Threat Facilitates Subsequent Executive Attention During Anxious Mood Independently of Trait Anxiety

A thesis

submitted by

Jeffrey Birk

In partial fulfillment of the requirements
for the degree of

Master of Science

In

Psychology

TUFTS UNIVERSITY

February 2011

ADVISER: Heather L. Urry, Ph.D.

Threat Facilitates Subsequent Executive Attention During Anxious Mood Independently of Trait Anxiety

Jeffrey L. Birk,[1] Tracy A. Dennis,[2] Lisa M. Shin, [1, 3] and Heather L. Urry[1]

[1]Tufts University, [2]Hunter College, City University of New York, and [3]Massachusetts General Hospital/Harvard Medical School

Author Note

Jeffrey L. Birk, Department of Psychology, Tufts University; Tracy A. Dennis, Department of Psychology, Hunter College, City University of New York; Lisa M. Shin, Department of Psychology, Tufts University, and Psychiatric Neuroimaging Group, Massachusetts General Hospital/Harvard Medical School; Heather L. Urry, Department of Psychology, Tufts University.

We thank S. Bansil, A. Bellet, P. Bene, K. Brethel, E. Brown, C. Callahan, R. Citron, E. Davidowitz, M. DeMatteo, S. DelDonno, R. Gavrielov, J. Laks, B. Meller, D. Millstein, M. Patlingrao, V. Peisch, P. Pensuwan, P. Pop, C. Rucinski, M. Santarsieri, S. Sloley, R. Trumball, V. Tran, A. Wei, and J. Yih for assistance with data collection and processing. We also thank P. Opitz, S. Cavanagh, and J. DiCorcia for valuable feedback and technical assistance, and F. Wilhelm and P. Peyk for making ANSLAB, a suite of open source Matlab routines used to process physiological data, available as freeware in the Society for Psychophysiological Research Software Repository (http://www.sprweb.org/repository).

Correspondence concerning this article should be addressed to Jeffrey L. Birk, Department of Psychology, Tufts University, 490 Boston Avenue, Medford, MA 02155. Email: jeffrey.birk@tufts.edu.

Abstract

Dual Competition Framework (DCF) posits that mild threat facilitates behavioral performance by influencing executive control functions and that anxiety strengthens this effect by enhancing threat's affective significance. A key aspect of executive control concerns the ability to inhibit one's dominant response tendencies. The effects of threat and anxiety on executive control function (specifically, the efficiency of response inhibition) are examined in two studies. In Study 1, participants induced to be in an aroused anxious state demonstrated facilitated efficiency of executive control following briefly presented stimuli that were mildly threatening (i.e., fearful faces) relative to nonthreatening (i.e., neutral faces). No such effect occurred for participants in an aroused happy state. In Study 2, we assessed both the effects of manipulated state and individual differences in trait anxiety on executive control efficiency. Consistent with Study 1, among participants with effectively induced moods, an anxious but not a neutral state was associated with facilitated executive control efficiency following fearful relative to neutral faces. Unexpectedly, trait anxiety did not influence executive control efficiency on its own or in the context of threat. The findings are partially consistent with the predictions of DCF in that state—but not trait—anxiety improved executive function following low-level threat.

Threat Facilitates Subsequent Executive Attention During Anxious Mood Independently of Trait Anxiety

The human attentional system is biased toward the detection of threatening information. Indeed the presence of threat-related stimuli (e.g., fearful faces) leads to enhancement at an early stage of visual processing (Phelps, Ling, & Carrasco, 2006) and captures attention so efficiently that subsequent benefits to performance (e.g., accurate detection of emotional words, speeded detection of emotional faces) can occur even in the absence of conscious awareness of the threat (Dijksterhuis & Aarts, 2003; Marcos & Redondo, 2005). Although the evolutionary roots of this remarkable prioritization of threat detection are fairly well understood (LoBue, 2010), the specific attentional mechanisms underlying threat's effect on behavior remain largely unexplored.

One aspect of attention is executive control, which refers to the ability to organize cognitive and sensory processing in a goal-directed way in order to guide appropriate action (Miller & Cohen, 2001). In particular, the ability to resolve conflict among competing responses using inhibition is an essential component of executive control (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Miller and Cohen (2001) define this ability as "[selecting] a weaker, task-relevant response (or source of information) in the face of competition from an otherwise stronger, but task-irrelevant one" (p. 170). This ability to inhibit may be critical for promoting adaptive functions following threat experiences because, from an evolutionary standpoint, a reliance on automatic behavioral responses might be particularly costly in threatening circumstances (e.g., behavior following the appearance of a poisonous snake).

Therefore the effect of threat on the executive control of attention—specifically, the inhibition function—merits further investigation. However, it is not entirely clear from an evolutionary perspective whether facilitation or suppression of executive control should be expected to follow a threatening experience. On the one hand, one might predict that threatening stimuli should enhance executive function globally in order to facilitate subsequent processing and increase the likelihood of navigating successfully in a situation of potential danger. On the other hand, one might reasonably predict that threat should disrupt executive function such that subsequent processing is hindered for all stimuli other than the threat itself.

A real-life example illustrates these contrasting predictions. Imagine that you are picking blackberries, attempting to distinguish only the ripest ones from amid an array of similar but not-quite-ripe ones. Suddenly a bumblebee flies noisily around your hand and quickly disappears into the bush ahead of you. Moments later, as you resume the task of differentiating among the berries and inhibiting the tendency to simply pluck any blackberry you find, has your executive control of attention been improved or hindered by the prior appearance of the bumblebee?

There is a fair amount of indirect evidence that threat improves executive control function. For instance, visual search is not only faster for threatening stimuli (e.g., angry faces) versus nonthreatening stimuli (e.g., happy faces), it is also more efficient, as indexed by smaller costs to reaction time for threatening versus nonthreatening images as the number of distracters is systematically increased (Blanchette, 2006; Öhman, Flykt, & Esteves, 2001; but see Krysko & Rutherford, 2009). Similarly, Schimmack (2005) reported that, whereas negatively arousing, but nonthreatening images (e.g., a drug addict with syringes) hindered the attentional control required to do a subsequent task, negatively arousing, threatening images (e.g., a snake with its head pointed at the viewer) actually caused a significantly faster average response relative to the average response for other distracter stimuli (i.e., nonthreatening negative, positive, and neutral images). In these studies reduced behavioral costs in visual search and speeded reaction time in mathematical computation are certainly consistent with the idea of facilitated executive function, but neither measure directly captures executive control efficiency in a targeted and controlled way. In order to determine conclusively whether executive function is improved by threat, a direct measure of executive control efficiency is needed.

The effects of threat on attention are not constant for all people in all circumstances. A large body of literature demonstrates that the attentional effects of threat are influenced dramatically by anxiety. It has been reliably demonstrated that attentional capture by threat is greater for high versus low levels of state (e.g., Fox & Knight, 2005; Fox, Russo, Bowles, & Dutton, 2001) and trait (e.g., Mogg, Holmes, Garner, & Bradley, 2008) anxiety. There is some indication that experimental demonstrations of threat-related attentional capture may reflect an interaction of state and trait anxiety such that trait differences are only evident during high state anxiety (for a review, see Williams, Mathews, & MacLeod, 1996), indicating the likely importance of anxious mood in potentiating the effect of threat on attention.

The attentional bias to threat in anxiety is often measured experimentally using tasks in which threat stimuli and target stimuli are systematically manipulated to appear in the same or different spatial locations (e.g., dot probe task, attentional cueing task), and recent research using these tasks suggests that delayed disengagement from the location of threat is the critical mechanism underlying the attentional effect (for a review, see Cisler, Bacon, & Williams, 2009). If this is the case, it raises the question of how attention is influenced when the target occupies the same general area of space as the threat. In other words, does difficulty disengaging from threat necessarily require a spatial shift of attention? Studies that address the specific effect of threat on executive control function in anxiety often rely on a task that addresses this question. Modified versions of the Stroop interference task (Stroop, 1935) require response inhibition to ignore threat-related aspects of stimuli and respond to non-emotional aspects of those same stimuli. A typical example requires that participants quickly name the colors of threatening and nonthreatening words. Notably, the threats and the targets are necessarily occurring in the same area of space. In this task elevated anxiety is associated with hindered executive control when the targets consist of threat stimuli (e.g., Kwakkenbos, Becker, & Rinck, 2010), and this reduced executive efficiency has been consistently demonstrated by anxious people (for a meta-analytic review, see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). It is important to note, however, that the majority of experimental studies indicating this disrupted executive control function in anxiety have examined task processing in the presence of simultaneous or nearly simultaneous threats and targets (i.e., variants of the emotional Stroop task). Furthermore, to the extent that the threats and targets are embedded in unified stimuli, they are necessarily task-relevant stimuli.

A relatively unexplored question in this area concerns the effect of a prior, task-irrelevant threat on subsequent target processing during high and low levels of anxiety. It may be that the effects of threat on attention differ substantially in cases when the threat's presence is effectively sustained until the time of attentional measurement (i.e., dot probe task, emotional Stroop task, visual search task, attentional cueing task) compared to cases in which the threat's effect on attention is measured after a substantial delay during which sensory processing of the threat stimulus has ceased. The question is important both practically and theoretically. First, in the real-world, stimuli often appear sequentially in non-overlapping ways such that a threat may be separated in time from a subsequent stimulus that requires a response. Second, when threat and target stimuli co-occur in time (or very nearly so), one cannot adequately disentangle the influence of the concrete threat stimulus itself (i.e., sensory processing of a currently visible threat) from the influence of its abstracted affective significance (i.e., evaluation of the negative value of a threat), which manifests for some period of time even in the absence of the original visual perception. In the bumblebee scenario, there are two relevant questions arising from this gap in the literature. First, would the threatening insect facilitate or hinder executive attention moments after its disappearance? Second, would the presence or absence of an aroused anxious mood further determine whether the bee's prior appearance helps or hurts one's current ability to focus on the task at hand?

A recently formulated model called Dual Competition Framework (DCF) is ideal for addressing this theoretical question because it integrates the factors of threat and state/trait anxiety with perceptual processing and executive control to account for the mechanisms underlying the effects of threat on performance (Pessoa, 2009). According to DCF, threat-related stimuli carry affective significance, which alters performance by strengthening sensory representations at the perceptual level and by prioritizing attention at the executive level. The model predicts that, although threat consistently leads to prioritized processing, the effects on executive control functions differ dramatically according to the level of threat (e.g., high/extreme, low/mild). Whereas a high-threat stimulus is expected to prioritize processing of the threat stimulus itself and therefore diminish executive resources available for subsequent task processing (i.e., "hard prioritization"), a low-threat stimulus is hypothesized to enhance processing at the location of the threat and therefore enhance task performance at that same location (i.e., "soft prioritization"). Pessoa (2009) proposes a mechanism that accounts for the way in which this predicted enhancement might occur. He suggests that low-threat emotional stimuli (e.g., fearful faces used as task-irrelevant stimuli) might aid subsequent target processing if "the spatial locus of the emotional item is privileged, possibly because items that are low in threat are somewhat ambiguous and so might attract further attention as part of additional information gathering" (p. 161). Furthermore, in line with research showing a strong association between anxiety and attentional bias to threat, DCF posits that elevated levels of anxiety should result in a greater modulation of executive control functions due to the threat's heightened affective significance. Taken together, these aspects of DCF lead to the predictions that low-level threat stimuli enhance executive attention under particular circumstances and that this executive enhancement should be especially high for people in an elevated state of anxiety for whom the affective significance of the threat is heightened.

To test the specific idea from DCF that mildly threatening stimuli aid performance by influencing the executive control of attention, one needs a direct measure of executive control function. One such measure is the conflict score from the Flanker task (Eriksen & Eriksen, 1974) that has been refined and incorporated in the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002), in which context it has been shown to have a moderate-to-high level of reliability in a meta-analytic review (MacLeod, Lawrence, McConnell, Eskes, Klein, & Shore, 2010). The conflict score is a behavioral index of the efficiency with which a person uses executive control to inhibit a dominant response. In the two present studies, therefore, we used the ANT to measure the executive control efficiency in order to test directly DCF's predictions.

The findings are mixed regarding the threat-related modulation of executive control efficiency in a context of anxious mood. In one study, the presentation of low-threat stimuli (i.e., fearful faces) relative to neutral stimuli (i.e., neutral faces) impaired subsequent executive control efficiency for people with low levels of a naturally occurring state anxiety but not for people with high levels of anxiety (Dennis, Chen, & McCandliss, 2008). These findings are consistent with DCF since the high-anxious group showed greater executive efficiency following threat than the low-anxious group (unpublished comparison), but the findings are inconsistent with the model in that neither group showed facilitated executive efficiency for trials following threat-related versus neutral stimuli. Similarly, a second study found that executive control efficiency following presentation of task-irrelevant fear-evoking stimuli (e.g., pictures of sharks) but not neutral stimuli (e.g., pictures of fish) was correlated with high levels of naturally occurring state anxiety (Finucane & Power, 2010). These results support DCF as well because the participants' state anxiety level varied systematically with their executive control function following threatening images but not following nonthreatening stimuli. However, because naturally occurring state anxiety might covary systematically with other unmeasured/unknown factors (e.g., arousal, intelligence, personality traits), it is possible that a third variable might explain the effects that were observed in these two studies. Experimental manipulation of state anxiety has the advantage of controlling for such potentially confounding variables.

In a related vein, a shared limitation of existing studies is their focus on one, unpleasant aroused mood state—namely, anxiety. It may be that task-irrelevant threat affects subsequent executive control efficiency during anxious mood states because anxiety represents a state of heightened arousal. In that case, any aroused state, even one that is pleasant rather than unpleasant, might similarly influence executive control efficiency. Indeed, there is some evidence that a state of happiness, an arousing, positively-valenced mood, impairs performance efficiency on tasks requiring executive attention such as the Flanker task (Rowe, Hirsh, & Anderson, 2007) and the alternating Stroop task (Phillips, Bull, Adams, & Fraser, 2002) compared to a neutral state (but see Finucane, Whiteman, & Power, 2009). To our knowledge, only one study has directly compared effects of experimentally-induced anxious and positive (“nonanxious”) moods on executive control efficiency (Pacheco-Unguetti et al., 2010) and, in that study, there was no effect of induced mood state on this measure. Importantly, these investigators did not evaluate the effect of task-irrelevant threat.

