>
<tr>
<td><strong>N170</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat</td>
<td>-2.86 (2.61)</td>
<td>-2.99 (2.17)</td>
<td>-2.09 (2.10)</td>
<td>-2.45 (2.05)</td>
</tr>
<tr>
<td>Non-Threat</td>
<td>-2.70 (2.40)</td>
<td>-3.38 (2.53)</td>
<td>-2.27 (2.27)</td>
<td>-2.71 (2.27)</td>
</tr>
<tr>
<td><strong>P2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat</td>
<td>5.10 (2.80)</td>
<td>4.90 (2.65)</td>
<td>5.19 (2.39)</td>
<td>5.02 (2.95)</td>
</tr>
<tr>
<td>Non-Threat</td>
<td>5.00 (2.96)</td>
<td>4.93 (3.15)</td>
<td>5.21 (2.79)</td>
<td>5.40 (3.57)</td>
</tr>
<tr>
<td><strong>N2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat</td>
<td>-4.17 (1.56)</td>
<td>-4.36 (1.22)</td>
<td>-3.49 (1.20)</td>
<td>-3.76 (1.38)</td>
</tr>
<tr>
<td>Non-Threat</td>
<td>-3.92 (1.46)</td>
<td>-4.52 (1.61)</td>
<td>-3.31 (1.57)</td>
<td>-3.98 (2.10)</td>
</tr>
</tbody>
</table>

*Note.* Amplitudes (µV) are presented as means with standard deviations in parentheses.
Table 3

**Descriptive Statistics for ERP Amplitudes for the Train away from Threat Group**

<table>
<thead>
<tr>
<th></th>
<th>Pre-Training</th>
<th>Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 ms</td>
<td>500 ms</td>
</tr>
<tr>
<td><strong>P1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat</td>
<td>4.98 (2.26)</td>
<td>4.54 (2.25)</td>
</tr>
<tr>
<td>Non-Threat</td>
<td>5.24 (2.38)</td>
<td>4.64 (2.17)</td>
</tr>
<tr>
<td><strong>N170</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat</td>
<td>-3.05 (2.29)</td>
<td>-3.18 (2.14)</td>
</tr>
<tr>
<td>Non-Threat</td>
<td>-3.12 (2.15)</td>
<td>-3.25 (2.04)</td>
</tr>
<tr>
<td><strong>P2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat</td>
<td>4.33 (2.06)</td>
<td>3.81 (2.16)</td>
</tr>
<tr>
<td>Non-Threat</td>
<td>4.41 (2.79)</td>
<td>4.04 (2.45)</td>
</tr>
<tr>
<td><strong>N2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat</td>
<td>-3.72 (1.23)</td>
<td>-3.75 (1.49)</td>
</tr>
<tr>
<td>Non-Threat</td>
<td>-3.75 (1.43)</td>
<td>-4.13 (1.62)</td>
</tr>
</tbody>
</table>

*Note.* Amplitudes (µV) are presented as means with standard deviations in parentheses.
Table 4

*Descriptive Statistics for Participants with Behavioral Biases at 100 ms*

<table>
<thead>
<tr>
<th></th>
<th>Train Toward Threat</th>
<th>Train Away From Threat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Training</td>
<td>Post-Training</td>
</tr>
<tr>
<td>Attention Bias</td>
<td>-17.73 (13.97)</td>
<td>4.72 (28.33)</td>
</tr>
<tr>
<td>Vigilance</td>
<td>-2.80 (16.70)</td>
<td>6.86 (26.07)</td>
</tr>
<tr>
<td>Disengagement</td>
<td>-14.93 (21.08)</td>
<td>-2.14 (21.32)</td>
</tr>
</tbody>
</table>

*Note.* Difference scores of response times are presented as mean difference scores of reaction times (ms) with standard deviations in parentheses. There were 26 participants with biases in the 100 ms condition (train toward threat: \(N = 14\); train away from threat: \(N = 12\)).
Table 5

*Descriptive Statistics for Participants with Behavioral Biases at 500 ms*

<table>
<thead>
<tr>
<th></th>
<th>Train Toward Threat</th>
<th></th>
<th>Train Away From Threat</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Training</td>
<td>Post-Training</td>
<td>Pre-Training</td>
<td>Post-Training</td>
</tr>
<tr>
<td>Attention Bias</td>
<td>-9.70 (7.13)</td>
<td>3.79 (13.60)</td>
<td>14.33 (9.84)</td>
<td>4.57 (24.40)</td>
</tr>
<tr>
<td>Vigilance</td>
<td>-0.29 (14.48)</td>
<td>-5.03 (17.01)</td>
<td>11.08 (13.32)</td>
<td>8.29 (22.27)</td>
</tr>
<tr>
<td>Disengagement</td>
<td>-9.40 (16.37)</td>
<td>8.82 (22.63)</td>
<td>3.25 (17.73)</td>
<td>-3.72 (22.64)</td>
</tr>
</tbody>
</table>

*Note.* Difference scores of response times are presented as mean difference scores of reaction times (ms) with standard deviations in parentheses. There were 24 participants with biases in the 500 ms condition (train toward threat: \(N = 11\); train away from threat: \(N = 13\)).
Figure 1. Sequence of events in the dot probe task for Study 1.
Figure 2. Grand averaged scalp topographies and waveforms for ERP components (P1, N170, P2, N2) generated to the face pair cues during the pre-training dot probe task. TN refers to threat-neutral face pairs and NN refers to neutral-neutral face pairs.
Figure 3. Attentional bias scores increased for the train toward threat group and decreased for the train away from threat group for participants who showed pre-training biases at 100 ms.
Figure 4. Vigilance decreased for the train away from threat group for participants who showed pre-training biases at 100 ms.
Figure 5. Attentional bias increased for the train toward threat group for participants who showed pre-training biases at 500 ms.
Chapter 3: Study 2

I. Introduction

The goal of Study 2 was to extend the neurocognitive approach of Study 1 to a sample of highly trait anxious participants. Study 2 investigated whether ERP responses to threat, both at baseline and in response to ABMT, predicted the efficacy of training attention away from threat in highly trait anxious participants. Thus far, only one study has explored neurocognitive changes in attention to threat following ABMT in highly trait anxious participants (Eldar & Bar-Haim, 2010).

The majority of ABMT research thus far has employed either emotional words or faces. An innovation to this present study, compared to previous studies, is the use of more salient stimuli – complex emotional images taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). A 2010 meta-analysis of ABMT (Hakamata et al., 2010) found larger effect sizes for word stimuli as compared to emotional faces. While the word stimuli are less salient in terms of being images versus text, the content of the text may actually be more arousing than the emotional faces. As such, it is important to explore whether the use of higher arousal non-verbal stimuli yield comparable ABMT effects on threat bias, anxiety, and stress reactivity. Using complex emotional images, Koster et al. (2008) found reductions in attentional threat bias at later but not early stages of threat processing following ABMT in non-anxious participants. Because complex images were used instead of facial stimuli, the N1 component will be measured instead of the N170 (Itier & Taylor, 2004a). Additionally, in order to decrease the number of factors only one presentation duration was used (500 ms, in order to be consistent with the majority of previous ABMT research; Hakamata et al., 2010).
An important addition to Study 2 was the inclusion of a stress reactivity assessment before and after ABMT, to compare both changes in mood and emotional vulnerability following attention training. Study 1 did not find any group differences in state anxiety following training towards versus away from threat. Given that ABMT is thought to exert its influence on anxiety through changes in stress reactivity (Eldar et al., 2008; Hallion & Ruscio, 2011; MacLeod et al., 2002), we included a measure and predicted reductions in stress reactivity following ABMT.

The first hypothesis was that ABMT, compared to the placebo training (PT) condition, would reduce threat bias, subjective anxiety, and stress reactivity. The second hypothesis was that ABMT compared to PT would result in reduced attention capture by threat (smaller P1, N1, and P2 amplitudes to threat cues) and increased cognitive control of threat (larger N2 amplitudes to threat cues). To test how ABMT reduces anxiety and stress reactivity, our third hypothesis was that ABMT-induced changes in ERP measures of attention capture and cognitive control of threat predicted ABMT effects on anxiety and stress reactivity. To examine this hypothesis, we tested whether ABMT-induced changes in ERPs predicted training effects on behavioral threat bias, anxiety and anxious stress reactivity. Finally, to examine for whom ABMT may be most effective, our fourth and exploratory analysis was to test whether baseline ERP measures of attention capture and cognitive control predicted ABMT effects on anxiety and stress reactivity. One possibility is that individuals with greater early attention capture by threat and reduced attentional control when processing threat at baseline will show greater benefits of ABMT.