The primary goal of Study 1 was to determine whether low-level threat stimuli would affect subsequent executive control efficiency in the context of induced states of anxiety and happiness in a manner consistent with DCF. Given that threat is perceived more readily in ambiguous scenarios during an anxious compared to a happy state (Barazzone & Davey, 2009), there is reason to believe that the mood-related augmentation of threat’s affective significance is greater for an anxious mood state relative to an equally arousing but pleasant mood state. Therefore we included a happy condition to serve as a control with respect to the critical anxious condition. In order to bypass the limitations of examining naturally occurring state anxiety, we experimentally manipulated mood state, randomly assigning participants to either an anxious or happy mood group. Consistent with the research on optimizing mood induction procedures (for a review, see Gilet, 2008), we used a novel, multimodal mood induction procedure that incorporated narrative text, mood-congruent music, emotional images, and imagined self-involvement. Our goal was to maximize the effectiveness of the mood manipulations (and thus their potential to influence executive control efficiency) but to minimize many of the limitations that are inherent to single-modality procedures.

In Study 1, participants completed two mood induction procedures in counterbalanced order, one arousing (anxious or happy) mood and one nonaroused (neutral) mood. To be certain that our novel mood induction procedures were effective, we measured self-reported affect and facial electromyography (EMG) over the *corrugator supercilii* muscle region, which is active when frowning (Cacioppo, Martzke, Petty, & Tassinary, 1988). Following each mood induction participants completed a modified version of the Attention Network Test (ANT) to assess executive control efficiency and, as a test of specificity, alerting efficiency. In our variant of the ANT, each trial was preceded by a briefly presented, task-irrelevant threat-related (fearful face) or non-threat-related (neutral face) stimulus.

Based on the literature reviewed above and the predictions of DCF, we tested two competing predictions for Study 1. One possibility is that, for all participants in an aroused mood (anxious or happy), the presentation of a fearful face relative to a neutral face would increase executive efficiency on a subsequent task occurring at the same spatial location. If the effect of an anxious mood state is explained by arousal, then a similar effect should be observed during a happy mood state. In contrast, a second possibility is that the facilitative effect of threat would be greater for people in an aroused anxious mood than for those in an aroused happy mood with the rationale that the mood manipulation should augment the affective significance of threat. Given the well-established link between anxiety and threat, one might expect that this mood-related augmentation should not depend simply on the arousal level of the moods but rather would exist only for the anxious mood state.

Study 1

Method

Participants.

Sixty-one undergraduate students from Tufts University (35 female; M_{age} = 20.10 years, SD_{age} = 1.76 years) participated for course credit or monetary compensation. Participants were 67.2% Caucasian, 19.7% Asian or Asian American, 8.2% Black or African American, and 4.9% declined to provide this information. Of the total sample, 9.8% endorsed being of Hispanic origin. All study procedures were approved by the Institutional Review Board at Tufts

University, and all participants provided informed consent prior to participating in the study.

Materials.

Mood induction. Mood was manipulated on a between-subjects basis. Participants were randomly assigned to one of two groups. Thirty participants completed an anxious mood induction, and thirty-one participants completed an equally-arousing happy mood induction. All participants also completed a nonaroused neutral mood induction, which served as a basis for comparison in mood manipulation checks. In the anxious mood induction, participants imagined being a passenger in a drunk-driving car accident and helping injured people in its aftermath. In the happy mood induction, participants imagined walking with a friend on a warm day in early summer amid picnicking families, playing children, and running dogs. In the neutral mood induction, participants imagined a sequence of mundane activities such as shopping for groceries, doing small tasks at home, and calling a family member.

Mood-congruent instrumental music, selected based on pilot testing of effects on self-reported affect, was played during each scene (selections available upon request from the corresponding author). In addition, pictures that accompanied the narrative were shown. Pictures with established positive, negative, and neutral valence were selected from the International Affective Picture Series[1] (Lang, Bradley, & Cuthbert, 2005); supplementary pictures were obtained from Shutterstock (http://www.shutterstock.com) and Wellcome Images (http://images.wellcome.ac.uk).

The mood induction procedure was programmed in E-Prime 1.2.1 software (Psychology Software Tools, Sharpsburg, PA). Each mood induction contained twelve pictures with associated storyline text and lasted four minutes. Each picture was presented initially with text at the top of the screen for twelve seconds and then without text for eight seconds. Participants were instructed to read the text first and then view the image while imagining that the depicted events were occurring in their real lives. The order of the neutral and anxious (or happy) mood inductions was counterbalanced across participants.

Mood measures. Participants completed a computerized version of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) before and after each mood induction. Participants reported how much they felt each of 20 adjectives "right now, at this very moment" on a 5-point scale from 1, *very slightly or not at all*, to 5, *extremely*. We computed a positive affect (PA) score by summing scores for *enthusiastic*, *proud*, *inspired*, and *determined*, and a negative affect (NA) score by summing scores for *distressed*, *upset*, *guilty*, *scared*, *hostile*, *irritable*, *ashamed*, *nervous*, *jittery*, and *afraid*. We also computed an arousal score by summing scores for *interested*, *excited*, *alert*, *attentive*, *strong*, and *active*. These latter six items are typically included as items on the PA scale (Watson et al., 1988), but Patrick and Lavoro (1997) demonstrated that they index arousal instead, as evidenced by the fact that both positive *and* negative pictures elicit higher ratings on these items relative to neutral pictures.

In addition, for a more objective assessment of emotional valence, we measured electromyography (EMG) activity over the *corrugator supercilii* muscle region. Relative to a neutral baseline, greater *corrugator* activity is observed for unpleasant emotions while lower *corrugator* activity is observed for pleasant emotions (Larsen, Norris, & Cacioppo (2003). *Corrugator* EMG activity was measured using shielded 4-mm Ag/AgCl electrodes. Following site preparation with an electrode preparation pad, a pair of sensors was attached directly above the eyebrow and a ground electrode was attached to the middle of the forehead consistent with guidelines by Fridlund and Cacioppo (1986).

EMG data were collected using MP 150 hardware and AcqKnowledge 3.8.2 software (Biopac, Goleta, CA). Data were sampled at 1000 Hz and filtered from 5 Hz to 3 kHz (60-Hz notch filter on) online. Offline, data were resampled to 400 Hz, rectified and smoothed with a 16-Hz low-pass filter, decimated to 4 Hz, and smoothed with a 1-s prior moving average filter. These steps were completed with Matlab software (Mathworks, Natick, MA) using ANSLAB routines (Wilhelm & Peyk, 2005). *Corrugator* activity was averaged across each mood induction condition and log-transformed to achieve normality.

Attention Network Test. After each of the two mood inductions, participants completed a modified version of the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) similar to that used by Dennis and colleagues (2008). The modified ANT allowed us to measure the efficiency and accuracy of executive control and alerting attention networks. The task of participants was to respond via mouse buttons with the thumbs of both hands to indicate whether a centrally located arrow (i.e., target) pointed to the left or right. Each trial lasted for 4,050 ms (see Figure 1 for trial structure). Note that we excluded trials from the original ANT that measure the efficiency of the orienting network. We reasoned that the effects of induced mood could be time-limited. We thus sought to minimize the time it would take to complete the attentional task while at the same time maximizing our ability to test hypothesized effects on executive control efficiency.

To assess executive control, the target was surrounded by four stimuli (i.e., flankers), two each on the left and the right. There were three varieties of flankers that differed across trial types: congruent (i.e., arrows pointing in the same direction as the target), incongruent (i.e., arrows pointing in the opposite direction of the target), and neutral (i.e., horizontal lines with no directional information). Greater conflict is present on trials in which the flanking arrows are incongruent with the target arrow relative to trials in which the flanking arrows are congruent or neutral. As is standard practice with the ANT (Fan et al., 2002), conflict scores for the aroused mood conditions were generated by subtracting congruent-flanker performance from incongruent-flanker performance. Therefore the conflict scores are an index of top-down attentional dysfunction. They are inversely related to the executive control of attention necessary for ignoring distracting information and resolving response conflict through cognitive inhibition (Miyake et al., 2000).

To assess alerting, on each trial the target was preceded by a double warning cue (i.e., asterisks above and below the fixation cross) or there was no cue preceding the target (i.e, fixation cross only). Greater alerting is present on trials in which the target is preceded by the double asterisks relative to trials in which there is no cue. Again, following standard practice with the ANT (Fan et al., 2002), alerting scores were generated by subtracting double-cue performance from no-cue performance. The alerting scores are an index of stimulus-driven attentional sensitivity associated with the maintenance of an alert state.

To examine the influence of task-irrelevant threat on subsequent processing efficiency and accuracy of the executive control and alerting attentional networks, each trial began with the presentation of one of two types of faces, fearful (i.e., threat-related) or neutral. In order to ensure that we were investigating the effects of prior threat on subsequent attention, we introduced a substantial delay between the offset of the face and the onset of the target that varied randomly between 900 ms and 1800 ms (see Figure 1). Faces from 12 actors were selected from the NimStim collection (Tottenham, Borscheid, Ellertsen, Marcus, & Nelson, 2002). Greater task-irrelevant threat is present on trials preceded by fearful faces than by neutral faces. Conflict and alerting scores were calculated separately for fearful and neutral face trials.

Only correct trials were included when examining reaction times.

Procedure.

Participants completed the tasks in the following sequence: baseline PANAS, mood induction 1, PANAS, ANT 1, PANAS, mood induction 2, PANAS, ANT 2, PANAS. Each ANT began with a practice block of 12 trials that were accompanied by response time and accuracy feedback. Then 192 no-feedback trials were presented in four experimental blocks of 48 trials each. Participants were instructed to take a break between each block. At the end of the session, participants provided demographic information and were debriefed about the nature of the study.

Results

Data retention and analysis.

Within each reaction time measure (conflict score and alerting score) the estimated Mahalanobis distance across variables was computed for each participant. One participant was excluded from the analysis of conflict scores and two participants were excluded from the analysis of alerting scores on the basis of these tests ($p < .001$). Note that the factors of Arousal and Mood Group are never entered together in the same analysis because the levels of Mood Group (anxious, happy) are not fully crossed with the levels of Arousal (aroused mood, nonaroused mood) such that the manipulation of anxiety or happiness pertains exclusively to the aroused level of this latter factor. For the nonaroused level of the factor participants in both mood groups completed an identical neutral mood induction as a basis for comparison. Therefore separate statistical tests will be conducted examining the levels of arousal within each group.

Manipulation checks.

To determine whether the mood manipulations achieved a positively-valenced mood state in the happy group and a negatively-valenced mood state in the anxious group, repeated-measures General Linear Model analyses (GLMs) were performed within each group with factors of Arousal (aroused mood, nonaroused mood) x Study Period (pre-induction, post-induction) on self-reported PA and NA from the PANAS. Paired samples t-tests were also performed within each group to compare the aroused and nonaroused conditions on mean *corrugator* activity, a second index of mood valence.

In the happy group, a significant interaction of Arousal x Study Period emerged for PA scores, $F(1, 30) = 18.61$, $p < .001$, $\eta_p^2 = .383$, but not for NA scores, $F(1, 30) = 1.10$, $p = .303$, $\eta_p^2 = .035$. As shown in Table 1, Fisher's LSD tests showed that post-induction PA was higher for the aroused (happy) than the nonaroused (neutral) condition ($p < .001$), but there was no such difference in pre-induction PA ($p = .291$). In addition, mean *corrugator* activity was significantly lower (i.e., less "frowning") during the aroused (happy $M = 0.60$, $SD = 0.33$) than during the nonaroused (neutral $M = 0.74$, $SD = 0.35$) condition, $t(30) = -2.42$, $p = .022$. Collectively, these PA and *corrugator* results indicate that the happy induction elicited the intended positive mood state.

In the anxious group, there was a significant interaction of Arousal x Study Period for NA scores, $F(1, 29) = 29.26$, $p < .001$, $\eta_p^2 = .502$, but not for PA scores, $F(1,29) = 1.82$, $p = .187$, $\eta_p^2 = .059$. As shown in Table 1, post-induction NA was higher for the aroused (anxious) than the nonaroused (neutral) condition ($p < .001$), but there was no such difference in pre-induction NA ($p = .562$). In addition, mean *corrugator* activity was significantly greater (i.e., more "frowning") during the aroused (anxious M = 0.69, SD = 0.34) than during the nonaroused (neutral M = 0.60, SD = 0.32) condition, $t(29) = 2.25$, $p = .032$. Collectively, these NA and *corrugator* results indicate that the anxious mood induction elicited the intended negative mood state.

Next, to determine whether the mood manipulations achieved a state of arousal in both groups, repeated-measures GLMs were performed within each group with factors of Arousal (aroused mood, nonaroused mood) x Study Period (pre-induction, post-induction) on self-reported arousal from the PANAS. As expected, there were significant Arousal X Study Period interactions for the happy, $F(1, 30) = 7.34$, $p = .011$, $\eta_p^2 = .197$, and anxious, $F(1, 29) = 15.78$, $p < .001$, $\eta_p^2 = .352$, groups. As shown in Table 1, post-induction arousal was higher for the aroused (anxious or happy) than the nonaroused (neutral) condition in both groups (both *p*s < .001), but there was no such difference in pre-induction arousal in either the happy ($p = .954$) or anxious groups ($p = .890$).

Finally, to determine whether the anxious and happy mood states were equally arousing, we directly compared arousal scores for the happy and anxious groups using independent samples t-tests. The post-induction arousal score was higher in the anxious group than in the happy group, $t(59) = 2.11$, $p = .039$. However, the pre-induction arousal score was also marginally higher in the anxious group than in the happy group, $t(59) = 1.80$, $p = .077$. Taking this pre-induction difference into account (i.e., by subtracting pre-induction levels of arousal from post-induction levels), the group difference was no longer significant, $t(59) = .086$, $p = .932$. Collectively, these arousal results suggest that the happy and anxious mood inductions both elicited the intended, aroused state, and that this was achieved to an equivalent degree in the two groups.

Overall analyses of executive control and alerting efficiency.

Reaction time data for the aroused mood conditions were first analyzed in a GLM with factors of Time (early, late; 96 trials each), Threat (fearful face, neutral face), Flanker (congruent, incongruent, neutral), Cue (double cue, no cue), and Mood Group (happy, anxious). As expected, there were large, significant main effects of Flanker, $F(1, 58) = 303.58$, $p < .001$, $\eta_p^2 = .913$, and Cue, $F(1, 59) = 76.08$, $p < .001$, $\eta_p^2 = .563$. See Table 2 for descriptive statistics on reaction times. Using Fisher's LSD tests, reaction times were slower for the incongruent-flanker than the congruent-flanker condition, $p < .001$, and reaction times were faster for the double-cue than the no-cue condition, $p < .001$. These results, which are standard for the ANT, validated the use of the conflict (incongruent – congruent) and alerting (no cue – double cue) scores, respectively, in our analyses below.