II. Method

Participants. Participants were 57 non-diagnosed adults recruited through the psychology participant research pool at Hunter College, The City University of New York. Three participants discontinued participation in the study; the final sample consisted of 54 adults (9
males, 45 females) aged 18 to 38 ($M = 20.28$, $SD = 4.33$). Self-reported race/ethnicity was as follows: 18 White, 9 Hispanic, 19 Asian or Pacific Islander, 6 African American, and 2 self-reported other race/ethnicity. In order to qualify for the study, potential participants needed to report at least +1SD from the college norm for trait anxiety scores (score of 49 or higher; Spielberger, 1983). Trait anxiety scores ranged from 49 to 75, with an average of 55.52 ($SD = 5.71$). Additional participants were excluded from analyses for each of the measures: two due to excessive errors in dot probe reaction times ($N = 53$); one due to poor EEG recording resulting in a loss of all ERP data ($N = 51$); one due to video consent refusal and one due to failure of video recorder during the stressor resulting in a loss of behavioral stress reactivity measures ($N = 52$).

**Procedures.** Participants spent approximately three hours in the laboratory. Following informed consent and a questionnaire period, participants completed the pre-training Trier Social Stress Task (TSST; Kirschbaum, Pirke, & Hellhammer, 1993). The TSST involved a pre- and post-stressor mood questionnaire and video recording. Following the TSST, an elasticized nylon cap was fitted on participants and scalp electrodes were applied. Participants were seated 65 cm from a 17 in monitor and instructed to remain still and not blink when the stimuli appeared on the screen to reduce the occurrence of muscle or ocular artifacts in the EEG recording. Next, participants completed a pre-training mood questionnaire and threat bias assessment (using the dot probe). Next participants completed ABMT or PT, followed by post-training threat bias and mood assessments. Finally, after EEG cap removal participants completed the post-training TSST.

**Baseline mood questionnaires.** Anxiety symptoms were measured using the State-Trait Anxiety Inventory (STAI; Spielberger, 1983). The State-Trait Anxiety Inventory is a 40-item questionnaire that measures participants’ perceptions of their current (state) and general (trait)
level of nervousness, anxiety, and shyness; scores range from 20 to 80 with higher scores indicating greater anxiety. Trait anxiety was measured during a screening prior to recruitment for the present study; state anxiety was measured when participants first arrived for the study and again following the attention training task.

*Trier Social Stress Task (TSST; Kirschbaum et al., 1993).* The TSST includes a social-evaluative threat, where participants must give a speech in front of two judges, and a lack of control task, where participants must complete a difficult arithmetic task. Participants were given a three-minute preparation period following the speech instructions then they completed a three-minute speech and a three-minute arithmetic task. There were two versions of each task (i.e., different content for speeches and different starting number for arithmetic) which were counterbalanced across pre- and post-training to avoid order effects. For the speeches, participants were asked to either introduce themselves as though they were applying for a job or to defend their stance on the death penalty. For the arithmetic task, participants were asked to count backwards by 13 from either 1,022 or 1,999; every time they made a mistake they were stopped and asked to begin again from the original number. The TSST was filmed via a camera mounted on the wall with sound recording via two microphones affixed to the ceiling. These devices were pointed out to the participant during the instructions for the task. The recording started when participants began their speech and ended when the three minutes for the arithmetic had elapsed. Two measures of stress reactivity were taken: self-reported mood before and after the stressors and coded anxious behaviors during the stressors.

*Profile of Mood States (POMS; McNair, Lorr, Heuchert, & Droppleman, 2003).* Self-reported mood was recorded before and after the TSST using the 65-item Profile of Mood States (POMS; McNair, Lorr, Heuchert, & Droppleman, 2003). Participants are instructed to indicate
on a five-point scale how well each adjective describes their current mood (not at all to extremely). The POMS measures six different mood states (Tension/Anxiety, Depression/Dejection, Anger/Hostility, Vigor/Activity (reverse scored), Fatigue/Inertia, Confusion/Bewilderment) which are combined to generate a Total Negative Mood score. Difference scores of post-TSST versus pre-TSST were generated for the pre- and post-training stressors to index pre- and post-training changes in negative mood following a stressor.

Anxious behavior coding. Behaviors were coded during the speech and mental arithmetic stressors in 10 second time bins. Behaviors consisted of flight behaviors from Troisi (1999): looking down/away from the judge; closing the eyes; drawing the chin in toward the chest; crouching; being still or freezing. Additionally, nervous speech (e.g., “umm” or “hmm”) and expressions of frustration (e.g., “Oh my goodness!” or groaning) were also coded. The final score was the sum instances (coded yes/no) across all behaviors collapsed across the speech and mental arithmetic stressors. Reliability (α = .91) was calculated using Krippendorff’s alpha for nominal data (present/absent).

The dot probe task. The dot probe task begins with a fixation cross for 1000 ms, followed by a pair of cue stimuli for 500 ms. Images subtended 41 cm x 13 cm and were presented equal distance to the right and left of the fixation cross. Following the cues was a variable interstimulus interval from 100-300 ms followed by a probe (arrow) for 200 ms in the location occupied previously by either stimulus. Participants have up to 1300 ms to respond and are required to determine whether the arrow is pointing to the left or the right. Each trial ends with an intertrial interval of 500-1000 ms. See Figure 6 for a schematic of a single trial of the dot probe task.
Cue pairs were a threatening and a non-threatening image (TN), two non-threatening images (NN), or two threatening images (TT). Probes can appear in the location of the threatening stimulus from TN pairs (threat cue), the non-threatening stimulus from TN pairs (non-threat cue), either stimulus from NN pairs, or either stimulus from TT pairs. The attention bias, vigilance, and disengagement scores were calculated as in Study 1.

**Threatening and non-threatening stimuli.** This study included 192 picture stimuli from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008): 48 threat-neutral pairs, 24 neutral-neutral pairs, 24 threat-threat pairs. Threatening images contain knives, guns, and aggressive animals and non-threatening images contain tools, shoes, and household objects. Images pairs were matched for brightness and color based on subjective judgments by several research assistants.

**Pre- and post-training threat bias assessment.** Participants received an equal number of threat, non-threat, and baseline cue trials during the pre- and post-training dot probe task, for a total of 192 trials in each assessment.

---

3 Threat-neutral pairs: 1019-5533; 1030-7170; 1050-5800; 1052-7550; 1070-5750; 1111-5530; 1120-2200; 1300-7006; 1301-2600; 1310-2570; 1930-7061; 1932-2441; 2120-2107; 2683-7240; 2692-7058; 3500-2980; 3530-2396; 5950-7249; 5961-2357; 5972-7039; 6190-2032; 6200-6570.2; 6211-5520; 6213-2487; 6220-2397; 6230-7031; 6231-2575; 6240-2411; 6250-7025; 6263-7062; 6350-7175; 6510-7490; 6520-1935; 6530-7710; 6540-1908; 6550-5661; 6570-2635; 6940-2383; 9600-5390; 9623-7487; 9630-2038; 9635-1-5395; 9800-7130; 9810-7590; 9901-7496; 9902-5250; 9909-5731; 9911-2026; threat: valence (M = 3.04, SD = 0.84), arousal (M = 6.24, SD = 0.56); neutral: valence (M = 5.29, SD = 0.47), arousal (M = 3.46, SD = 0.75)

4 Neutral-neutral pairs: 1122-2273; 2235-2594; 2579-2595; 2870-6930; 5534-6150; 7000-7010; 7004-7080; 7014-7016; 7018-7021; 7019-7195; 7020-7035; 7032-7040; 7036-7037; 7043-7056; 7045-7059; 7053-7055; 7057-7060; 7077-7150; 7242-7300; 7255-7513; 7497-7495; 7509-8191; 7547-7632; 7950-8117; valence (M = 5.18, SD = 0.41), arousal (M = 3.45, SD = 0.88)

5 Threat-threat pairs: 1022-1525; 1026-6561; 1033-1302; 1040-6560; 1051-1304; 1090-6210; 1113-6360; 1114-2811; 1303-6243; 1321-6244; 1726-6212; 2100-2110; 5971-5973; 6241-1931; 6242-6821; 6260-6300; 6370-5970; 6410-9620; 6571-6312; 6313-5920; 6315-2682; 9622-5940; 9903-9910; 9904-9908; valence (M = 3.26, SD = 0.83), arousal (M = 6.03, SD = 0.64)
**ABMT and PT conditions.** Half of the participants completed an ABMT condition intended to induce an attentional bias away from threatening stimuli (non-threat cues only; \( n = 27 \)) or a PT condition (equal number threat and non-threat cues; \( n = 27 \)). There were 576 training trials in both conditions, with an equal number of TN and NT pairs (no NN or TT), consistent with other single-session ABMT studies (Beard, Sawyer, & Hofman, 2012; Hakamata et al., 2010).