Executive control.

Effects of mood. Separate paired t-tests were conducted on conflict scores for the two mood groups comparing the aroused (i.e., anxious or happy) and nonaroused (i.e., neutral) conditions. For the anxious group, reaction time conflict scores did not differ between the aroused (anxious $M = 101.34$, $SD = 33.86$) and nonaroused (neutral $M = 104.83$, $SD = 38.34$) conditions, $t(28) = -0.56$, $p = .577$. Similarly, for the happy group, conflict scores did not differ between the aroused (happy $M = 102.01$, $SD = 32.12$) and nonaroused (neutral $M = 99.55$, $SD = 29.16$) conditions, $t(30) = 0.61$, $p = .545$. These results show that aroused mood alone was not sufficient to influence executive control efficiency for either group.

Interactions with threat. GLMs were conducted for the aroused mood conditions to assess the effects of Time (early trials (blocks 1-2), later trials (blocks 3-4)), Threat (fearful face, neutral face) and Mood Group (happy, anxious) on conflict scores for RT. There were no main effects of Threat, $F(1, 58) = 2.75$, $p = .103$, $\eta_p^2 = .045$, or Mood Group, $F(1, 58) = 0.01$, $p = .938$, $\eta_p^2 < .001$. There was a significant interaction of Time x Threat, $F(1, 58) = 6.07$, $p = .017$, $\eta_p^2 = .095$. Fisher's LSD tests demonstrated that for early trials occurring close to the end of the mood induction, conflict scores were significantly lower for the fearful (*M* = 88.33, *SD* = 37.03) relative to the neutral (*M* = 107.09, *SD* = 43.94) condition (*p* = .002). For later trials, however, conflict scores did not differ for the fearful (*M* = 106.60, *SD* = 42.56) relative to the neutral (*M* = 104.70, *SD* = 53.03) condition (*p* = .723). Critically, there was a significant Threat x Mood Group interaction, $F(1, 58) = 4.37$, $p = .041$, $\eta_p^2 = .070$. Fisher's LSD tests showed that in the anxious group, conflict scores were significantly diminished for trials preceded by fearful faces relative to neutral faces, $p = .012$, but no such difference was observed in the happy group, $p = .757$ (see Figure 2a). There was no significant interaction of Time x Threat x Mood Group, $F(1, 58) < 0.01$, $p = .957$, $\eta_p^2 < .001$.

To examine the nature of the conflict effect in the anxious group, a follow-up GLM for only these participants was conducted with Threat and Flanker (incongruent, neutral, congruent) as factors. An interaction of Threat x Flanker, $F(2, 27) = 7.46$, $p = .003$, $\eta_p^2 = .356$, indicated that the threat-related conflict effect described above was explained by faster RT for incongruent-flanker trials preceded by fearful faces (*M* = 597.71, *SD* = 61.69) versus neutral faces (*M* = 608.67, *SD* = 75.74), $p = .023$. In addition, RT were slower for congruent-flanker trials preceded by fearful faces (*M* = 505.90, *SD* = 55.22) versus neutral faces (*M* = 497.79, *SD* = 58.64), but this was a marginally significant effect, $p = .072$. The anxious group's speeding of responses in the fearful-neutral comparison within the incongruent condition suggests that the effect of manipulated anxiety on executive control efficiency primarily involves a threat-related decrease in stimulus interference (i.e., the disruption in attention due to the incongruent arrows' conflicting information).

A GLM was conducted on conflict scores for accuracy with factors of Time, Threat, and Mood Group. There was a marginally significant effect of Threat, $F(1, 56) = 3.48$, $p = .067$, η_p^2

= .059,such that conflict scores for accuracy were slightly lower for fearful-face trials (*M* = 0.05, *SD* = 0.05) than neutral face trials (*M* = 0.07, *SD* = 0.08), but not significantly so. Note that a positive conflict score indicates greater accuracy for incongruent compared to congruent trials (i.e., an increase in accuracy associated with incongruent-flanker conflict), and thus a lower score for fearful compared to neutral trials indicates a threat-related reduction of accuracy associated with conflict. Considered together with the threat-related facilitation of executive control *efficiency* for participants experiencing an anxious mood, we conclude that this threat-related reduction in *accuracy* may reflect a speed-accuracy trade-off such that some participants responded faster but less accurately during conflict when the task-irrelevant distracters were threatening versus nonthreatening. Apart from this nearly significant main effect, there were no other main effects and no interactions, all other *F*s $\leq$ 0.508, all *p*s > .479. Although there was a nearly significant threat-related reduction in accuracy associated with conflict across all participants, the threat-related facilitation of executive control efficiency in the anxious group was not accompanied by a significant and parallel change in performance.

Alerting.

Effects of mood. Separate paired t-tests were conducted on alerting scores for the two mood groups comparing the aroused (i.e., anxious or happy) and nonaroused (i.e., neutral) conditions. For the anxious group, reaction time alerting scores did not differ between the aroused (anxious *M* = 18.66, *SD* = 21.82) and nonaroused (neutral *M* = 23.11, *SD* = 18.80) conditions, $t(28) = -1.03$, $p = .310$. Similarly, for the happy group, alerting scores did not differ between the aroused (happy *M* = 25.93, *SD* = 18.68) and nonaroused (neutral *M* = 28.17, *SD* = 20.60) conditions, $t(29) = -0.65$, $p = .521$. These results show that aroused mood alone was not sufficient to influence alerting efficiency for either group.

Interactions with threat. GLMs were conducted for the aroused mood conditions to assess the effects of Time (early trials, later trials), Threat (fearful face, neutral face) and Mood Group (happy, anxious) on alerting scores for RT. There were no main effects of Threat, $F(1, 57) = 0.07$, $p = .797$, $\eta_p^2 = .001$, or Mood Group, $F(1, 57) = 1.89$, $p = .174$, $\eta_p^2 = .032$, and no Threat x Mood Group interaction, $F(1, 57) = 0.01$, $p = .910$, $\eta_p^2 < .001$ (see Figure 2b). The main effect of Time was the only significant finding in this analysis, $F(1, 57) = 10.31$, $p = .002$, $\eta_p^2 = .153$, indicating that alerting efficiency was higher overall in the later relative to the earlier trials. Thus, there was no threat-related facilitation of alerting efficiency in either group, which suggests specificity in the threat-related facilitation of executive control efficiency in the anxious group.

A comparable GLM was conducted on alerting scores for accuracy with factors of Time, Threat, and Mood Group. There were no significant effects involving Threat. There was, however, a marginally significant interaction of Time x Mood Group, $F(1, 55) = 3.03$, $p = .087$, $\eta_p^2 = .052$, such that participants in the happy mood demonstrated alerting scores for accuracy that were lower for early ($M = -0.01$, $SD = 0.05$) relative to later ($M = 0.01$, $SD = 0.05$) trials ($p = .037$), but participants in the anxious mood demonstrated no such difference between early ($M = 0.00$, $SD = 0.06$) and later ($M = 0.00$, $SD = 0.05$) trials ($p = .735$). To the extent that double-cue versus no-cue trials are associated with an accuracy gain due to effective alerting attention, the alerting accuracy scores decrease as this gain in accuracy lessens. Therefore activity of the alerting network is inversely related to these scores. The marginally significant interaction indicates, for the happy group but not the anxious group, a possible decrease over time in alerting attention as measured by accurate performance. Other than this nearly significant interaction, there were no main effects or interactions, all other Fs ≤ 2.83, all ps $\geq .128$. Critically, there were no threat-related effects on alerting accuracy scores.

Discussion

Using a novel, multimodal mood induction procedure, we found that threat-related stimuli facilitated subsequent executive control efficiency during an induced state of anxious mood. There was no effect of anxious mood on subsequent alerting efficiency, which suggests that induced state anxiety had a specific effect on executive control. Despite a notable trend toward threat-related reduction in accuracy associated with conflict across all participants, there were no significant threat-related or anxiety-related effects on accuracy, thus the above threat-related efficiency effect during anxious mood does not have a corresponding effect on actual performance. Finally, threat-related facilitation of executive control efficiency occurred only during the anxious mood state and not during the equally arousing, happy mood state, which suggests that the effect of threat on executive control efficiency during state anxiety cannot be explained by arousal. These findings indicate that state anxiety may potentiate the facilitative effect of a briefly appearing threat on subsequent executive control efficiency measured after a substantial delay.

An important omission in Study 1 is the measurement of the inevitable natural variability in participants' level of anxious disposition. Given that threat is known to have an inhibiting effect on executive control among people with elevated trait anxiety (Derakshan & Eysenck, 2009; Derryberry & Reed, 2002; Eysenck, Derakshan, Santos, & Calvo, 2007; Wood, Mathews, & Dalgleish, 2001), an important question is whether the threat-related facilitation of executive control efficiency observed during state anxiety in Study 1 would be absent or perhaps even reversed in a parallel analysis of high versus low trait anxiety in a follow-up study. If trait anxiety establishes a context of disrupted executive control efficiency in a context of threat, then one might expect that threat would not lead to a facilitation of executive control efficiency for high trait-anxious people; indeed, they may demonstrate the opposite pattern, impaired executive control efficiency following threat. However, if state anxiety plays a dominant role in modulating executive function following threat, then a facilitation effect should emerge during anxious mood even in high trait-anxious people. The potential for a modulating effect of trait anxiety on executive function following a threat stimulus is therefore an open question.

Another important limitation of Study 1 is the lack of a baseline measure of attention efficiency scores for executive control and alerting. Although unlikely, it is possible that the observed effect of threat on executive efficiency might have existed in these participants prior to any experimental manipulation of mood. A second question therefore concerns the degree to which the facilitative effect of Study 1 can be attributed to state anxiety.

A third limitation of the present design is that, although the anxious and happy moods were purposefully matched for arousal, the mood states might have differed in other undesirable ways. Happiness might be uniquely associated with potentially confounding influences on the dependent measure, such as alterations in self-focused attention (Green, Sedikes, Saltzberg, Wood, & Forzano, 2003) or a generally reduced cognitive capacity (Mackie & Worth, 1989). Therefore, it is important to use a nonanxious (i.e., neutral) mood as the control condition in order to address the question of anxiety's modulation of the attentional effects of threat in a well controlled manner.

A fourth limitation is that, despite the apparent success of the mood manipulations, we could not ultimately confirm that we manipulated anxiety specifically. Our measures were only sensitive to valence and arousal. It is important to redress this limitation by verifying that the anxious mood manipulation predominantly manipulates anxiety and not all aspects of negative emotion.

We conducted a follow-up study to address these four points.

Study 2

According to DCF, state and trait anxiety should each contribute to modulations in executive control functions due to their purported amplification of threat's affective significance. The model does not specify, however, how state and trait anxiety might have independent or interacting modulating effects on threat's facilitation of executive control. Thus, in Study 2 we measured trait anxiety in addition to manipulating state anxiety. One possibility is that state and trait anxiety may have interactive effects on the processing efficiency of attentional networks. Consistent with this idea, Egloff and Hock (2001) demonstrated that, among people with high trait anxiety, higher state anxiety was correlated with poorer executive control efficiency (i.e., interference on an emotional Stroop Task). Among people with low trait anxiety, however, higher state anxiety was correlated with better executive control performance.

In Study 2 participants were randomly assigned to an anxious mood or a neutral mood condition. As in Study 1, facial EMG was recorded from the *corrugator supercilii* muscle to measure emotional expressiveness during the mood inductions. In order to assess mood-related changes in attention efficiency, participants completed a short, pre-mood-induction, baseline ANT and a short, post-mood-induction, experimental ANT. As in Study 1, all ANT trials were preceded by briefly presented task-irrelevant threatening or nonthreatening stimuli (fearful and neutral faces, respectively). Before and after every mood induction and ANT, a self-report measure was administered in order to assess qualitatively whether anxiety was successfully induced.

We had two hypotheses for Study 2. First, consistent with Study 1, a facilitative effect of threat on executive control efficiency should occur for people in an anxious mood but not for those in a neutral mood. Second, consistent with the literature showing threat-related disruptions of executive control in elevated trait anxiety, the facilitative effect of threat should be present only for participants with low but not high trait anxiety.

Method

Participants.

One hundred twenty-one undergraduate students from Tufts University (69 female; M_{age} = 20.55 years, SD_{age} = 4.45 years) participated for course credit or monetary compensation. Participants were 71.1% Caucasian, 20.7% Asian or Asian American, 4.1% Black or African American, 0.8% American Indian or Alaska Native, and 3.3% declined to provide this information. Of the total sample, 14.9% endorsed being of Hispanic origin. All study procedures were approved by the Institutional Review Board at Tufts University, and all participants provided informed consent prior to participating in the study.

Materials.

Mood induction. Participants were randomly assigned to one of two groups. Sixty participants completed an anxious mood induction, and sixty-one participants completed a neutral mood induction. The anxious and neutral mood induction conditions were presented using E-Prime 1.2.1 software and consisted of identical narrative content, images, musical selections, display timings, and on-screen instructions as in Study 1.

Mood measures. Participants completed a computerized version of the State-Trait Inventory of Cognitive and Somatic Anxiety (STICSA; Grös, Antony, Simms, & McCabe, 2007) before and after each task of the experiment. Participants reported how much they felt each of 20 descriptions “right now, at this very moment” on a 4-point scale from 1, *not at all*, to 4, *very* *much so*. We computed a somatic anxiety score and a cognitive anxiety score for each time point in the study.

Participants also reported how they felt using a newly developed Mood Rating Scale (MRS) before and after each task of the experiment consisting of adjective triplets that specifically capture anxiety (e.g., *anxious, worried, fearful*) and general arousal (e.g., *active, alert, keyed up*) (see Nitschke, Heller, Palmieri, & Miller, 1999). The MRS also includes items corresponding to other negative emotional states as well as positive emotional states so as not to emphasize negative mood categories (and anxiety specifically). This approach is implemented to reduce demand characteristics. In addition to the two critical sets of triplets above, the other nine triplets in this scale are: *lonely, distant, isolated*; *self-confident, capable, worthwhile*; *sad, depressed, down*; *rejected, put down, hurt*; *happy, pleased, contented*; *judged, scrutinized, evaluated*; *angry, irritated, provoked*; *affectionate, loving, connected to others*; *embarrassed, humiliated, ashamed*. Participants reported how strongly they felt each emotional dimension “right now, at this very moment” on a 4-point scale from 1, *not at all*, to 6, *very much*.

We measured electromyography (EMG) activity over the *corrugator supercilii* muscle region using shielded 4-mm Ag/AgCl electrodes with identical site preparation procedure and placement locations as in Study 1. Also unchanged for this measure were the hardware, software, sampling rate, and online filtering procedures. *Corrugator* activity was averaged across each mood induction condition and log-transformed to achieve normality.

Attention Network Test. Before and after the mood induction, participants completed a briefer version of the Attention Network Test administered in Study 1 (ANT; Fan et al., 2002) to assess simultaneously the efficiency and accuracy of executive control and alerting attention networks. Since the threat-related effects were strongest in the first half of the trials during

Study 1, the overall length of the ANT was shortened substantially in Study 2 to focus on attentional effects occurring close to the end of the mood induction. The shortened task duration decreased the likelihood that the attention task would outlast the duration of the induced mood states. Based on tests of internal consistency reliability of the ANT data from Study 1, we determined that the task length could be halved while still maintaining adequate reliability (Cronbach's alpha $\geq$ .70 for all cells of the study design). Again conflict scores for the aroused mood conditions were generated by subtracting congruent-flanker performance from incongruent-flanker performance, and alerting scores were generated by subtracting double-cue performance from no-cue performance. Critically, the trials were again preceded by task-irrelevant stimuli that provided no predictive indication of the type of trial that would follow. As in Study 1, half of the trials were preceded by low-level threatening stimuli (i.e., fearful faces) and the other half by nonthreatening stimuli (i.e., neutral faces). The identities of these distracter faces from the NimStim collection and the timing specifications of all trial events were identical to those used in Study 1. As before, only correct trials were included when examining reaction times.

Procedure.

Participants completed the tasks in the following sequence: dot probe task (for the sake of brevity, the data are not presented in this manuscript), demographic questionnaires and trait questionnaires, STICSA/MRS 1, baseline ANT, STICSA/MRS 2, mood induction (ANX or NEU), STICSA/MRS 3, experimental ANT, STICSA/MRS 4. As in Study 1, each ANT began with a practice block of 12 trials with response time and accuracy feedback. In the shortened ANT 96 no-feedback trials were presented in two experimental blocks of 48 trials each. Participants were instructed to take a break between each block. At the end of the session, participants were debriefed about the nature of the study.

Results

Trait anxiety groups.

The total scores for the STAIT-Trait scale covered a wide spectrum (*M* = 40.79, *SD* = 10.21, median = 39, min = 21, max = 65). Participants with scores less than or equal to the median were included in the low trait anxiety group (n = 62; *M* = 32.50, *SD* = 4.79, range: 21 - 39), and participants with scores greater than the median were included in the high trait anxiety group (n = 59; *M* = 49.39, *SD* = 6.38, range: 40 - 65).

Data retention and analysis.

Within each reaction time measure (conflict score and alerting score) the estimated Mahalanobis distance across variables was computed for each participant. Three participants were excluded from the analysis of conflict scores and four participants were excluded from the analysis of alerting scores on the basis of these tests ($p < .001$). Additionally, two participants were excluded because they represented age outliers within their respective groups (i.e., greater than 35 years old). Finally, one participant was automatically excluded from the analysis of conflict scores due to missing data, which resulted from a 100% proportion of incorrect responses for multiple trial types. One hundred fifteen participants were included in the manipulation check analyses and in the preliminary analyses regarding executive control (34 anxious mood, low trait anxiety; 24 anxious mood, high trait anxiety; 26 neutral mood, low trait anxiety; 31 neutral mood, high trait anxiety). Note that, unlike in Study 1, a factor of Time (i.e., early versus late trials) is not included in the analyses because each ANT consists only of blocks 1 and 2, which are equivalent to the early trials for which the facilitation effect was discovered in Study 1. In the GLMs below we report results for multivariate statistics.

Manipulation checks.

To determine whether the mood manipulations were successful, repeated-measures GLMs were performed with factors of Mood Group (Anxious, Neutral) x Study Period (pre-induction, post-induction) on self-reported somatic and cognitive anxiety from the STICSA and on the anxiety-relevant self-reported items from the MRS (see Table 3 for descriptive statistics). An independent samples t-test was also performed to compare the mean *corrugator* activity of the two groups, an index of mood valence that is less subject to demand characteristics.

There was a significant main effect of Study Period on STICSA somatic anxiety average scores, $F(1, 114) = 16.24$, $p < .001$, $\eta_p^2 = .125$, and also a main effect of Mood Group, $F(1, 114) = 1.67$, $p < .001$, $\eta_p^2 = .014$. These main effects were qualified by a significant interaction of Study Period x Mood Group, $F(1, 114) = 35.90$, $p < .001$, $\eta_p^2 = .239$, which revealed that pre-induction scores were not different for the anxious ($M = 1.30$, $SD = 0.28$) relative to the neutral ($M = 1.35$, $SD = 0.35$) group ($p = .369$), but post-induction scores were greater for the anxious ($M = 1.52$, $SD = 0.42$) relative to the neutral ($M = 1.31$, $SD = 0.34$) group ($p = .003$). There were no significant effects or interactions for STICSA cognitive anxiety average scores, all Fs ≤ 1.67, all ps $> .100$.

The parallel analysis on scores for the *Anxious, Worried, Fearful* triplet on the MRS showed main effects of Study Period, $F(1, 114) = 20.69$, $p < .001$, $\eta_p^2 = .154$, and Mood Group, $F(1, 114) = 6.06$, $p = .015$, $\eta_p^2 = .050$. Critically and as expected, there was also an interaction of Study Period x Mood Group, $F(1, 114) = 39.35$, $p < .001$, $\eta_p^2 = .257$, such that pre-induction scores were not different for the anxious ($M = 1.48$, $SD = 0.68$) relative to the neutral ($M = 1.74$, $SD = 1.24$) group ($p = .166$), but post-induction scores were greater for the anxious ($M = 2.67$, $SD = 1.32$) relative to the neutral ($M = 1.56$, $SD = 1.11$) group ($p < .001$).

The analysis on scores for the *Active, Alert, Keyed Up* triplet on the MRS showed no main effect of Study Period, $F(1, 114) < 0.00$, $p > .999$, $\eta_p^2 < .001$. There was a main effect of Mood Group, $F(1, 114) = 8.91$, $p = .003$, $\eta_p^2 = .072$, and, as expected, a significant interaction of Study Period x Mood Group, $F(1, 114) = 27.71$, $p < .001$, $\eta_p^2 = .196$. The follow-up tests revealed that, as above, pre-induction scores were not different for the anxious (*M* = 3.62, *SD* = 1.37) relative to the neutral (*M* = 3.45, *SD* = 1.60) group ($p = .535$), but post-induction scores were greater for the anxious (*M* = 4.22, *SD* = 1.51) relative to the neutral (*M* = 2.85, *SD* = 1.62) group ($p < .001$).

In an attempt to demonstrate a significant overall difference in *corrugator* activity between the anxious and neutral mood groups, we conducted an independent-samples t-test. Contrary to expectations, no significant difference existed, $t(114) = -0.54$, $p = .594$. Therefore, despite the evidence of the self-report measures, the mood inductions did not succeed in establishing an anxious mood characterized by greater expressive “frowning” behavior compared to a neutral mood as they did in Study 1. Given the great importance of the *corrugator* measure as an index of the mood manipulation success that is relatively free of demand characteristics, we will address this point at a later stage of the results.

Overall analyses of executive control and alerting efficiency.

In a manner consistent with Study 1, reaction time data for the post-induction ANT were first analyzed in a GLM with factors of Study Period (pre-induction, post-induction), Threat (fearful face, neutral face), Flanker (congruent, incongruent, neutral), Cue (double cue, no cue), Mood Group (anxious, neutral), and Trait Anxiety Group (low TA, high TA). As expected, there were large, significant main effects of Flanker, $F(2, 110) = 332.52$, $p < .001$, $\eta_p^2 = .858$, and Cue, $F(1, 111) = 133.36$, $p < .001$, $\eta_p^2 = .546$. See Table 4a and 4b for descriptive statistics on reaction times for the pre-induction and post-induction periods, respectively. As anticipated, in Fisher's LSD tests, reaction times were slower for the incongruent-flanker than the congruent-flanker condition, $p < .001$, and reaction times were faster for the double-cue than the no-cue condition, $p < .001$.

Analysis of executive control.

The effects of threat and anxious mood on executive attention were examined by conducting a GLM on conflict scores for RT with factors of Study Period (pre-induction, post-induction), Threat (fearful face, neutral face), Mood Group (neutral, anxious), and Trait Anxiety Group (low TA, high TA). As expected, there was a main effect of Threat, $F(1, 111) = 19.10$, $p < .001$, $\eta_p^2 = .147$, with fearful-face trials ($M = 93.88$, $SD = 47.29$) showing reduced conflict scores relative to neutral-face trials ($M = 110.62$, $SD = 51.90$). There was also a main effect of Study Period, $F(1, 111) = 16.65$, $p < .001$, $\eta_p^2 = .130$, such that conflict decreased substantially in the second iteration of the ANT for both groups. Notably, there were no significant effects involving Trait Anxiety Group. The expected interaction of Study Period x Threat x Mood Group was not present, $F(1, 111) = 0.43$, $p = .515$, $\eta_p^2 = .004$, indicating that threat's effect on executive control efficiency was not affected differently by the anxious and neutral mood induction conditions.

To test for a similar threat-related facilitation effect as observed in Study 1, we also conducted a planned GLM examining only the post-induction ANT. This GLM included factors of Threat, Mood Group, and Trait Anxiety Group. Contrary to expectations, but consistent with the nonsignificant three-way interaction described above, there was no interaction of Threat x Mood Group, $F(1, 112) = 0.05$, $p = .819$, $\eta_p^2 < .001$. Therefore, in Study 2, the participants assigned to the anxious relative to the neutral group did not show a substantially greater facilitation of executive control efficiency due to threat.

Accounting for individual differences in the effectiveness of induced mood.

Given the previously mentioned failure to demonstrate an overall difference in *corrugator* activity between the two mood groups (despite the increased power relative to Study 1), it seems likely that mood was not successfully induced in all participants included in the analyses above. We therefore applied a conservative criterion in order to identify and exclude participants for whom the independent variable of mood was not manipulated to a sufficient degree. Specifically, the degree of proportional change in *corrugator* activity from the beginning to the end of the mood inductions was assessed. This measure was computed for each participant by subtracting the average activity during the five-second period at the start of the induction from the average activity during the five-second period at the end of the induction and dividing this difference by the baseline corrugator level at the start of the induction. Validating the use of this measure as a criterion of mood induction success, correlation analyses revealed that it was positively associated with change scores from pre- to post-induction for *anxious, worried, fearful*, $r(114) = .20$, $p = .035$, and *active, alert, keyed up*, $r(114) = .23$, $p = .015$. Furthermore, the *corrugator* change measure is a good index of elicited anxiety specifically because it was uncorrelated with the following other negative mood triplets: *lonely, distant, isolated*; *sad, depressed, down*; *rejected, put down, hurt; judged, scrutinized, evaluated; embarrassed, humiliated, ashamed; angry, irritated, provoked* (all p's $\geq .110$).

Participants in the anxious mood group displaying at least a 50% proportional increase in *corrugator* activity were included in the principal analyses, and participants in the neutral mood group with less than a 50% proportional increase in *corrugator* activity were included in these analyses. Seventy participants were included in the final analyses (17 anxious mood, low trait anxiety; 11 anxious mood, high trait anxiety; 19 neutral mood, low trait anxiety; 23 neutral mood, high trait anxiety).

In order to ensure that the mood groups did not differ in level of trait anxiety, an independent-samples t-test was conducted comparing STAI average scores for participants assigned to the anxious and neutral mood conditions. There was no significant difference in level of trait anxiety for participants assigned to the anxious (M = 39.60, SD = 2.00) and neutral (M = 41.8, SD = 1.60) mood conditions, $t(69) = 0.839$, $p = .404$.

The total scores for the STAIT-Trait scale were reassessed for the final subset of eligible participants. The descriptive statistics for these scores were very similar in this subset of participants as in the entire sample (see above): low trait anxiety group (n = 36; M = 32.56, SD = 4.78, range: 22-39); high trait anxiety group (n = 34; M = 49.65, SD = 6.46, range: 40-65).

Analysis of executive control following successful mood induction.

The effects of threat and anxious mood on executive attention were re-examined by conducting a GLM on conflict scores for RT with factors of Study Period (pre-induction, post-induction), Threat (fearful face, neutral face), Mood Group (neutral, anxious), and Trait Anxiety Group (low TA, high TA). As before, there was a main effect of Threat, $F(1, 66) = 19.91$, $p < .001$, $\eta_p^2 = .204$, with fearful-face trials (M = 88.02, SD = 43.09) showing reduced conflict scores relative to neutral-face trials (M = 106.94, SD = 45.68). There was also a main effect of Study Period, $F(1, 66) = 7.44$, $p = .008$, $\eta_p^2 = .101$, such that the post-induction ANT had lower conflict scores overall relative to the pre-induction ANT. The critical interaction of Study Period x Threat x Mood Group was significant, $F(1, 66) = 8.61$, $p = .005$, $\eta_p^2 = .115$. Notably, there were no significant effects involving trait anxiety, and no other main effects or interactions were significant, all Fs ≤ 1.78, all ps $\geq .187$.

The Study Period x Threat x Mood Group interaction was explored by running separate GLMs for the pre-induction ANT and the post-induction ANT with factors of Threat, Mood Group, and Trait Anxiety Group. As expected, the pre-induction analysis revealed no main effects or interactions, all *F*s ≤ 1.67, all *p*s ≥ .200. In contrast, the post-induction analysis revealed a main effect of Threat, $F(1, 66) = 14.02$, $p < .001$, $\eta_p^2 = .175$, and, most importantly, a significant interaction of Threat x Mood Group, $F(1, 66) = 9.37$, $p = .003$, $\eta_p^2 = .124$. Crucially, for the anxious mood group, conflict scores for trials preceded by fearful faces (*M* = 68.34, *SD* = 41.96) versus neutral faces (*M* = 111.90, *SD* = 53.44) were dramatically reduced, $p < .001$. However, for the neutral mood group, LSD tests showed that conflict scores for trials preceded by fearful faces (*M* = 90.52, *SD* = 41.22) versus neutral faces (*M* = 94.89, *SD* = 52.43) were not significantly different ($p = .587$). Again, there were no significant effects involving Trait Anxiety Group (see Figure 3a).