**Electrophysiological recording and data reduction.** EEG activity was recorded using the same procedures as Study 1.

Artifacts were identified using the following criteria and removed from analyses: data with voltage steps greater than 50 µV, changes within a given segment greater than 300 µV, and activity lower than .5 µV per 100 ms. In addition to this semi-automatic identification of artifacts, trials were also visually inspected for any further artifacts and were removed on a trial-by-trial-basis.

Electrodes were chosen via visual inspection of the topographical distribution of the pre-training dot probe task data, grand averaged across all stimulus conditions and participants (see Figure 7). ERPs were quantified as the mean amplitude for each cue condition and averaged over clusters of electrodes: the P1 was generated from 100-160 ms over P7/P9/PO7 and P8/P10/PO8; the N1 was generated from 150-180 ms over CP5/P5/P7 and CP6/P6/P8; the P2 was generated from 200-400 ms over O1/PO3/PO7 and O2/PO4/PO8; the N2 was generated from 250-350 ms over FCz. Difference scores were generated to the threatening (TN and TT) versus the non-threatening (NN) cue conditions to index ERP processing of threat.

Trial counts were grand averaged across all stimulus conditions and participants. The average trial count for P1 was 43.58 (SD = 3.47), for N1 was 43.67 (SD = 3.35), for P2 was
43.65 (SD = 3.40), and for N2 was 43.75 (SD = 3.32). There were no significant group differences in the average trial counts between the ABMT and PT groups, all ts < 1.00, ps > .80.

III. Results

Participant demographics and baseline anxiety and depression symptoms for both of the training groups (ABMT and PT) are presented in Table 6 and pre- and post-training threat bias, ERP amplitudes, state anxiety, and stress reactivity are presented in Table 7. There were no differences between training conditions on any of the measures (all ps > .28). All statistical analyses were conducted in SPSS (Version 20) using general linear model and hierarchical regressions.

**ABMT effects on outcome measures.** First, we tested the hypotheses that ABMT versus PT would reduce threat bias, state anxiety, stress reactivity (self-reported mood, observed anxious behaviors), and alter ERP amplitudes to cues (i.e., reduced P1, N1, and P2 amplitudes and increased N2 amplitudes). This hypothesis was tested using a series of ANCOVAs with post-training as the dependent variable, the corresponding pre-training measure as the covariate, and Training (ABMT or PT) as the between-subjects factor.

**ABMT effects on threat bias, anxiety, and stress reactivity.** Counter to predictions, there was a significant effect of Training on state anxiety, such that participants in the ABMT group (M = 46.90, SD = 1.74) versus PT group (M = 40.66, SD = 1.77) showed greater state anxiety, F(1, 52) = 6.31, p = .02, partial η² = .11. No other effects reached significance.

**ABMT effects on ERPs.** We predicted that ABMT compared to PT would result in reductions in P1, N1, and P2 amplitudes (reflecting dampened attention capture) and increases in N2 amplitudes (reflecting strengthened cognitive control). There was a trend-level effect of Training on N2 amplitudes such that, as predicted, participants in the ABMT group (M = -0.03,
$SD = 0.33$) versus PT group ($M = 0.82, SD = 0.34$) showed greater N2 amplitudes to threat, $F(1, 48) = 3.16, p = .08$ partial $\eta^2 = .06$. This effect was not significant for the threat alone condition (TT versus NN) indicating it uniquely emerged on trials in which the threat stimulus competed for attention with non-threat (TN versus NN).

**The impact of ERPs on ABMT effects.** Next, we used a series of hierarchical regressions to test the hypothesis that ERP measures of threat processing would moderate or mediate ABMT effects on state anxiety and stress reactivity. We examined training-induced changes in ERPs *how ABMT works*) and baseline measures of ERPs *for whom ABMT works*). Each of the post-training measures were entered separately as the dependent variable with the following variables entered in separate steps: 1) the corresponding pre-training measure; 2) Training Group; 3) ERP (P1, N1, P2, or N2); 4) interaction between Training and ERP (e.g., ABMT x N2). Given recommendations concerning probing interaction effects (Aiken & West, 1991; Finney, Mitchell, Cronkite, & Moos, 1984), if interaction terms’ contributions to $R^2$ approached significance ($p = .10$), the interactions were followed up with the PROCESS macro for SPSS (Hayes, 2013) by using simple regression equations. The dependent variable on the y-axis was plotted against the levels of Training Condition (ABMT and PT). Plotted regression lines represent increases/no change/decreases in ERP amplitudes from pre- to post-training or greater/equal/reduced ERP amplitudes to threat at baseline. Regression lines were generated as the mean value and +/- two standard deviations from the mean. For all steps of the analyses, predictor variables were centered to reduce problems of lack of invariance of regression coefficients and multicollinearity.6

---

6 All moderation analyses using behavioral threat bias as a moderator were not significant. Mediation analyses using both groups of predictors (ERPs, behavior) were not significant.
**Interactions with ABMT-induced changes.** One significant interaction effect emerged between Training Condition and changes in ERPs due to ABMT. Specifically, Training condition interacted with change in N1 amplitudes to threat (TN versus NN): negative mood after the TSST was reduced following ABMT versus PT, but only for participants who showed decreases in N1 amplitudes to threat from pre- to post-training \( t = -2.82, p = .01 \); full model: \( F(4, 46) = 5.23, p = .002, R^2 = .31 \); interaction step change statistics: \( F(1, 46) = 7.91, p = .007, R^2 = .12 \); see Figure 8]. This effect was also significant for the threat alone condition (TT versus NN).\(^7\) No other effects reached significance.

**Interactions with measures at baseline.** Two significant interaction effects emerged between Training Condition and ERPs at baseline. First, Training Condition interacted with N1 amplitudes to threat (TN versus NN) to predict changes in self-reported negative mood after the TSST: negative mood after the TSST was reduced following ABMT versus PT, but only for participants who showed greater N1 amplitudes to threat versus non-threat at baseline \( t = -2.22, p = .03 \); full model: \( F(4, 46) = 3.77, p = .01, R^2 = .25 \); interaction step change statistics: \( F(1, 46) = 3.56, p = .07, R^2 = .06 \); see Figure 9]. This effect was not significant for the threat alone condition (TT versus NN).

Second, Training Condition interacted with N2 amplitudes to threat (TN versus NN) to predict state anxiety: state anxiety was greater following ABMT versus PT, but only for participants who showed reduced N2 amplitudes to threat versus non-threat at baseline \( t = 3.48, p = .001 \); full model: \( F(4, 46) = 6.14, p < .001, R^2 = .35 \); interaction step: \( F(1, 46) = 4.06, p = .05, R^2 = .06 \); see Figure 10]. This effect was not significant for the threat alone condition (TT versus NN). This effect clarified the counterintuitive finding reported above that ABMT versus

\(^7\) TT versus NN statistics: \( t = -2.07, p = .04 \); full model: \( F(4, 46) = 4.68, p = .003, R^2 = .29 \); interaction step change statistics: \( F(1, 46) = 4.27, p = .04, R^2 = .07 \)
PT was associated with greater state anxiety by demonstrating that only a certain subset of participants evidenced changes in state anxiety in the opposite direction as predicted. No other effects, including mediation analyses, reached significance.

IV. Discussion

Study 2 examined the effects of ABMT in adults with elevated trait anxiety using ERPs, with a focus on delineating the bottom-up and top-down neurocognitive processes by which ABMT reduces anxiety and stress reactivity. In addition, to increase the salience of threat stimuli, complex emotional pictures (instead of faces or words) were used. Overall, results suggest that participants receiving ABMT versus PT showed enhanced N2 amplitudes to threat, suggesting strengthening of controlled attention. Highlighting the importance of accounting for baseline individual differences in threat processing, we also found that those participants showing reduced N2 amplitudes to threat at baseline showed greater state anxiety after ABMT versus PT, while, in contrast, greater N1 amplitudes to threat at baseline and greater reductions in N1 amplitudes to threat from pre- to post-training was associated with reduced negative mood after the social stressor. Findings concerning bottom-up attention capture are particularly novel, and suggest that attention capture could be a key factor influencing the efficacy of ABMT on anxious stress reactivity.

Importantly, while previous, largely theoretical research implicates changes in attentional control as the most likely candidate for how ABMT reduces anxiety and threat bias, findings from the current suggest a more prominent role for early attention capture as measured via the N1. First, only those individuals who showed larger N1 amplitudes to threat versus non-threat at baseline showed reduced negative mood after a stressor. Furthermore, findings demonstrate that the degree to which ABMT reduces attention capture by threat as measured by the N1 predicts
the strength of training effects on stress reactivity. This effect of changes in N1 amplitudes may be a useful marker for training-relevant plasticity in early threat processing following ABMT. Taken together, these findings suggest that individuals showing increased attentional capture by threat (N1) may be the best candidates for ABMT, and that successful ABMT operates at least in part through reductions in attentional capture by threat. Taken together with findings that N2 amplitudes to threat increase following training, the present findings suggest that ABMT may retune bottom-up attentional capture via changes in more top-down control processes. In this way, changes in early bottom-up attentional filters lead downstream to reductions in behavioral reactivity to threat (Todd et al., 2012). This study is among the first to document that both individual differences and changes in neurophysiological responses to threat influence the efficacy of ABMT.

Consistent with a previous ABMT study using ERPs (Eldar & Bar-Haim, 2010) we found greater N2 amplitudes as post-training for participants who completing ABMT versus PT, suggesting that top-down control of attention to threat is bolstered as a result of ABMT. These findings are in line with models proposing that changes strategic attention to threat underlie successful ABMT (Bar-Haim et al., 2011; Heeren et al., 2013). The role of strategic attention in ABMT is further supported by moderation analyses of ABMT effects on state anxiety: counter-intuitive increases in state anxiety following ABMT are limited to participants with poor baseline attentional control when processing threat. Taken together with the finding concerning the role of early attention capture (N1), the present study suggests that individual differences in both attention capture and attentional control must be considered when identifying individuals most likely to benefit from ABMT.
Findings suggest that ABMT with complex emotional scenes as stimuli is effective, but perhaps not as strongly as the traditional word pairs or emotional faces considering the lack of differences in behavioral biases for the sample as a whole. The use of these more complex stimuli may have negative effects for some individuals, as evidenced by greater state anxiety for ABMT versus control for participants with poor attentional control at baseline. Future studies should explore the effects of varying the type of stimulus (words, faces, scenes) to determine whether one may be more beneficial to certain individuals than others.

Limitations of the present study include the black background for the dot probe task, the brevity of training, and not testing for generalization effects of ABMT. The black background and flashes images may have created a changing contrast that affected participants’ ability to attend to the task; for study 3 a white background is used to reduce such interference. ABMT studies have ranged from a single session up to 15, with effects growing stronger as the number of sessions increases (Hakamata et al., 2012). Future research will take this same statistical approach while increasing the number of training sessions to better understand mediation effects in the context of the existing literature. Regarding generalization, the present study used the same stimuli for both assessment and training. Future studies should incorporate a second stimulus set, or completely novel stimuli (e.g., words) to determine whether ABMT effects are specific to the stimuli used during training (e.g., Amir, Beard, Taylor, et al., 2009).

In summary, ERPs may be a useful tool for understanding how ABMT works and for identifying those individuals for whom ABMT will be most effective. ABMT holds promise as a powerful adjunct to current gold-standard treatments for anxiety. By better understanding neurocognitive individual differences and plasticity related to ABMT, we can move towards creating a standardized protocol for administering ABMT in a therapeutic setting.
Table 6

Participant Demographics and Baseline Anxiety and Depression Symptoms

<table>
<thead>
<tr>
<th></th>
<th>ABMT (n = 27)</th>
<th>PT (n = 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (% women)</td>
<td>89%</td>
<td>78%</td>
</tr>
<tr>
<td>Age (years)</td>
<td>20.20 (4.15)</td>
<td>20.26 (4.58)</td>
</tr>
<tr>
<td>Education (years)</td>
<td>14.37 (1.74)</td>
<td>14.19 (1.73)</td>
</tr>
<tr>
<td>Ethnicity (frequency)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Asian</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Native Hawaiian or Other Pacific Islander</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Black or African American</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>White</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>More than one race</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Trait Anxiety</td>
<td>52.74 (7.49)</td>
<td>50.74 (10.14)</td>
</tr>
</tbody>
</table>

*Note.* Standard deviations presented in parentheses.
Table 7

*Threat Bias, ERP Amplitudes, Anxiety, and Stress Reactivity*

<table>
<thead>
<tr>
<th></th>
<th>ABMT Pre-Training</th>
<th>ABMT Post-Training</th>
<th>PT Pre-Training</th>
<th>PT Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threat Bias</td>
<td>5.37 (19.14)</td>
<td>-5.77 (21.49)</td>
<td>7.09 (17.78)</td>
<td>0.36 (24.54)</td>
</tr>
<tr>
<td>ERPs (TN versus NN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1 Amplitudes</td>
<td>0.37 (1.09)</td>
<td>-0.10 (1.22)</td>
<td>0.39 (1.12)</td>
<td>0.15 (1.25)</td>
</tr>
<tr>
<td>N1 Amplitudes</td>
<td>0.16 (0.95)</td>
<td>-0.44 (1.26)</td>
<td>0.26 (0.84)</td>
<td>-0.01 (1.26)</td>
</tr>
<tr>
<td>N2 Amplitudes</td>
<td>0.04 (1.48)</td>
<td>-0.03 (1.93)</td>
<td>0.30 (1.45)</td>
<td>0.82 (1.35)</td>
</tr>
<tr>
<td>ERPs (TT versus NN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1 Amplitudes</td>
<td>0.66 (1.34)</td>
<td>-0.23 (1.60)</td>
<td>0.43 (1.11)</td>
<td>-0.11 (1.47)</td>
</tr>
<tr>
<td>N1 Amplitudes</td>
<td>0.56 (0.81)</td>
<td>-0.20 (1.45)</td>
<td>0.11 (1.09)</td>
<td>0.08 (1.15)</td>
</tr>
<tr>
<td>N2 Amplitudes</td>
<td>0.04 (2.45)</td>
<td>0.37 (1.94)</td>
<td>0.32 (1.69)</td>
<td>0.98 (1.36)</td>
</tr>
<tr>
<td>State Anxiety</td>
<td>42.22 (9.80)</td>
<td>46.96 (9.62)</td>
<td>40.70 (11.11)</td>
<td>40.41 (10.21)</td>
</tr>
<tr>
<td>Mood Change (TSST)</td>
<td>24.78 (22.04)</td>
<td>9.15 (16.32)</td>
<td>14.59 (33.22)</td>
<td>10.48 (13.68)</td>
</tr>
<tr>
<td>Anxious Behaviors</td>
<td>75.64 (27.80)</td>
<td>69.52 (31.50)</td>
<td>75.37 (30.80)</td>
<td>73.00 (35.68)</td>
</tr>
</tbody>
</table>

*Note.* Threat bias (ms) and amplitudes (µV) presented as difference scores between threat (threat-neutral or threat-threat pairs) and non-threat (neutral-neutral pairs). Standard deviations presented in parentheses.
Figure 6. Sequence of events in the dot probe task for Study 2.
Figure 7. Grand averaged scalp topographies and waveforms for ERP components (P1, N1, P2, N2) generated to the image pair cues during the pre-training dot probe task. TN refers to threat-neutral pairs, NN refers to neutral-neutral pairs, and TT refers to threat-threat pairs.
Figure 8. Self-reported negative mood following the TSST was reduced for the ABMT versus PT groups, but only for those participants who showed decreased N1 amplitudes (µV) to threat from pre- to post-training.
Figure 9. Self-reported negative mood following the TSST was reduced for the ABMT versus PT groups, but only for those participants who showed enhanced N1 amplitudes (μV) to threat versus non-threat at baseline.
Figure 10. State anxiety was greater for the ABMT versus PT groups at post training, but only for those participants who showed reduced N2 amplitudes (µV) to threat versus non-threat at baseline.
Chapter 4: Study 3

I. Introduction

The goal of the F31-funded (1F31MH097317-01A1) Study 3 was to investigate the same hypotheses as Study 2 while making several important methodological changes to the dot probe task and training delivery. The field of ABMT research is still limited by the lack of a fully standardized task to measure the threat bias and present ABMT trials. While many studies have been conducted, important methodological details (e.g., stimulus type, stimulus duration, location of stimuli on the screen, number of trials) have varied from experiment to experiment (Hakamata et al., 2010). A recently created ABMT protocol uses a version of the dot probe task developed after a thorough review of what parameters have worked in the literature. This task is available through the collaborative Tel-Aviv University/National Institute of Mental Health (TAU/NIMH; Bar-Haim & Pine) project, which plans to bring together international labs to compile a database on ABMT effects from a lifespan developmental perspective in order to inform and facilitate future research. Study 3 also increased the number of training trials (from 576 in Study 2 to 640), which were delivered over the course of two sessions one week apart to more closely match studies with clinical samples where training is delivered over the course of multiple sessions rather than during a single massed delivery. Additionally, recent research suggests that giving participants time to consolidate the effects of ABMT contributes to training effects on stress reactivity (Abend, Karni, Sadeh, Fox, & Pine, 2013).