To examine the nature of the conflict effect in the anxious mood group, a follow-up GLM on raw RT scores was conducted with Threat and Flanker (incongruent, neutral, congruent) as factors. An interaction of Threat x Flanker emerged with a large effect size, $F(2, 26) = 12.64$, $p < .001$, $\eta_p^2 = .493$. As in Study 1, only the incongruent condition showed faster RTs for the fearful (*M* = 561.12, *SD* = 105.20) versus neutral (*M* = 585.79, *SD* = 96.20) comparison ($p = .007$). For the congruent condition, the opposite effect occurred to a marginally significant degree, with slower RTs for the fearful (*M* = 490.30, *SD* = 92.81) versus neutral (*M* = 473.29, *SD* = 83.92) comparison ($p = .077$). Similarly, for the neutral flanker condition, RTs were significantly slower for the fearful (*M* = 485.53, *SD* = 81.59) versus neutral (*M* = 466.71, *SD* = 78.68) comparison ($p = .019$). This pattern of results indicates that the threat-related conflict effect described above for participants in an anxious mood was explained by a threat-related speeding of RTs in the incongruent condition and possibly a threat-related slowing in both of the other conditions, thereby supporting the notion that threat aided in the resolution of conflicting responses.

In a GLM with factors of Study Period, Threat, and Mood Group on conflict scores for accuracy, there were no main effects and no interactions, all *F*s $\leq$ 2.70, all *p*s $\geq$ .105. Thus, as expected, threat-related facilitation of executive control efficiency in the anxious group was not accompanied by a parallel change in performance.

Alerting.

A GLM was conducted on alerting scores for RT with factors of Study Period (pre-induction, post-induction), Threat (fearful face, neutral face), Mood Group (neutral, anxious), and Trait Anxiety Group (low TA, high TA). There were no significant main effects or interactions, all *F*s $\leq$ 2.27, all *p*s $\geq$ .137. Thus, there was no threat-related facilitation of alerting efficiency in either group, which suggests specificity in the threat-related facilitation of executive control efficiency in the anxious group. In parallel with the presentation of conflict scores, see Figure 3b for a presentation of the alerting scores showing the levels of Threat, Mood Group, and Trait Anxiety Group for the post-induction ANT.

In a comparable GLM with factors of Study Period, Threat, Mood Group, and Trait Anxiety Group on alerting scores for accuracy, there was, unexpectedly, a very nearly significant interaction of Study Period x Threat x Trait Anxiety Group, $F(1, 66) = 4.00$, $p = .050$, $\eta_p^2 = .057$. Follow-up analyses revealed that no Threat x Trait Anxiety Group interaction existed for the pre-induction ANT, $F(1, 66) = 0.05$, $p = .833$, $\eta_p^2 = .001$, but the same interaction was significant for the post-induction ANT, $F(1, 66) = 4.25$, $p = .043$, $\eta_p^2 = .061$. In the second ANT participants with high trait anxiety showed lower scores for trials preceded by fearful (*M* = -0.01, *SD* = 0.06) relative to neutral (*M* = 0.02, *SD* = 0.06) faces (*p* = .049), whereas participants with low trait anxiety showed no difference for trials preceded by fearful (*M* = 0.01, *SD* = 0.06) relative to neutral (*M* = -0.01, *SD* = 0.06) faces (*p* = .402). Recall that activity of the alerting network is inversely related to these scores. Since high trait-anxious people displayed lower scores following fearful faces than neutral faces, this effect constitutes a threat-related enhancement of the alerting network as measured by accurate performance. Despite this weak but significant effect of trait anxiety, it is notable that there were no effects on alerting scores for accuracy involving mood group.

Discussion

Consistent with our first hypothesis, participants effectively induced into an anxious mood state demonstrated facilitated efficiency of executive control following briefly presented task-irrelevant stimuli that were mildly threatening relative to nonthreatening. Also consistent with this hypothesis, no such effect was present for participants effectively induced into a neutral mood state. For executive control, there were no effects on accuracy involving anxious mood, and therefore the threat-related effect on executive attention concerned efficiency only. As predicted, for alerting, there were no threat-related or overall effects involving state anxiety on attentional efficiency or accuracy. Contrary to our second hypothesis, there were no effects of trait anxiety on executive control efficiency. Not only did the facilitative effect of threat during state anxiety not depend on trait anxiety, trait anxiety also did not affect executive control overall, across levels of threat. In sum, these results suggest that an attentional boost follows threat during an anxious state, regardless of one's level of anxious disposition, and this attentional benefit specifically takes the form of improved efficiency of executive control.

General Discussion

Taken together, the present studies demonstrate a replicable, threat-driven improvement in executive attention during state anxiety. Moreover, the findings from Study 1 reveal that the mood-related aspect of the effect is not simply due to emotional arousal, and the findings from Study 2 reveal that the effect is not dependent on the level of trait anxiety. The demonstration that emotional arousal alone does not account for the attentional effect is not entirely surprising in light of research showing that an arousing, negative state of anxiety influences attentional performance during a challenging task differently than an arousing, positive state of happiness (e.g., Jefferies, Smilek, Eich, & Enns, 2008). The second point, however, is unexpected given that trait anxiety has been consistently associated with disrupted executive control function.

Before attempting to account for the aspect of the enhancement effect that is attributable to state anxiety and for the apparent absence of a contribution by trait anxiety, it is important to appreciate the specific nature of the executive control improvement observed in these studies. A recent neuroimaging experiment by Egner and Hirsch (2005) is relevant to this point. They demonstrated that executive control can affect performance via sensory perception by enhancing activity in brain regions associated with the processing of task-relevant information (e.g., elevated activation of the fusiform face area in a Stroop task when faces appeared as targets versus distracters). The manner in which executive control influences performance, therefore, is not necessarily only a matter of redirecting the attentional "spotlight" to a particular area of visual space. Executive control function can be modulated, as in the present two studies, even within a single area of visual space (i.e., the central area of fixation in the ANT) such that executive inhibition is enhanced. We propose that this sort of executive modulation underlies the attentional enhancement effects reported in this paper. In this case, the visual aspect that receives prioritized processing due to enhanced executive control is the task-relevant central arrow in the target display on each trial of the ANT.

Implications for Dual Competition Framework.

The present findings regarding state anxiety are entirely consistent with the predictions of DCF. Specifically, in people with experimentally confirmed transient elevations in anxiety, the low-level threat of fearful faces was sufficient to promote efficient top-down attention on a subsequent task. This important aspect of the model has previously received only indirect support. Prior studies have shown that low-level threat can cause prioritized attentional processing in anxious people, presumably due to threat's effects on executive attention (e.g., Fox et al., 2001), but few previous studies have addressed the combined effects of threat and state anxiety on the efficiency of executive attention, and to date those studies have examined only natural variability in anxious mood (Dennis et al., 2008; Finucane & Power, 2010). The present studies were the first ones to address this question by randomly assigning participants to mood conditions and manipulating mood states in order to eliminate the influence of confounding nuisance variables (e.g., enduring personality characteristics that systematically predispose particular people to experience state anxiety at the study session). This point is especially important when attempting, as in the present investigation, to disentangle the effects of state and trait anxiety since trait anxiety is defined, in part, as a tendency to experience anxious moods on a frequent basis.

It is notable that the present findings regarding the happy and neutral mood states are not fully consistent with the predictions of DCF. Although the model posits that the effect of low-level threat on executive function should be greatest during anxiety, it also suggests that threat should influence top-down attention, though to a lesser degree, even for people not in an anxious state. We propose that that anxiety-related variations in the estimation of affective significance likely played the key role in modulating executive function in the present studies and that affective significance was simply too low for people in happy and neutral moods to produce an effect on executive attention.

According to Pessoa (2009), emotionally salient stimuli can either enhance or impair subsequent behavior. He proposes that low-threat emotional stimuli should enhance subsequent target processing when the threat appears in a privileged location. In the present study, the fearful faces were presented centrally, overlaying the position that the target would eventually occupy. Thus prioritized processing of the central spatial location may have facilitated response to the target.

Of interest in this regard, it has been suggested that fearful faces (unlike angry faces) are ambiguous in the sense that they signal the presence of threat but not the source (Whalen, Shin, McInerney, Fischer, Wright, & Rauch, 2001). It may be that ambiguity as to source of threat in this task was important in signaling a need for executive control to resolve the ambiguity. Such an adaptation makes evolutionary sense because it should lead to an increase in the probability of quickly identifying the source of threat, thus resolving the ambiguity, and responding adaptively.

If that account is accurate, one might ask why we did not observe a corresponding increase in alerting efficiency in conjunction with the increase in executive control efficiency. One explanation is that the alerting cues used in our modified Attention Network Test (ANT; asterisks presented above and below a central fixation cross) may have been too subtle. Pacheco-Unguetti and colleagues (2010) used an auditory tone to induce alerting in their version of the ANT, and observed greater alerting to the tone in the anxious group compared to the positive, “nonanxious” group. A stronger alerting manipulation may have been necessary to prompt a threat-related boost in alerting in the present study. A second explanation is that a floor effect in alerting scores may have hampered the detection of an effect. Given that an alerting efficiency score of zero milliseconds was within one standard deviation from the mean, slight modulations of this measure by prior threat may have been difficult to detect.

An alternative account for the pattern of findings centers on the idea that the substantial delay between the appearance of the threat and target plays a critical role in revealing the attentional effect. It may be that state anxiety potentiates the effect of threat on executive attention but only after a considerable delay. This timing consideration may be particularly important with respect to explaining the unanticipated lack of trait anxiety effects in Study 2. It may be that the attentional bias to threat leads to attentional disruptions among chronically anxious people only when the threat-to-target period is considerably shorter than in the present investigation and/or when the threat stimulus is still present when the target appears. In fact, although anxious people demonstrate a difficulty disengaging their attention from threat stimuli at short durations (e.g., 500 ms), they often actually show attentional *avoidance* of threat at longer durations (e.g., 1250 ms) (Cisler & Koster, 2010). In the present studies the elapsed time between the offset of the 50-ms threat to the onset of the target varied between 900 ms and 1800 ms in the modified ANT. Therefore an effective elimination of the attentional bias to threat at these long durations in high trait-anxious people might cause them to behave more like low trait-anxious people, which may account for the similar pattern of executive function following threat for high and low trait-anxious participants in Study 2. Regarding this point, the relatively long delay in timing may be the reason that, unlike Egloff and Hock (2001), we did not demonstrate an interaction of state and trait anxiety.

Interestingly, a negative anxious mood has been shown to result in improved executive control following cognitive conflict in comparison to positive moods (van Steenbergen, Band, &

Hommel, 2010). This result is worth considering in that the processing of threat in the present studies might, in and of itself, entail cognitive conflict since the threats were task-irrelevant with respect to the successful performance of the arrow task. Based on ample evidence of an automatic threat detection system in humans (Dijksterhuis & Aarts, 2003; Marcos & Redondo, 2005; Phelps, Ling, & Carrasco, 2006) and because the face stimuli in this task are always distracters to be ignored, the appearance of the fearful relative to the neutral faces may increase the burden on the executive control system. The reason is that fearful but not neutral faces may require the inhibition of an innate, automatic, and dominant response (i.e., to attend to threat) in order to focus instead on the goal of performing the task well. If indeed the threatening faces are associated with greater cognitive conflict than the nonthreatening faces, then our findings are fully consistent with those of Steenbergen and colleagues. Specifically, the improved executive control following threat stimuli among people in an anxious, but not a happy or neutral, mood may mirror the observation that conflict adaptation is especially improved during a negative relative to a positive mood state. This possibility should be explored in future research.

Implications for Attentional Control Theory.

On the surface, the results of the present studies seem to contradict the predictions of Attentional Control Theory (ACT), which posits that anxiety impairs executive control efficiency and that this anxiety-related impairment is most evident in a context of threat (for a review, see Eysenck et al., 2007; Derakshan & Eysenck, 2009). The focus of the present studies differs in a critical way, however, from the abundance of literature supporting ACT. As previously noted, the threat stimuli were presented prior to the measurement of executive control efficiency in the present studies, whereas the studies supporting ACT have shown effects when threats and targets occur concurrently. It may be that the combination of anxious mood and threat disrupts the efficiency of executive control when threats occur in close temporal proximity to targets because executive function is devoted to organizing the ongoing sensory processing of the threat stimuli rather than to directing attention to the task. Therefore the present line of investigation is not a direct test of ACT but rather addresses a somewhat different question: How does a prior experience of threat modulate the subsequent executive control of attention after a substantial delay for people in an anxious mood?

Regarding the present findings' bearing on ACT, it is also worth noting the threat stimuli and target stimuli occupied the same central area of visual space in the present studies. Given that anxious people show an attentional bias to threat, it may be that the fearful faces held attention at this central area to a greater degree for the anxious group than the nonanxious (happy and neutral) groups, thereby improving threat-related task performance after the delay. In this sense the threats may not have been entirely task-irrelevant because the area of visual space was always subsequently relevant to successful task processing. If the threatening distractors were indeed perceived to be task-relevant, ACT predicts that they may actually enhance processing efficiency for anxious people, consistent with the present findings. Interestingly, however, the threat stimuli seemed to improve executive control efficiency and not simply reduce processing time overall; in both studies participants in an anxious mood showed significantly faster threat-related response times within the incongruent condition and nearly significantly slower response times within the congruent condition. It is worth noting that, if the anxious participants' attention was held at the central fixation due to the prior threat, then one might contend that they should subsequently show enhanced threat-related alerting efficiency as well. As mentioned above, the potential floor effect in the alerting efficiency scores could have obscured any such effect.

Connections with Recent Findings on the Effects of Induced Anxiety on Attention.

At this point, very few studies have combined an experimental anxious mood manipulation with measures of attention as operationalized in the Attention Network Test. To our knowledge, the only other such study is the one published by Pacheco-Unguetti, Acosta, Callejas, and Lupiáñez (2010). These investigators conducted two experiments, one each assessing trait and state anxiety effects on executive control, alerting, and orienting efficiency. Experiment 1 indicated that high trait anxiety was associated with impaired executive control efficiency relative to low trait anxiety, but there was no effect on alerting or orienting efficiency. Experiment 2 indicated that induced state anxiety had no effect on executive control efficiency relative to a positive, nonanxious control mood, but it facilitated both alerting and orienting efficiency. The authors concluded that trait anxiety impairs top-down attentional processes while state anxiety facilitates bottom-up attentional processes. The present findings both converge and diverge from these results in important ways.