In addition to these changes to the dot probe and ABMT parameters, Study 3 also included a new task to test the generalization of training effects beyond the threat bias as measured by the dot probe. Before and after training participants viewed a series of threatening and non-threatening complex emotional images. We assessed whether ABMT affected
neurocognitive processing of more ecologically salient images using an ERP component called the late positive potential (LPP). The LPP reflects facilitated attention towards and increased processing of complex emotional stimuli such that amplitudes are enhanced for pleasant and unpleasant stimuli as compared to neutral (e.g., Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006). Additionally, a growing number of studies suggest that the LPP is also sensitive to individual differences in anxiety (DeCicco, Solomon, & Dennis, 2012; MacNamara & Hajcak, 2009; Mocaiber et al., 2009; Solomon, DeCicco, & Dennis, 2012). The LPP begins around 250-300 ms after stimulus presentation over centroparietal sites and continues for several seconds, providing excellent temporal resolution of automatic (early) and strategic (late) processing of emotional stimuli. We predicted that ABMT would reduce LPP amplitudes to threatening versus non-threatening images and explored whether training-induced changes in LPP amplitudes or baseline LPP amplitudes to threatening versus non-threatening stimuli moderate the effects of ABMT on anxiety and stress reactivity.

II. Method

Participants. Participants were 54 non-diagnosed adults recruited through flyers and the psychology participant research pool at Hunter College, The City University of New York and via Craigslist advertisements. As in Study 2, potential participants needed to report at least +1SD from the college norm for trait anxiety scores to qualify for the study (score of 49 or higher; Spielberger, 1983). Trait anxiety scores ranged from 42 to 78, with an average of 61.18 ($SD = 8.83$). Participants were further screened with Mini-International Neuropsychiatric Interview (MINI; Sheehan et al., 1998) at the beginning of the first visit. The MINI is a short (approximately 15 minutes with no diagnoses, up to 45 minutes with multiple diagnoses) and reliable structured diagnostic interview for DSM-IV disorders. Three participants were excluded
due to high suicidality and one was excluded due to an endorsement of psychotic disorder symptoms. Additionally, two participants discontinued participation during the first visit and nine participants did not return for the second visit. The final sample consisted of 39 adults (13 males, 26 females) aged 18 to 40 ($M = 21.56, SD = 5.62$). Self-reported race/ethnicity was as follows: 10 White, 11 Hispanic, 11 Asian, 4 African American, and 3 self-reported other race/ethnicity. Primary MINI diagnoses for the final sample were as follows: 1 hypomanic episode (current), 1 generalized anxiety disorder (current), 2 panic disorder (lifetime), 2 generalized social phobia (current), 3 agoraphobia (current), major depressive episode (1 current, 10 recurrent, 4 past), and 15 no diagnosis.

**Procedures.** At Time 1, participants completed a behavioral baseline threat bias assessment using the dot probe task (without EEG recording). Participants then completed the MINI to determine if they qualify for the study. After the MINI, participants who qualified for the study will complete a pre-training assessment of stress reactivity and threat bias (while EEG was recorded), and the ABMT task. At Time 2 (one week later), participants returned to the laboratory for a second session of the ABMT task, followed by a post-training assessment of the threat bias and stress reactivity. State anxiety was also assessed following each of the TSSTs. Prior to EEG recording, participants were fitted with an elasticized nylon cap and scalp electrodes were applied. For all computerized tasks participants were seated 65 cm from a 17 in monitor and instructed to remain still and not blink when the stimuli appeared on the screen to reduce the occurrence of muscle or ocular artifacts in the EEG recording.

**Mood questionnaires.** Baseline anxiety symptoms were again measured using the State-Trait Anxiety Inventory (STAI; Spielberger, 1983).
**Trier Social Stress Task (TSST; Kirschbaum et al., 1993).** Stress reactivity was assessed using the same TSST parameters as Study 2. The TSST was filmed via a camera placed on a tripod on the table between the participant and the judges. The recording started when participants began their speech and ended when the three minutes for the arithmetic had elapsed. The self-report and behavior coding measures were changed (described below).

*Self-report of mood.* State anxiety from the STAI was used as the self-report measure, to better compare to changes in anxiety from pre- to post-training.

*Anxious behavior coding.* The behavior coding scheme was changed from Study 2 in order better capture global stress reactivity along with verbal and non-verbal behaviors; the coding scheme from Study 2 (Troisi, 1999) was based on animal models and may have failed to capture more ecologically valid indicators of stress reactivity in human subjects. Behaviors were coded in three domains for each task as a whole: global performance (e.g., content was understandable, appeared confident), non-verbal behaviors (e.g., kept eye contact with the audience, fidgeted), and verbal behaviors (e.g., stuttered, voice quivered). Anxiety-related behaviors (e.g., fidgeted, stuttered, voice quivered) were reverse coded prior to summing scores from a five-point Likert scale (0 = not at all, 1 = slightly, 2 = moderately, 3 = much, 4 = very much). Thus, lower scores indicate signs of stress reactivity, reflected in poorer performance on the TSST. Reliability (speech: $\alpha = .79$; math: $\alpha = .78$) was calculated using Krippendorff’s alpha for ordinal data.

**The dot probe task.** The dot probe parameters discussed below are consistent with the Tel-Aviv University/National Institute of Mental Health (TAU/NIMH) attention bias modification training protocol (see Figure 11).
Experimental stimuli. Stimuli for the dot probe task are pictures of 20 different individuals (10 males, 10 females) from the NimStim stimulus set (Tottenham et al., 2009)\(^8\), with the exception of one female taken from the Matsumoto and Ekman set (Matsumoto & Ekman, 1989). The face pairs were divided into two sets: each participant received one set for the pre- and post-training threat bias assessment and the other for the ABMT task. Since facial stimuli are used like in Study 1, the N170 was generated instead of the N1. Behavioral bias scores (attentional bias, vigilance, disengagement) were calculated the same as Study 1 and 2.

Pre- and post-training threat bias assessment. Participants were shown two images simultaneously (cue) followed by a target in the location of one of the images (probe) and will be asked to indicate the direction the target arrow is pointing. Fixation will be presented for 500 ms, followed by cues for 500 ms, and then the probe until a response is made by clicking the right or left button on the mouse to indicate the direction of the arrow (see Figure 7). During each trial a pair of pictures are presented, either angry-neutral faces or a neutral-neutral face of the same individual. Face images subtended 5.5 cm x 5.5 cm and were presented equal distance above and below the fixation cross. Probes were equally likely to appear on the top or the bottom, and equally likely to be pointing to the left or the right in each position. Following each trial there was an inter-trial interval of 500 ms. There were 120 trials in the pre- and post-training threat bias assessments (80 angry-neutral trials and 40 neutral-neutral trials).

ABMT and PT conditions. The ABMT task consisted of four blocks of 160 trials of the dot probe (120 angry-neutral pairs and 40 neutral-neutral pairs) using the set of emotional face stimuli not used for the pre- and post-training threat bias assessment. There were two training conditions. Half of the participants completed ABMT, where the probe is always cued by the

---

neutral picture (all neutral cues from angry-neutral pairs). The other half of the participants completed PT, where the probe is equally likely to be cued by the angry face or the neutral face (equal numbers threat and neutral cues from angry-neutral pairs). Participants were given the opportunity to take a short break after every 40 trials.

**Passive viewing task.** Participants also passively viewed 30 threatening\(^9\) and 30 neutral\(^10\) pictures from the IAPS before and after ABMT or PT. Following a fixation cross presented for 1000 ms, pictures were displayed on the screen for 3000 ms, with each trial ending with a 1000 ms intertrial interval. Participants were instructed to passively view the images, similar to how they would watch television.

**Electrophysiological recording and data reduction.** EEG activity was recorded and reduced using the same procedures as Study 2.

EEG data was segmented from 200 ms before to 600 ms after stimulus presentation for the dot probe task. Electrodes were chosen via visual inspection of the topographical distribution of the pre-training dot probe task data, grand averaged across all stimulus conditions and participants (see Figure 12). ERPs were quantified as the mean amplitude for each cue condition and averaged over clusters of electrodes: the P1 was generated from 90-140 ms over P5/P7/PO7 and P6/P8/PO8; the N170 was generated from 140-190 ms over P5/P7/PO7 and P6/P8/PO8; the P2 was generated from 200-350 ms over O1/PO3/PO7 and O2/PO4/PO8; the N2 was generated from 275-345 ms over FCz and Fz. Difference scores were generated to the threatening (TN) versus the non-threatening (NN) cue conditions to index ERP processing of threat.

\(^9\) 1050, 1300, 1301, 1304, 1525, 2811, 3500, 3530, 6200, 6230, 6231, 6244, 6250, 6260, 6263, 6300, 6312, 6313, 6315, 6360, 6510, 6520, 6550, 6560, 6563, 6570, 6821, 9413, 9414, 9425; valence ($M = 2.53, SD = 0.52$), arousal ($M = 6.60, SD = 0.39$)

\(^{10}\) 2036, 2190, 2191, 2235, 2384, 2393, 2400, 2480, 2518, 2525, 2593, 2745.1, 2791, 7000, 7002, 7004, 7006, 7010, 7025, 7034, 7035, 7040, 7041, 7056, 7090, 7100, 7150, 7175, 7493, 9002; valence ($M = 5.06, SD = 0.60$), arousal ($M = 2.99, SD = 0.67$)
EEG data was segmented from 200 ms before to 2000 ms after stimulus presentation for the passive viewing task. Electrodes were chosen via visual inspection of the topographical distribution of the pre-training passive view data, grand averaged across both stimulus types and all participants (see Figure 13). ERPs were quantified as the mean amplitude in response to the threatening and non-threatening images and averaged over clusters of electrodes: the early window was generated from 300-800 ms over P3/P5/PO3 and P4/P6/PO4; the late window was generated from 800-1200 ms over P3/P5/CP5 and P4/P6/CP6.

Trial counts were grand averaged across all stimulus conditions and participants. The average trial count for P1 and N1 was 39.24 ($SD = 0.65$), for P2 was 39.24 ($SD = 0.65$), for N2 was 39.26 ($SD = 0.62$), for early LPP was 29.98 ($SD = 1.73$), and for late LPP was 29.29 ($SD = 1.74$). There were no significant group differences in the average trial counts between the ABMT and PT groups, all $ts < 1.30$, $ps > .16$.

III. Results

Participant demographics and baseline anxiety for both of the training groups (ABMT and PT) are presented in Table 8 and pre- and post-training threat bias, ERP amplitudes, stress reactivity (state anxiety and performance score) are presented in Table 9. All statistical analyses were conducted in SPSS (Version 20) using general linear model and hierarchical regressions.

Baseline differences between training groups. We assessed whether there were any baseline difference between training groups – such differences may influence the efficacy of ABMT in reducing anxiety and stress reactivity. There was a trend for the PT group to show more behavioral indicators of stress reactivity during the pre-training TSST compared to the
ABMT group (independent samples t-tests): global performance ($p = .33$), non-verbal behaviors ($p = .08$), verbal behaviors ($p = .08$).\footnote{When a repeated-measures ANOVA approach was used, the Test x Training interactions reflected a pattern such that the PT group shows more behavioral indicators of stress reactivity at pre-training and then improving to the level of the ABMT group, who did not change: global performance ($p = .07$), non-verbal behaviors ($p = .07$), verbal behaviors ($p = .18$).}

**ABMT effects on outcome measures.** We again tested the hypotheses that participants in the ABMT versus PT group would reduce threat bias, state anxiety, stress reactivity (self-reported mood, observed anxious behaviors), and alter ERP amplitudes to cues (i.e., reduced P1, N1, and P2 amplitudes and increased N2 amplitudes) and passively viewed images (i.e., reduced early and late LPP). This hypothesis was tested using a series of ANCOVAs with post-training as the dependent variable, the corresponding pre-training measure as the covariate, and Training (ABMT or PT) as the between-subjects factor.

**ABMT effects on threat bias, anxiety, and stress reactivity.** Counter to predictions, there was a significant effect of Training on stress reactivity (i.e., state anxiety following the stressor), such that participants in the ABMT group ($M = 59.31, SD = 1.61$) versus PT group ($M = 53.62, SD = 1.65$) showed greater state anxiety, $F(1, 36) = 5.97, p = .02$, partial $\eta^2 = .14$.

Additionally, there was a trend suggesting that participants in the ABMT group versus PT group showed greater behavioral threat bias [attention bias: $F(1, 36) = 2.16, p = .15$, partial $\eta^2 = .06$; vigilance: $F(1, 36) = 2.01, p = .17$, partial $\eta^2 = .05$; disengagement: $F(1, 36) = 2.30, p = .14$, partial $\eta^2 = .06$]. To follow-up on this effect we inspected behavioral attention bias scores at all three times (upon first arriving in the laboratory, at pre-training, and at post-training). The pattern in the data suggests that all participants showed reductions from baseline to pre-training; this reduction persisted following PT but participants in the ABMT group showed increases in
attention bias that approached their baseline, prior-to-training levels (see Figure 14). No other effects reached significance.

**ABMT effects on ERPs.** We predicted that ABMT compared to PT would result in reductions in P1, N1, and P2 amplitudes (reflecting dampened attention capture) and increases in N2 amplitudes (reflecting strengthened cognitive control) to the cues during the dot probe task and reductions in LPP amplitudes (early and late) to the passively viewed images. Consistent with predictions, there was a pattern such that LPP amplitudes to threat versus non-threat in the late window (800-1200 ms) were reduced for the ABMT group ($M = 4.19$, $SD = 4.76$) versus PT group ($M = 7.43$, $SD = 7.59$), $F(1, 36) = 2.31$, $p = .065$ (one-tailed) partial $\eta^2 = .06$. No other effects reached significance.

**The impact of ERPs on ABMT effects.** Moderation analyses were conducted the same as in Study 2. The impact of ERPs from the dot probe task and the passive viewing task were assessed.\(^\text{12}\)

**Interactions with ABMT-induced changes.** No effects reached significance.

**Interactions with measures at baseline.** Training Condition interacted with baseline N2 amplitudes to threat (TN versus NN) to predict stress reactivity (non-verbal behavioral indicators) during the TSST: participants showed greater stress reactivity (i.e., lower scores or poorer performance) following ABMT versus PT, but only for participants who showed reduced N2 amplitudes to threat compared to non-threat at baseline [$t = 2.18$, $p = .04$; full model: $F(4, 34) = 9.17$, $p < .001$, $R^2 = .52$; interaction step: $F(1, 34) = 5.04$, $p = .03$, $R^2 = .07$; see Figure 15].

\(^{12}\) All moderation analyses using behavioral threat bias as a moderator were not significant. Mediation analyses using both groups of predictors (ERPs, behavior) were not significant.
IV. Discussion

Study 3 again examined the effects of ABMT in adults with elevated trait anxiety using behavioral and neurophysiological measures. Additionally, we altered the dot probe and training parameters to contribute towards a standardization of the protocol. We also included a second task, passive viewing, to assess the generalization of ABMT effects to other neurocognitive processes. Taken together, these methodological changes served to potentially strengthen training effects and to investigate the task-specificity of training effects. Results again demonstrate the importance of considering baseline biases when assessing the effects of ABMT. Consistent with Study 2 findings, the ABMT versus PT group showed greater stress reactivity (as measured by subjective state anxiety) following training. Moderation analyses suggest that paradoxical increases in stress reactivity (i.e., non-verbal behavioral indicators) may be limited to individuals with poor attention control when processing threat at baseline (i.e., N2 amplitudes).