First, like these authors, we did not observe a difference in executive control efficiency between our anxious and happy groups in Study 1. We also did not observe a difference in executive control efficiency when comparing each of these two moods to a neutral mood within each group, a comparison that these authors could not make since they did not have a neutral control condition. Similarly, we did not observe a difference in executive control efficiency when comparing anxious and neutral mood groups in Study 2. This pattern strongly suggests that neither anxious nor happy moods alone are sufficient to impact executive control efficiency. However, we observed *facilitation* of executive control efficiency on trials following a task-irrelevant fearful versus neutral face stimulus in the anxious groups but not in the happy (Study 1) or neutral (Study 2) groups, suggesting that task-irrelevant threat is sufficient to influence executive control efficiency for acutely anxious people but not for those in happy or neutral moods. This pattern of findings suggests that, in the right context, state anxiety actually can affect top-down attentional processes, not just bottom-up. Pacheco-Unguetti and colleagues did not assess the downstream effects of task-irrelevant threat. Had they done so, it is possible they would have observed a similar effect.

Second, unlike Pacheco-Unguetti and colleagues, we excluded cues that would have allowed us to measure the efficiency of the orienting network in order to minimize the time it would take to complete the attentional task while at the same time maximizing our ability to test hypothesized effects on executive control efficiency. We did, however, measure alerting efficiency and, unlike Pacheco-Unguetti and colleagues, we did not observe any effect of anxious, happy, or neutral moods on this measure. In Study 1, this null result for alerting efficiency was found when anxious and happy mood groups were compared directly and also in within-group comparisons to a neutral mood. In Study 2, no modulation of alerting efficiency was found when anxious and neutral mood groups were compared directly. Moreover, the presentation of task-irrelevant, threat-related stimuli failed to reveal any significant differences in alerting efficiency in both present studies. One important difference between Experiment 2 of Pacheco-Unguetti and colleagues and the present studies is that they enrolled participants whose scores fell in the middle of the distribution of trait anxiety (scores between 14 and 32 on the Spanish version of the measure, which is similar to scores of 34 and 52, respectively, on the English version). In addition, they entered trait anxiety as a covariate in their analyses of the effects of state anxiety on alerting efficiency. Thus, in Study 1, it is possible that between-subjects variation in trait anxiety hampered our ability to identify similar state effects on alerting efficiency and/or that our sample happened to have trait anxiety scores that fell outside their range. We did not collect this measure for Study 1 and were thus unable to characterize or control for levels of trait anxiety in that sample. The verification that trait anxiety (and baseline state anxiety) did not differ for the two mood groups in Study 2, however, addresses this issue.

Theoretical Links to the Literature on Attentional Bias in Anxiety.

A wealth of literature supports the idea that high levels of anxiety cause attentional capture by task-irrelevant stimuli, particularly those that are threat-related. High levels of trait (Mogg, Holmes, Garner, & Bradley, 2008) and state (Fox & Knight, 2005) anxiety are accompanied by a bias to attend preferentially to threat-related stimuli. In this experimental context, in which we manipulated anxiety and task-irrelevant threat and then measured executive control efficiency, the assumption underlying our results is that a state of anxiety led participants to pay greater attention to the threat-related stimuli than the neutral stimuli (i.e., there was an attentional bias to threat that led them to respond faster). However, we had no direct measure of attentional bias to the task-irrelevant stimuli in the ANT and thus cannot confirm this possibility to be the case.

Regardless, we echo MacLeod, Koster, and Fox (2008) in noting that the causal influence between anxiety (or other mood states) and attentional bias can flow in the opposite direction. Indeed, from a theoretical standpoint, Gross (1998) has suggested that deployment of attention is one of several processes that can be used in the service of regulating emotion experience, expression, and physiology. Supporting this contention, experiments suggest that directing attention to emotional versus neutral information in unpleasant photos influences emotion experience and expressive behavior (Urry, 2010) and neural activity as measured using the late positive potential (Dunning & Hajcak, 2009; Hajcak et al., 2009). In addition, experiments in which attentional bias to threat is trained over time produce elevated anxiety in response to a laboratory stressor (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002). Moreover, anxious people who are trained over time to avoid attending to threat experience reduced levels of anxiety over time (e.g., Schmidt, Richey, Buckner, & Timpano, 2009; See, MacLeod, & Bridle, 2009). Thus, although presumably we have shown in the present study that affective processes influence attention to threat-related information, attentional maneuvers can also clearly influence affective processes.

Additional Limitations and Directions for Future Research.

These studies have made a novel contribution to the literature by demonstrating that threat facilitates subsequent executive control efficiency in the context of experimentally-induced state anxiety. Nevertheless, there were some notable limitations to this work. First, the scenarios used in the arousing mood inductions in Study 1 (anxious, happy) might be expected to cause differing levels of emotional arousal in a real-world context. That is, the emotional impact of a serious car accident is undoubtedly on a different order of magnitude than that of a pleasant walk outdoors. It should be emphasized, however, that the mood inductions were designed to create comparable mood strengths in a laboratory context, and the self-reported arousal findings lend support to our success in matching the manipulations on this dimension. Although the external validity might seem to be limited based on likely differences between laboratory and real-world domains, the most important outcome of the induction procedures was their ability to influence mood valence and arousal relative to a neutral control condition, and in this sense they succeeded. Nevertheless, future projects should assess the effects of induced anxiety on threat-related attention using mood manipulations that have greater ecological validity (e.g., induced anxiety via public speaking in an evaluative context in the laboratory).

Second, with respect to the goal of Study 1, although we had an objective confirmation of the valence of induced mood states (*corrugator* muscle activity) to supplement our self-report measures of positive and negative affect, we did not have a parallel objective confirmation of level of arousal. The use of objective measures of arousal (e.g., skin conductance) in future studies would solidify the conclusion that the anxious and happy mood states elicited in Study 1 were highly and equally arousing. That being said, we have little reason to doubt that the novel mood induction procedure we used had potent effects on both valence (the happy group responded positively, the anxious group responded negatively) and arousal (the happy and anxious groups both responded with high perceived arousal).

Third, we cannot assess the importance of the threat-to-target delay in the current demonstration of the executive control efficiency modulation because that interval was not systematically varied as a factor for analysis in either study. Future studies should determine whether the facilitation effect strengthens, disappears, or remains unchanged at short (e.g., 500 ms) durations or when threats and targets appear simultaneously, as is the case in the emotional Stroop task.

Fourth, the present investigation did not test the effect of high-level threat. DCF proposes that the opposite effect on executive control function might occur for more threatening stimuli. Therefore future research should address this question to determine whether hindered executive efficiency indeed occurs and whether in that case dispositional anxiety is a key factor in predicting the occurrence of the effect (e.g., use highly threatening spider images prior to the ANT trials with a study sample consisting of spider phobics and healthy controls).

Concluding Remarks.

The present studies offer evidence that an aroused, anxious mood can lead to enhanced executive control efficiency following the presence of brief, low-level threat-related stimuli that are irrelevant to the successful performance of the task at hand. The cognitive enhancement seems to be specific to a task requiring executive control and is due to its anxious/stressful quality, not to its arousing quality. From a theoretical standpoint, our findings raise the possibility that Dual Competition Framework should be modified to account separately for the effects of state and trait anxiety on executive control efficiency since only state but not trait anxiety produced threat-related facilitation of executive control efficiency. More broadly, the assumption that an anxious mood will necessarily have deleterious effects on the efficiency of tasks requiring executive control needs to be reconsidered in light of the present evidence. From a clinical standpoint, understanding the relationships among anxious mood, attention to threat, and executive control may be valuable for refining therapeutic practices that require deliberate shifts in attentional deployment to regulate emotions (e.g., Johnson, 2009). The ultimate goal of this research program is to promote advances that aid in recovery from anxiety and contribute to a healthy mental life.

References

Barazzone, N., & Davey, G. C. L. (2009). Anger potentiates the reporting of threatening interpretations: An experimental study. *Journal of Anxiety Disorders, 23*, 489-495. doi:10.1016/j.janxdis.2008.10.007

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: A meta-analytic study. *Psychological Bulletin, 133*, 1-24. doi: 10.1037/0033-2909.133.1.1

Blanchette, I. (2006). Snakes, spiders, guns, and syringes: How specific are evolutionary constraints on the detection of threatening stimuli? *The Quarterly Journal of Experimental Psychology, 59*, 1484-1504. doi: 10.1080/02724980543000204

Cacioppo, J. T., Martzke, J. S., Petty, R. E., & Tassinary, L. G. (1988). Specific forms of facial EMG response index emotions during an interview: From Darwin to the continuous flow hypothesis of affect-laden information processing. *Journal of Personality and Social Psychology, 54*, 592-604. doi: 10.1037/0022-3514.54.4.592

Cisler, J. M., Bacon, A. K., & Williams, N. L. (2009). Phenomenological characteristics of attentional biases towards threat: A critical review. *Cognitive Therapy and Research, 33*, 221-234. doi: 10.1007/s10608-007-9161-y

Cisler, J. M., & Koster, E. H. W. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review, 30*, 203-216. doi: 10.1016/j.cpr.2009.11.003

Dennis, T. A., Chen, C. C., & McCandliss, B. D. (2008). Threat-related attentional biases: An analysis of three attention systems. *Depression and Anxiety, 25*, E1-E10. doi: 10.1002/da.20308

Derakshan, N. & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: New developments from attentional control theory. *European Psychologist, 14*, 168-176. doi: 10.1027/1016-9040.14.2.168

Dijksterhuis, A., & Aarts, H. (2003). On wildebeests and humans: The preferential detection of negative stimuli. *Psychological Science, 14,* 14-18. doi: 10.1111/1467-9280.t01-1-01412

Dunning, J. P. & Hajcak, G. (2009). See no evil: Directing visual attention within unpleasant images modulates the electrocortical response. *Psychophysiology, 46,* 28-33. doi: 10.1111/j.1469-8986.2008.00723.x

Egloff, B. & Hock, M. (2001). Interactive effects of state anxiety and trait anxiety on emotional stroop interference. *Personality and Individual Differences, 31*, 875-882. doi: 10.1016/S0191-8869(00)00188-4

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience, 8,* 1784-1790. doi:10.1038/nn1594

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*, 143-149.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*, 336-353. doi: 10.1037/1528-3542.7.2.336

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*, 340-347. doi: 10.1162/089892902317361886

Finucane, A. M., Whiteman, M. C., & Power, M. J. (2009). The effect of happiness and sadness on alerting, orienting, and executive attention. *Journal of Attention Disorders,* doi:10.1177/1087054709334514

Finucane, A. M. & Power, M. J. (2010). The effect of fear on attentional processing in a sample of healthy females. *Journal of Anxiety Disorders, 24*, 42-48. doi: 10.1016/j.janxdis.2009.08.005

Fox, E., Russo, R., Bowles, R., & Dutton, K. (2001). Do threatening stimuli draw or hold visual attention in subclinical anxiety? *Journal of Experimental Psychology. General, 130*, 681-700. doi: 10.1037//0096-3445.130.4.681

Fox, L. S. & Knight, B. G. (2005). The effects of anxiety on attentional processes in older adults. *Aging & Mental Health, 9*, 585-593. doi: 10.1080/13607860500294282

Fridlund, A. J. & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology, 23*, 567-589. doi: 10.1111/j.1469-8986.1986.tb00676.x

Gilet, A. L. (2008). [Mood induction procedures: A critical review]. [Procedures d'induction d'humeurs en laboratoire: une revue critique] *L'Encephale, 34*, 233-239. doi: 10.1016/j.encep.2006.08.003

Green, J. D., Sedikides, C., Saltzberg, J. A., Wood, J. V., & Forzano, L. B. (2003). Happy mood decreases self-focused attention. *British Journal of Social Psychology, 42*, 147-157.

Grös, D. F., Antony, M. M., Simms, L. J., & McCabe, R. E. (2007). Psychometric properties of the state-trait inventory for cognitive and somatic anxiety (STICSA): Comparison to the state-trait anxiety inventory (STAI). *Psychological Assessment, 19*, 369-381. doi: 10.1037/1040-3590.19.4.369

Gross, J. J. (1998). Antecedent- and response-focused emotion regulation: Divergent consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology, 74,* 224-237.

Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: Time-course of the late positive potential. *Clinical Neurophysiology, 120,* 505-510. doi:10.1016/j.clinph.2008.11.028

Jefferies, L. N., Smilek, D., Eich, E., & Enns, J. T. (2008). Emotional valence and arousal interact in attentional control. *Psychological Science : A Journal of the American Psychological Society / APS*, *19*, 290-295.

Johnson, D. (2009.) Emotional attention set-shifting and its relationship to anxiety and emotion regulation. *Emotion, 9,* 681–690. doi: 10.1037/a0017095

Krysko, K. M., & Rutherford, M. D. (2009). The face in the crowd effect: Threat-detection advantage with perceptually intermediate distractors. *Visual Cognition, 17*, 1205-1217. doi: 10.1080/13506280902767789

Kwakkenbos, L., Becker, E. S., & Rinck, M. (2010). Fear of spiders: The effect of real threat on the interference caused by symbolic threat. *Cognition and Emotion, 24,* 800-809. doi: 10.1080/02699930902995901

Lang P. J., Bradley M. M., & Cuthbert B. N. (2005). International Affective Picture System (IAPS): Digitized photographs, instruction manual, and affective ratings (Tech. Rep. No. A-6). Gainesville: University of Florida, Center for Research in Psychophysiology. doi: 10.1111/1469-8986.00078

Larsen, J. T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii.

Psychophysiology, 40, 776-785. doi: 10.1111/1469-8986.00078

LoBue, V. (2010). What's so scary about needles and knives? Examining the role of experience in threat detection. *Cognition and Emotion, 24*, 180-187. doi: 10.1080/02699930802542308

Mackie, D. M., & Worth, L. T. (1989). Processing deficits and the mediation of positive affect in persuasion. *Journal of Personality and Social Psychology, 57*, 27-40.

MacLeod, C., Koster, E. H. W., & Fox, E. (2009). Whither cognitive bias modification research? Commentary on the special section articles. *Journal of Abnormal Psychology, 118*, 89-99. doi: 10.1037/a0014878.