ABMT-induced increases in anxiety and stress reactivity were found across both studies 2 and 3 in participants who showed poor attentional control towards threat at baseline. In both studies, participants in the ABMT versus PT groups showed greater anxiety and stress reactivity following training. Additionally, the effects of ABMT versus PT on anxiety and stress reactivity were moderated by baseline N2 amplitudes to threat: specifically, individuals with poor attentional control when processing threat do not show the expected benefits of ABMT. Taken together, these findings suggest that baseline attentional control may be a useful predictor in identifying individuals who are best suited for ABMT. In contrast, increases in anxiety and stress reactivity for these individuals may not represent a negative outcome. Similar to exposure therapy, anxious individuals with poor attentional control towards threat may benefit more from
additional training in coping mechanisms and anxiety management (e.g., Butler, Cullington, Munby, Amies, & Gelder, 1984).

Study 3 included an additional assessment of behavioral threat bias that Study 2 did not conduct. The descriptive data suggests that participants began the study showing an expected bias towards threat but that this bias was reduced by the ensuing stressors (MINI, TSST); as such, participants were trained away from threat when they were already in a potential avoidant mode. This may have led to paradoxical increases in stress reactivity following training due to an exacerbation of an avoidant mode, leading participants to fail to reach later, and more elaborated, stages of threat processing (Beck & Clark, 1997). Indeed, individuals under acute life-threatening danger (i.e., the threat of mortar attacks; Bar-Haim et al., 2010) and soldiers suffering from post-deployment post-traumatic stress disorder (Sipos, Bar-Haim, Abend, Adler, & Bliese, 2013) show avoidance of threatening versus non-threatening stimuli. These studies further demonstrate that greater avoidance of threat is associated with more distress and anxiety symptoms.

The inclusion of a generalization task further suggests that ABMT affects stimulus processing when threatening and non-threatening images are presented without competition (Mathews & Mackintosh, 1998). The pattern of LPP amplitude reductions in the late window to threat versus non-threat following ABMT suggest that the training may target later stages of threat processing after the initial capture of attention. There is inconsistent evidence for the generalization of ABMT effects to other task: there is no generalization to tasks where the threatening stimulus is presented as a distracter (Harris & Menzies, 1998; Van Bockstaele, Koster, Verschuere, Crombez, & De Houwer, 2012). The passive viewing task, however, does
not involve competition between threatening- and non-threatening stimuli or distraction by threatening stimuli.

Limitations of Study 3 include the presence of baseline differences in stress reactivity and changes in the threat bias due to stress exposure. The PT group showed greater stress reactivity at baseline (as measured by behavioral indicators during the TSST) but not after training. However, this pattern suggests a regression to the mean effect rather than the PT condition of the dot probe task causing changes in stress reactivity. Additionally, participants entered the study evidencing a bias towards threat that changed to an avoidance of threat following the pre-training stressor; thus, participants in the ABMT group were trained to attend away from threat further. This baseline flexibility of the threat bias may have contributed to counterintuitive increases in stress reactivity. Previous studies show that the flexibility of bias induction affects both positive and negative outcomes (Clarke et al., 2012; Clarke et al., 2008), suggesting that this type of threat bias flexibility may be an influence in ABMT effects.

In summary, providing participants with consolidation time for training with emotional faces appears to have similar effects as the training with complex emotional stimuli and no consolidation time (Study 2). The present findings also underscore the importance of considering both baseline neurocognitive biases towards threat and the flexibility of the behavioral threat bias in considering ABMT effects on stress reactivity.
### Table 8

**Participant Demographics and Baseline Anxiety**

<table>
<thead>
<tr>
<th></th>
<th>ABMT (n = 19)</th>
<th>PT (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (% women)</td>
<td>68%</td>
<td>65%</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.05 (60.06)</td>
<td>21.10 (5.28)</td>
</tr>
<tr>
<td>Ethnicity (frequency)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Asian</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Black or African American</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>White</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>More than one race</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Trait Anxiety</td>
<td>60.63 (8.53)</td>
<td>61.70 (9.30)</td>
</tr>
</tbody>
</table>

*Note.* Standard deviations presented in parentheses.
Table 9

*Threat Bias, ERP Amplitudes, and Stress Reactivity*

<table>
<thead>
<tr>
<th></th>
<th>ABMT</th>
<th></th>
<th>PT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Baseline Dot Probe Task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention Bias</td>
<td>5.89</td>
<td>16.75</td>
<td>1.75</td>
<td>18.75</td>
</tr>
<tr>
<td>Vigilance</td>
<td>0.63</td>
<td>17.63</td>
<td>-2.65</td>
<td>17.79</td>
</tr>
<tr>
<td>Disengagement</td>
<td>5.26</td>
<td>16.31</td>
<td>4.40</td>
<td>16.27</td>
</tr>
<tr>
<td>TSST Performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global Performance</td>
<td>18.84</td>
<td>5.00</td>
<td>17.25</td>
<td>4.98</td>
</tr>
<tr>
<td>Nonverbal Behaviors</td>
<td>24.68</td>
<td>4.42</td>
<td>22.45</td>
<td>3.28</td>
</tr>
<tr>
<td>Verbal Behaviors</td>
<td>33.21</td>
<td>2.35</td>
<td>31.45</td>
<td>3.52</td>
</tr>
<tr>
<td>State anxiety after TSST</td>
<td>62.47</td>
<td>11.79</td>
<td>66.75</td>
<td>10.45</td>
</tr>
<tr>
<td>Pre-Training Dot Probe Task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention Bias</td>
<td>-1.42</td>
<td>19.51</td>
<td>-4.35</td>
<td>22.94</td>
</tr>
<tr>
<td>Vigilance</td>
<td>-0.53</td>
<td>9.72</td>
<td>-2.25</td>
<td>11.61</td>
</tr>
<tr>
<td>Disengagement</td>
<td>-0.89</td>
<td>9.81</td>
<td>-2.10</td>
<td>11.35</td>
</tr>
<tr>
<td>P1 Amplitude</td>
<td>-0.04</td>
<td>0.90</td>
<td>-0.10</td>
<td>0.84</td>
</tr>
<tr>
<td>N1 Amplitude</td>
<td>-0.09</td>
<td>0.86</td>
<td>0.06</td>
<td>1.07</td>
</tr>
<tr>
<td>P2 Amplitude</td>
<td>-0.03</td>
<td>1.09</td>
<td>-0.08</td>
<td>0.83</td>
</tr>
<tr>
<td>N2 Amplitude</td>
<td>-0.05</td>
<td>1.07</td>
<td>0.33</td>
<td>0.99</td>
</tr>
<tr>
<td>Early LPP Amplitude</td>
<td>7.13</td>
<td>4.52</td>
<td>7.90</td>
<td>5.08</td>
</tr>
<tr>
<td>Late LPP Amplitude</td>
<td>6.03</td>
<td>4.65</td>
<td>6.81</td>
<td>6.51</td>
</tr>
</tbody>
</table>

*Note.* Threat bias (ms) and amplitudes (µV) presented as difference scores between threat-neutral and neutral-neutral pairs for dot probe and threat and neutral images for LPP. Standard deviations presented in parentheses.
Figure 11. Sequence of events in the dot probe task for Study 3.
Figure 12. Grand averaged scalp topographies and waveforms for ERP components (P1, N170, P2, N2) generated to the face pair cues during the pre-training dot probe task. TN refers to threat-neutral face pairs and NN refers to neutral-neutral face pairs.
Figure 13. Grand averaged scalp topographies and waveforms for ERP components (early and late LPP) generated to the images during the pre-training passive viewing task.
Figure 14. Attention bias scores at baseline, pre-training, and post-training.
Figure 15. Stress reactivity was greater (i.e., worse performance) for the ABMT versus PT groups at post-training, but only for those participants who showed reduced N2 amplitudes (µV) to threat versus non-threat at baseline.
Chapter 5: General Discussion

The goal of this dissertation was to address two overarching aims: 1) To investigate how ABMT changes neurocognitive measures of attention to threat and 2) To investigate whether neurocognitive responses to threat, both in response to ABMT and at baseline, predict the efficacy of ABMT in reducing anxiety and stress reactivity (i.e., how and for whom ABMT works). Previous research has demonstrated the efficacy of ABMT in reducing anxiety and stress reactivity, however it is still unclear what attentional processes are altered by the training and underlie training effects.