MacLeod, J. W., Lawrence, M. A., McConnell, M. M., Eskes, G. A., Klein, R. M., & Shore, D. I. (2010). Appraising the ANT: Psychometric and theoretical considerations of the attention network test. *Neuropsychology, 24*(5), 637-651. doi: 10.1037/a0019803

MacLeod, C., Rutherford, E.M., Campbell, L., Ebsworthy, G., & Holker, L. (2002). Selective attention and emotional vulnerability: Assessing the causal basis of their association through the experimental manipulation of attentional bias. *Journal of Abnormal Psychology, 111*, 107-123. doi: 10.1037//0021-843X.111.1.107

Marcos, J. L., & Redondo, J. (2005). Facilitation and interference of the automatic information processing on a reaction time task to threat-relevant stimuli. *Psicothema, 17*, 332-337.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “Frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49-100. doi:10.1006/cogp.1999.0734

Nitschke, J. B., Heller, W., Palmieri, P. A., & Miller, G. A. (1999). Contrasting patterns of brain activity in anxious apprehension and anxious arousal. *Psychophysiology, 36*, 628-637.

Mogg, K., Holmes, A., Garner, M., & Bradley, B. P. (2008). Effects of threat cues on attentional shifting, disengagement and response slowing in anxious individuals. *Behaviour Research and Therapy, 46*, 656-667. doi:10.1016/j.brat.2008.02.011

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General, 130*, 466-478. doi: 10.1037/AXJ96-3445.130.3.466

Patrick, C. J. & Lavoro, S. A. (1997). Ratings of emotional response to pictorial stimuli: Positive and negative affect dimensions. *Motivation and Emotion, 21*, 297-321. doi: 10.1023/A:1024432322584

Pacheco-Unguetti, A. P., Acosta, A., Callejas, A., & Lupiáñez, J. (2010). Attention and anxiety: Different attentional functioning under state and trait anxiety. *Psychological Science, 21*, 298-304. doi: 10.1177/0956797609359624

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences, 13,* 160-6. doi:10.1016/j.tics.2009.01.006

Phelps, E. A., Ling, S., & Carrasco, M. (2006). Emotion facilitates perception and potentiates the perceptual benefits of attention. *Psychological Science, 17*, 292-299. doi: 10.1111/j.1467-9280.2006.01701.x

Phillips, L. H., Bull, R., Adams, E., & Fraser, L. (2002). Positive mood and executive function: Evidence from Stroop and fluency Tasks. *Emotion, 2*, 12-22. doi: 10.1037//1528-3542.2.1.12

Rowe, G., Hirsh, J. B., & Anderson, A. K. (2007). Positive affect increases the breadth of attentional selection. Proceedings *of the National Academy of Sciences, 104,* 383–388. doi: 10.1073/pnas.0605198104

Schimmack, U., & Derryberry, D. (2005). Attentional interference effects of emotional pictures: Threat, negativity, or arousal? *Emotion, 5,* 55-66. doi: 10.1037/1528-3542.5.1.55

Schmidt, N. B., Richey, J. A., Buckner, J. D., & Timpano, K. R. (2009). Attention training for generalized social anxiety disorder. *Journal of Abnormal Psychology, 118*, 5-14. doi: 10.1037/a0013643

See, J., MacLeod, C., & Bridle, R. (2009). The reduction of anxiety vulnerability through the modification of attentional bias: A real-world study using a home-based cognitive bias modification procedure. *Journal of Abnormal Psychology, 118,* 65-75. doi: 10.1037/a0014377

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643-662.

Tottenham N., Borscheid A., Ellertsen K., Marcus D. J., & Nelson C. A. (2002). Categorization of facial expressions in children and adults: Establishing a larger stimulus set. San Francisco, CA.

Urry, H. L. (2010). Seeing, thinking, and feeling: Emotion-regulating effects of gaze-directed cognitive reappraisal. *Emotion, 10,* 125-135. doi: 10.1037/a0017434

van Steenbergen, H., Band, G. P., & Hommel, B. (2010). In the mood for adaptation: How affect regulates conflict-driven control. *Psychological Science : A Journal of the American Psychological Society / APS, 21,* 1629-1634. doi: 10.1177/0956797610385951

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social*

Psychology, *54*, 1063-1070. doi: 10.1037/0022-3514.54.6.1063

Whalen, P. J., Shin, L. M., McInerney, S. C., Fischer, H., Wright, C. I., & Rauch, S. L. (2001). A functional MRI study of human amygdala responses to facial expressions of fear vs. anger. *Emotion, 1*, 70-83. doi: 10.1037/1528-3542.1.1.70

Wilhelm, F. H. & Peyk, P. (2005). ANSLAB: Autonomic Nervous System Laboratory (Version 4.0). Available at the SPR Software Repository: http://www.sprweb.org. [Computer software].

Williams, J. M., Mathews, A., & MacLeod, C. (1996). The emotional stroop task and psychopathology. *Psychological Bulletin, 120*, 3-24.

Wood, J., Mathews, A., & Dalgleish, T. (2001). Anxiety and cognitive inhibition. *Emotion, 1,* 166-181. doi: 10.1037//1528-3542.1.2.166

Footnotes

[1] Identification numbers for IAPS pictures: 2570, 2751, 2810, 5760, 5800, 7022, 7035, 7041, 7060, 7090, 7100, 7175, 7211, 7217, 7233, 7235, and 7920.

Table 1

Self-Reported Affect Before and After the Mood Inductions in Study 1

	Pre-Induction		Post-Induction	
	Aroused Mood	Nonaroused Mood	Aroused Mood	Nonaroused Mood
Anxious Group				
PA	8.37 (3.66)	8.23 (3.36)	6.77 (2.80)	7.57 (3.20)
NA	13.33 (3.46)	12.87 (4.02)	18.83 (6.16) [a]	11.40 (1.48) [a]
Arousal	15.60 (4.98)	15.43 (4.66)	17.77 (4.22) [a]	13.70 (4.19) [a]
Happy Group				
PA	7.13 (3.55)	7.77 (3.79)	9.90 (3.18) [a]	7.03 (3.39) [a]
NA	14.00 (3.24)	13.71 (3.55)	11.84 (3.28)	12.45 (3.19)
Arousal	13.42 (4.48)	13.48 (5.09)	15.48 (4.23) [a]	12.23 (4.18) [a]

Note. Mean (*SD*) self-reported affect scores from the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). PA and NA denote, respectively, positive affect scores and negative affect scores.

[a] Means sharing this same superscript *within a row* are significantly different at $p < .05$.

Table 2

Reaction Times During the Modified Attention Network Test Following the Arousing Mood Induction (Anxious or Happy) in Study 1

	Early Trials (Blocks 1, 2)				Late Trials (Blocks 3, 4)			
	Double Cue		No Cue		Double Cue		No Cue	
	Fearful Face	Neutral Face	Fearful Face	Neutral Face	Fearful Face	Neutral Face	Fearful Face	Neutral Face
Anxious Group								
Congruent	504.37 (79.92)	486.41 (76.26)	512.20 (66.21)	507.14 (63.66)	511.07 (83.42)	497.19 (77.22)	523.93 (67.80)	529.23 (95.59)
Incongruent	590.26 (89.16)	601.28 (87.24)	595.47 (63.45)	615.85 (80.93)	609.77 (84.27)	617.59 (109.24)	632.84 (100.63)	634.62 (95.52)
Neutral	488.37 (65.98)	488.62 (66.56)	507.09 (46.75)	494.14 (69.02)	482.75 (73.20)	481.94 (75.52)	519.46 (61.76)	508.85 (64.28)
Happy Group								
Congruent	471.31 (64.16)	479.49 (71.09)	502.91 (73.20)	492.24 (68.74)	478.23 (69.84)	469.41 (72.14)	502.83 (56.56)	508.65 (67.36)
Incongruent	572.86 (99.30)	578.21 (78.67)	589.49 (73.80)	597.47 (81.24)	593.66 (75.24)	571.85 (83.60)	611.72 (90.32)	605.94 (78.02)
Neutral	477.31 (67.48)	463.39 (59.87)	497.27 (70.26)	493.90 (59.01)	475.65 (67.47)	456.27 (51.28)	509.35 (51.64)	490.63 (52.80)
All Participants								
Congruent	487.57 (73.64)	482.89 (73.14)	507.48 (69.43)	499.57 (66.17)	494.38 (77.95)	483.07 (75.37)	513.20 (62.73)	518.77 (82.42)
Incongruent	581.41 (94.07)	589.55 (83.12)	592.43 (68.40)	606.51 (80.94)	601.58 (79.55)	594.34 (98.96)	622.11 (95.32)	620.04 (87.54)
Neutral	482.75 (66.42)	475.80 (64.00)	502.10 (59.58)	494.02 (63.59)	479.14 (69.85)	468.89 (65.11)	514.32 (56.60)	499.59 (58.95)

Note. Mean (*SD*) reaction times are presented in milliseconds. The columns represent the Time, Face Type, and Cue Type factors. The rows represent the Mood Group and Flanker Type factors.

Table 3

Self-Reported Affect Before and After the Mood Inductions in Study 2

	Pre-Induction	Post-Induction
Anxious Group		
STICSA somatic	1.30 (0.28)	1.51 (0.41)
STICSA cognitive	1.44 (0.50)	1.46 (0.47)
Anxious, Worried, Fearful	1.48 (0.68)	2.63 (1.31)
Lonely, Distant, Isolated	1.77 (1.20)	1.90 (1.36)
Self-Confident, Capable, Worthwhile	4.65 (1.67)	4.18 (1.63)
Sad, Depressed, Down	1.45 (0.89)	2.23 (1.37)
Rejected, Put Down, Hurt	1.17 (0.72)	1.28 (0.83)
Happy, Pleased, Contented	4.30 (1.59)	3.53 (1.44)
Judged, Scrutinized, Evaluated	1.63 (0.90)	1.75 (1.24)
Angry, Irritated, Provoked	1.23 (0.65)	1.80 (1.22)
Affectionate, Loving, Connected To Others	3.93 (1.84)	3.58 (1.83)
Embarrassed, Humiliated, Ashamed	1.20 (0.55)	1.25 (0.77)
Active, Alert, Keyed Up	3.58 (1.37)	4.22 (1.49)
Neutral Group		
STICSA somatic	1.34 (0.34)	1.30 (0.34)
STICSA cognitive	1.53 (0.56)	1.51 (0.54)
Anxious, Worried, Fearful	1.74 (1.22)	1.54 (1.09)
Lonely, Distant, Isolated	1.64 (1.02)	2.16 (1.32)
Self-Confident, Capable, Worthwhile	4.44 (1.57)	4.16 (1.55)
Sad, Depressed, Down	1.34 (0.85)	1.82 (1.09)
Rejected, Put Down, Hurt	1.25 (0.75)	1.15 (0.70)
Happy, Pleased, Contented	3.97 (1.59)	3.77 (1.76)
Judged, Scrutinized, Evaluated	1.85 (1.28)	1.33 (0.77)
Angry, Irritated, Provoked	1.52 (0.94)	1.13 (0.39)
Affectionate, Loving, Connected To Others	3.49 (1.85)	3.54 (1.81)
Embarrassed, Humiliated, Ashamed	1.33 (0.72)	1.21 (0.69)
Active, Alert, Keyed Up	3.49 (1.58)	2.85 (1.65)

Note. Mean (*SD*) self-reported affect scores from the State-Trait Inventory of Cognitive and Somatic Anxiety (STICSA; Grös, Antony, Simms, & McCabe, 2007) and the eleven triplets of the Mood Rating Scale (MRS).

Table 4a

Reaction Times During the Modified Attention Network Test for Low Trait-Anxious Participants in Study 2

	Pre-Induction				Post-Induction			
	Double Cue		No Cue		Double Cue		No Cue	
	Fearful Face	Neutral Face	Fearful Face	Neutral Face	Fearful Face	Neutral Face	Fearful Face	Neutral Face
Anxious Group								
Congruent	498.80 (103.74)	480.59 (71.95)	511.38 (91.25)	505.78 (82.08)	456.78 (94.92)	449.53 (82.46)	487.31 (89.25)	480.73 (85.14)
Incongruent	597.90 (121.70)	597.87 (113.02)	608.91 (88.15)	615.49 (102.53)	549.85 (121.88)	560.48 (102.57)	559.57 (104.53)	575.45 (99.49)
Neutral	476.22 (84.41)	485.66 (75.82)	502.36 (75.87)	496.37 (74.18)	455.95 (86.22)	438.59 (74.82)	470.93 (72.15)	461.04 (74.14)
Neutral Group								
Congruent	502.81 (73.37)	502.40 (76.81)	515.49 (68.15)	529.90 (87.40)	485.46 (56.15)	474.65 (63.75)	513.06 (70.53)	497.12 (51.79)
Incongruent	594.45 (79.87)	613.41 (86.47)	612.11 (75.58)	620.61 (72.68)	578.99 (89.09)	570.99 (76.09)	574.86 (64.52)	605.51 (91.32)
Neutral	491.72 (74.17)	495.49 (81.02)	512.29 (59.70)	519.68 (54.58)	478.69 (56.90)	479.00 (76.34)	497.49 (52.54)	500.26 (56.6)
All Participants								
Congruent	500.54 (91.13)	490.04 (74.26)	513.16 (81.42)	516.23 (84.56)	469.21 (81.12)	460.42 (75.38)	498.47 (82.03)	487.83 (72.51)
Incongruent	596.40 (104.83)	604.60 (101.85)	610.30 (82.28)	617.71 (90.13)	562.48 (109.01)	565.03 (91.46)	566.19 (89.07)	588.48 (96.41)
Neutral	482.94 (79.85)	489.92 (77.60)	506.66 (68.95)	506.47 (66.90)	465.8 (75.23)	456.10 (77.51)	482.44 (65.25)	478.04 (69.39)

Note. Mean (*SD*) reaction times are presented in milliseconds. The columns represent the Study Period, Face Type, and Cue Type factors. The rows represent the Mood Group and Flanker Type factors.

Table 4b

Reaction Times During the Modified Attention Network Test for High Trait-Anxious Participants in Study 2

	Pre-Induction				Post-Induction			
	Double Cue		No Cue		Double Cue		No Cue	
	Fearful Face	Neutral Face	Fearful Face	Neutral Face	Fearful Face	Neutral Face	Fearful Face	Neutral Face
Anxious Group								
Congruent	515.36 (110.13)	503.58 (72.32)	517.68 (90.73)	533.49 (67.51)	490.99 (75.42)	484.21 (67.94)	528.57 (85.38)	509.41 (87.15)
Incongruent	630.98 (154.37)	641.56 (140.28)	635.23 (104.93)	663.90 (134.69)	584.02 (95.32)	592.02 (116.35)	609.75 (121.12)	619.55 (97.92)
Neutral	511.00 (79.42)	500.36 (64.49)	523.59 (75.24)	523.98 (85.48)	484.15 (67.67)	469.82 (65.54)	519.14 (84.20)	500.54 (75.79)
Neutral Group								
Congruent	497.65 (69.93)	497.77 (76.61)	529.64 (73.57)	532.79 (81.55)	476.46 (76.69)	484.95 (89.69)	494.88 (71.78)	515.75 (85.10)
Incongruent	604.44 (104.02)	634.39 (106.83)	615.31 (97.40)	648.90 (108.35)	572.23 (89.51)	586.22 (103.49)	589.97 (92.98)	608.72 (91.71)
Neutral	492.02 (82.79)	495.04 (81.71)	511.03 (69.28)	517.46 (75.11)	464.97 (81.40)	484.08 (68.19)	489.13 (72.72)	511.44 (78.74)
All Participants								
Congruent	505.38 (89.22)	500.30 (74.14)	524.42 (80.93)	533.10 (75.07)	482.80 (75.78)	484.63 (80.22)	509.58 (79.07)	512.99 (85.26)
Incongruent	616.02 (127.82)	637.52 (121.39)	624.00 (100.29)	655.44 (119.60)	577.37 (91.41)	588.75 (108.28)	598.60 (105.59)	613.45 (93.73)
Neutral	500.30 (81.15)	497.37 (74.08)	516.51 (71.53)	520.30 (79.10)	473.34 (75.66)	477.85 (66.81)	502.23 (78.63)	506.68 (76.94)

Note. Mean (*SD*) reaction times are presented in milliseconds. The columns represent the Study Period, Face Type, and Cue Type factors. The rows represent the Mood Group and Flanker

Type factors.

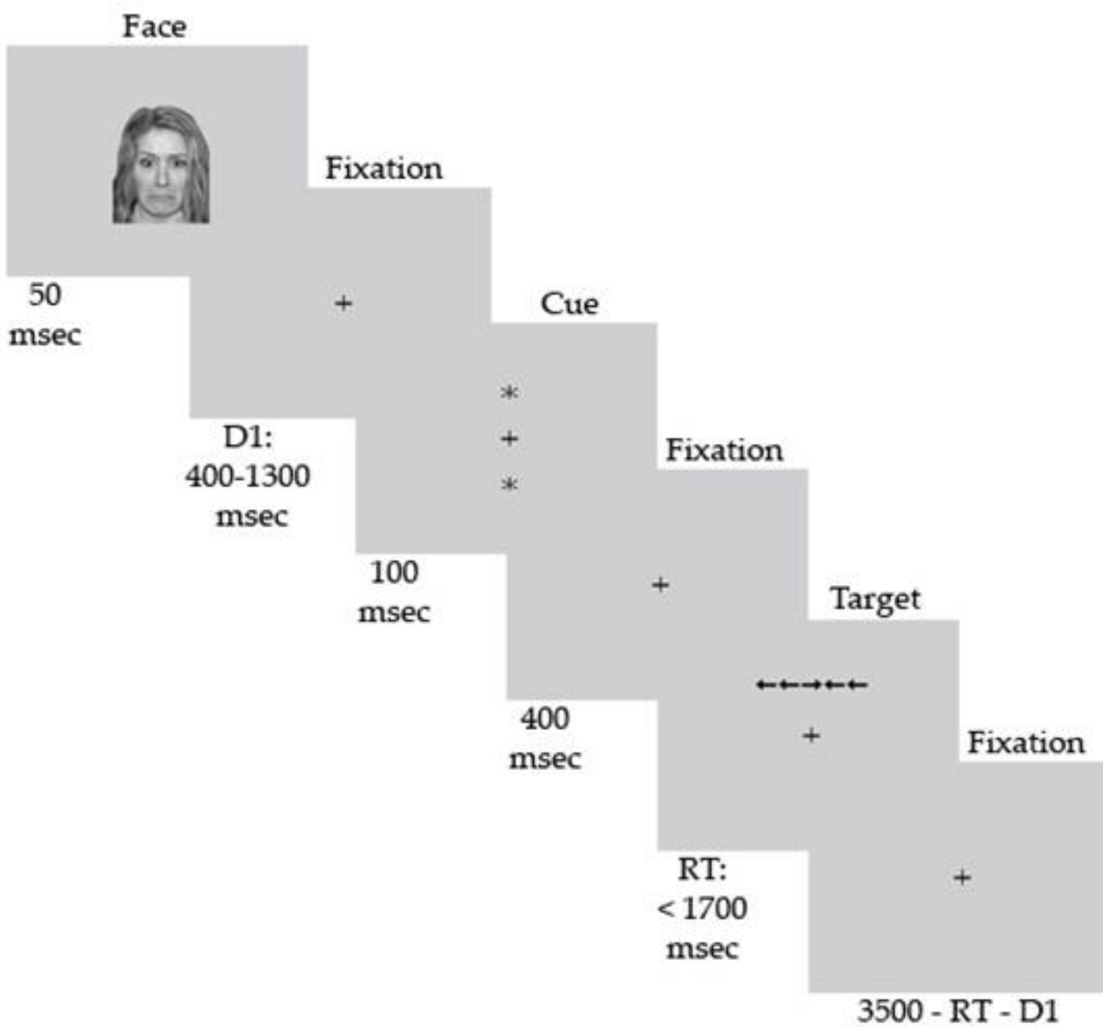

Figure 1. Trial structure for the modified Attention Network Test. In this example trial, the participant saw a fearful face as a task-irrelevant stimulus. This was followed by a fixation cross and then a double cue (which will tend to increase alerting efficiency relative to trials with no cue). The double cue was followed by another fixation cross and then the target was presented. The target in this case was a right-facing arrow which was surrounded by left-facing arrow flankers. Thus, this was an incongruent trial (which will tend to increase conflict, i.e., decrease executive control efficiency, relative to trials with congruent arrows). The trial ends with a variable-interval fixation cross that makes each trial last a total of 4,050 ms.

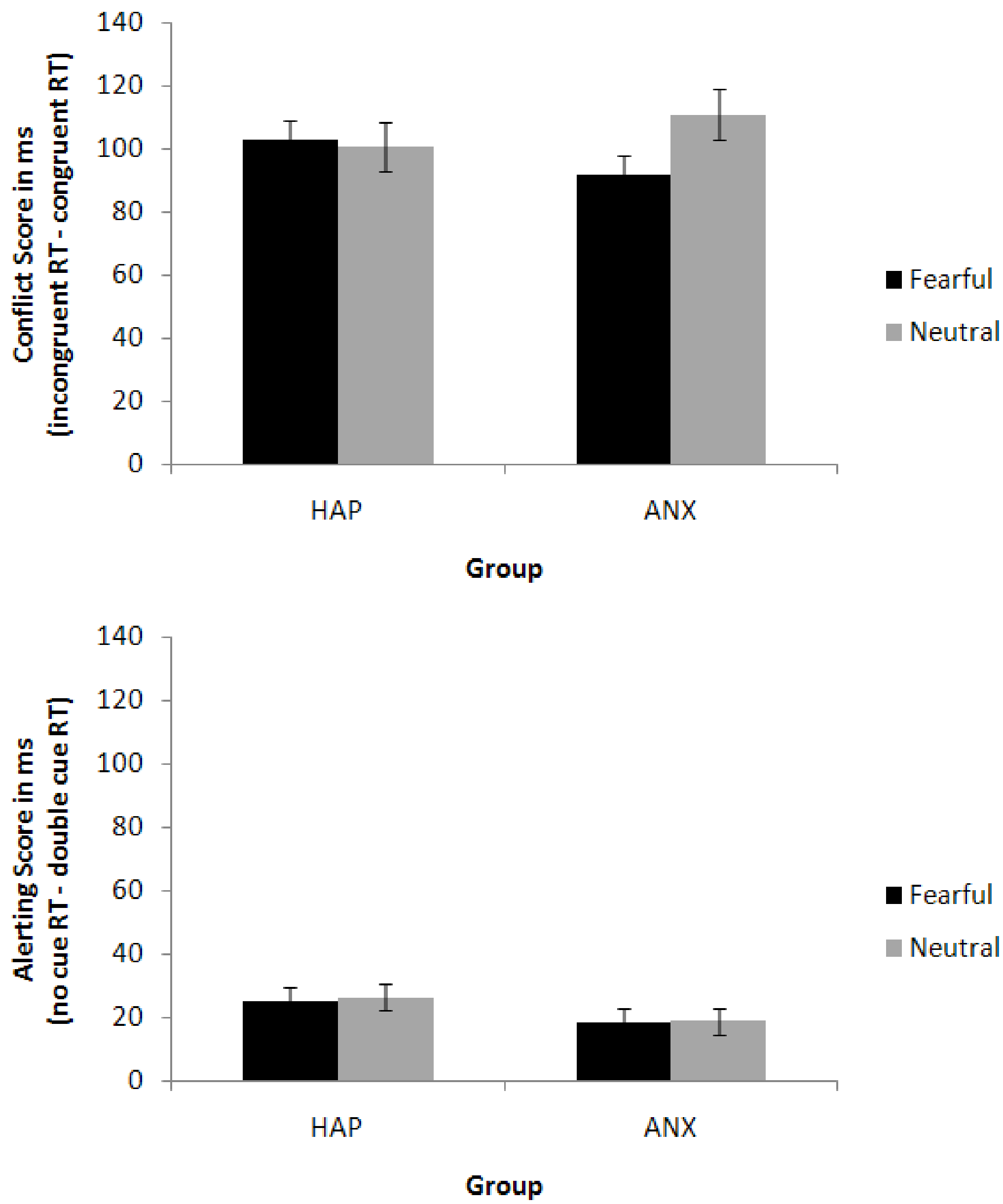

Figure 2. These two panels depict attention network efficiency scores for reaction time (RT) differences as a function of happy (HAP) and anxious (ANX) mood states for trials preceded by fearful faces (black bars) and neutral faces (gray bars). The top figure shows conflict scores (incongruent – congruent) and the bottom figure shows alerting scores (no cue – double cue). Note that conflict scores are inversely related to executive control network efficiency. Error bars represent standard error of the mean.

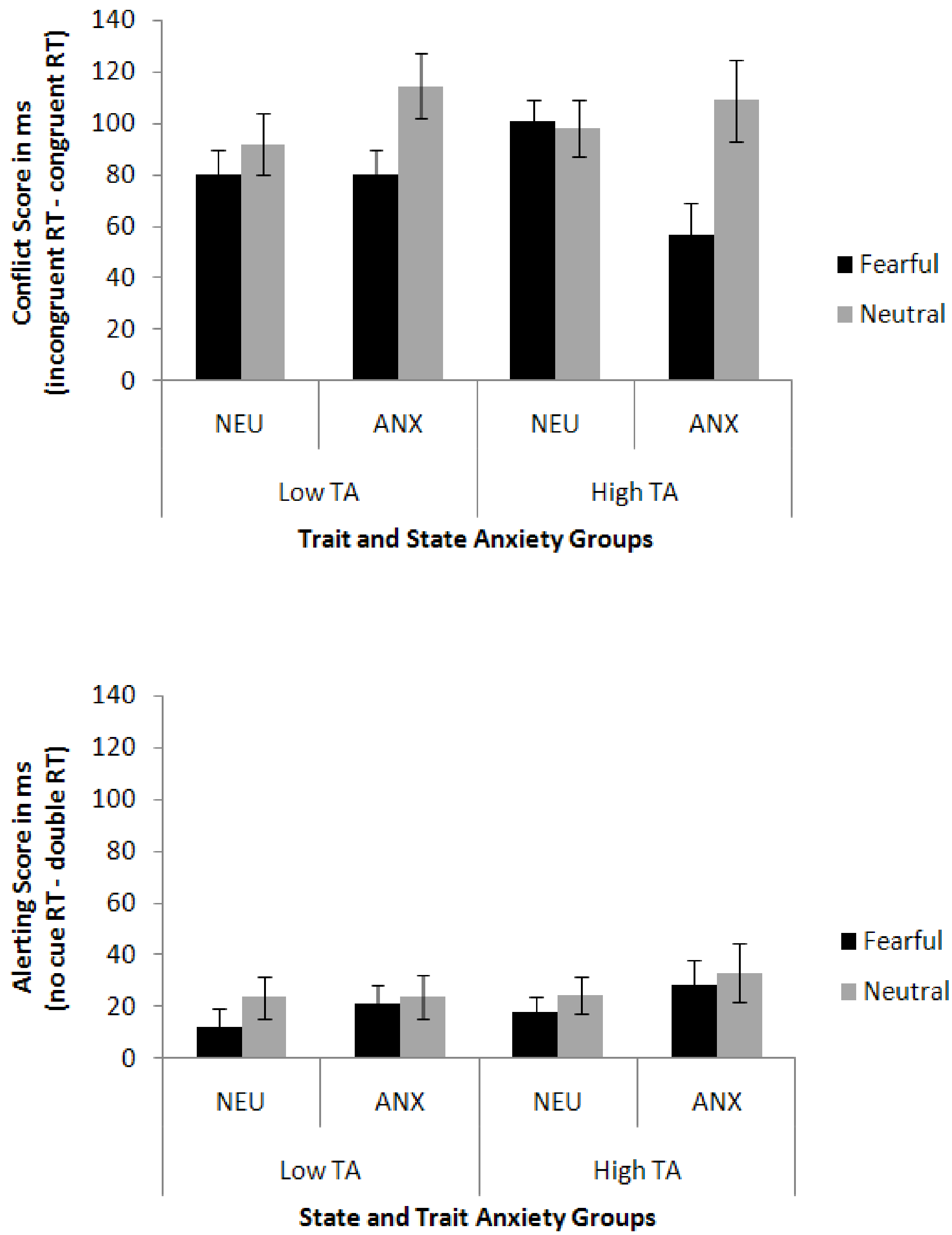

Figure 3. These two panels depict attention network efficiency scores for reaction time (RT) differences as a function of neutral (NEU) and anxious (ANX) mood states and low and high trait anxiety (TA) for trials preceded by fearful faces (black bars) and neutral faces (gray bars). The top figure shows conflict scores (incongruent – congruent) and the bottom figure shows alerting scores (no cue – double cue). Note that conflict scores are inversely related to executive control network efficiency. Error bars represent standard error of the mean.