Aim 1 summary. Consistent with predictions, we found that ABMT can both induce and reduce the threat bias in non-anxious participants, provided they showed baseline biases in the opposite direction (Study 1). Additionally, ABMT shifted neurocognitive measures of attentional processing of the cue stimuli (emotional faces) during the dot probe task: training attention away from threat lead to reductions in P1 amplitudes to all emotional faces at 100 ms and non-threatening faces at both durations (Study 1). Though these effects were not specific to threatening versus non-threatening stimuli they suggest a sensitivity of attentional capture processes to ABMT in non-anxious individuals. Also consistent with predictions, ABMT in highly trait anxious participants lead to increases in controlled attention to threat (i.e., greater N2 amplitudes; Study 2) and decreases in elaborated processing of threatening stimuli (i.e., reduced late LPP amplitudes; Study 3). Counter to predictions, both Study 2 and Study 3 demonstrated increases in anxiety and stress reactivity following ABMT versus PT; these findings, however, were clarified by moderation analyses. Taken together, the three studies presented in this dissertation suggest that ABMT to induce a bias towards threat is associated with changes in early attentional threat processing in non-anxious individuals while ABMT to reduce a bias
towards threat in anxious individuals is associated with changes in attentional control and elaborated threat processing.

**Aim 2 summary.** Somewhat consistent with predictions, increases in threat bias following training towards threat was associated with increases in P2 amplitudes to threat and decreases in N170 amplitudes towards threat. Further support for early attentional processing of threat in ABMT effects comes from Study 2 findings: ABMT versus PT led to reductions in stress reactivity but only for participants who showed reductions in N1 amplitudes to threat. Moderation analyses from Study 2 and Study 3 suggest that baseline ERPs may be useful markers for identifying individuals for whom ABMT will work best. Highly trait anxious individuals with enhanced N1 amplitudes to threat at baseline show reductions in stress reactivity (Study 2), while those individuals with reduced N2 amplitudes predict increases in stress reactivity following training (Study 2 and Study 3).

Behavioral measures (i.e., reaction time) only evidence changes when participants showed attention biases at baseline. ERPs provide more insight into the distinct processes being altered by ABMT: attentional capture by emotional stimuli is reduced (i.e., P1 amplitudes in Study 1) while attentional control when processing threat versus non-threat is bolstered (i.e., N2 amplitudes in Study 2). Though ABMT did not lead to expected changes in behavioral threat biases, there are changes in neural responses to threat that may reflect the recalibration of attention filters (Todd et al., 2012) which could be important for downstream changes in behavioral reactivity that impact anxiety symptoms. Thus, the calibration of attention filters as a result of ABMT appears to target both bottom-up (P1) and top-down (N2) attention to threat in competition with non-threat.
Additionally, changes in neurocognitive measures associated with relatively early attentional capture (N1) and threat processing (P2) are associated with training-induced changes in attention biases, anxiety, and stress reactivity. Taken together, these studies suggest that ABMT exerts its influence through both attentional capture and attentional control process (Heeren et al., 2013) though findings also suggest that baseline biases in neurocognitive attention to threat predict how well ABMT works.

Using ERPs to assess attentional capture and control processes also provided unique insights into understanding who responds best to ABMT. While the sample as a whole showed counterintuitive increases in anxiety and stress reactivity across Study 2 and 3, these effects were moderated by baseline neurocognitive measures of threat processing. Specifically, findings with N2 amplitudes in both Study 2 and Study 3 suggest that individuals who begin with poor attentional control when processing threatening versus non-threatening stimuli will show negative outcomes following ABMT (i.e., increased stress reactivity). In contrast, findings with N1 amplitudes in Study 2 suggest that individuals who begin with enhanced attentional capture by threatening versus non-threatening stimuli will show positive outcomes following ABMT (i.e., reduced stress reactivity). The current findings suggest that, while both attentional capture and control are implicated in the threat bias and ABMT effects, individuals showing greater attention capture by threat are more amenable to ABMT. Indeed, training away from threat when attentional control abilities are diminished at baseline leads to negative outcomes, suggesting that these individuals may be better suited for other treatment approaches or supplemental training in coping mechanisms for managing stress reactivity. Critically, this individual differences approach is a unique perspective on ABMT effects which should continue to be explored in order to better understand how and for whom ABMT works best.
Recent theoretical models propose that mood and anxiety disorders can be organized into two classes of internalizing disorders: fear (panic disorder, agoraphobia, social phobia, specific phobia) versus distress (generalized anxiety disorder, posttraumatic stress disorder) (Clark & Watson, 2006; Watson, 2005; Watson, O'Hara, & Stuart, 2008). While the threat bias is present across all anxiety disorders it may be driven by individual differences in these fear and distress symptoms. ABMT may be more effective for one group versus the other. A recent study of anxious youth demonstrated that distress-related disorders were associated with behavioral vigilance towards threat and fear-related disorders were associated with avoidance of threat (Salum et al., 2012). In contrast, distress may be reflected in avoidant tendencies rather than difficulty disengaging from threat (Lee, Orsillo, Roemer, & Allen, 2010). Study 3 findings suggest that ABMT for participants show behavioral avoidance of threat versus non-threat may lead to negative outcomes. However, behavioral avoidance may represent downstream processes following initial neurocognitive attentional capture by threat. Future research should explore neurocognitive markers of these internalizing symptoms to assess their interaction with attentional capture and control measures in predicting ABMT effects. Additionally, future studies should continue to probe for individual differences which can be used to identify conditions under which ABMT will work best. Such studies would be consistent with the dimensional approach of the NIMH’s Research Domain Criteria Project (Insel et al., 2010), which aims to create new classification schemes to better understand the mechanisms underlying mood disorders, and thus inform future intervention development.

A growing body of research is investigating whether ABMT is an effective adjunct to more traditional treatment, such as cognitive-behavioral therapy (CBT). While research has demonstrated that CBT reduces the threat bias (Mathews, Mogg, Kentish, & Eysenck, 1995)
findings are mixed thus far concerning the effects of combining ABMT and CBT (Britton et al., 2013; Rapee et al., 2013). A recent case study suggests that ABMT may be useful in ameliorating symptoms of anxiety in children who do not respond to CBT (Bechor et al., in press). A better understanding of how to identify individuals who will not respond to a particular intervention (e.g., CBT) can inform the choice of an alternative treatment option (e.g., ABMT). Additionally, the present studies’ findings suggest that study parameters, such as type of stimuli (e.g., faces or complex images) and stimulus duration, may influence ABMT efficacy. Just as participants with specific phobia have a limited set of stimuli that are threat-relevant, it may be possible to tailor the stimuli used in ABMT for other anxiety disorders to maximize efficacy (Bar-Haim, 2010).

Potential limitations of the present studies include the variability of baseline threat biases. Both Studies 1 and 2 showed one type of individual differences, with ABMT only affecting reaction time measures for those participants who showed baseline threat biases. Study 3 findings suggest that the threat bias may be flexible following stressor, which could in turn affect ABMT efficacy. Previous studies have documented differences in the threat bias based on the context in which it is measured (Bar-Haim et al., 2010; Shechner et al., 2012), suggesting that it may be more of a state variable than a trait one. Furthermore, research also suggests that the flexibility of the bias is related to both increases in anxiety after stress and reductions in anxiety after treatment (Clarke et al., 2012; Clarke et al., 2008). Thus, the presence of baseline threat bias differences in the present studies should not be approached necessarily as a limitation, but rather as suggesting additional individual differences that may contribute to the efficacy of ABMT.

In sum, the multimethod studies presented in this dissertation suggest that both attentional capture and control processes are influenced by ABMT, and that individual
differences in neurocognitive measures of attentional capture and control predict how and for whom ABMT works. Findings from these studies have contributed to both our understanding of ABMT as well as a growing number of questions remaining. Additional measures, such as eye tracking, can be incorporated to better understand attentional capture and control processes by directly tracking how eye gaze habits are changed by ABMT (Armstrong & Olatunji, 2012; Weierich et al., 2008). Furthermore, neurocognitive measures such as ERPs can be supplemented by analyses of EEG oscillatory dynamics, such as power in different frequency bands and the phase-locking of neural activity (Makeig, Debener, Onton, & Delorme, 2004) which may more closely represent the brain’s natural state of activity (Buzsáki, 2006). The addition of these measures to ABMT research will to future studies assessing the efficacy of ABMT as a viable treatment alternative and understanding how ABMT exerts its effects on attention and anxiety.
References


dissociation of P1 and N1 components. *Electroencephalography & Clinical Neurophysiology, 75*(6), 528-542. doi: 10.1016/0013-4694(90)90139-B


