Emotion
2011, Vol. 11, No. 6, 1291–1304

1528-3542/11/$12.00 DOI: 10.1037/a0026152

Threat Facilitates Subsequent Executive Control During Anxious Mood

Jeffrey L. Birk
Tufts University

Tracy A. Dennis
City University of New York

Lisa M. Shin
Tufts University and Massachusetts General Hospital/Harvard Medical School

Heather L. Urry
Tufts University

Dual competition framework (DCF) posits that low-level threat may facilitate behavioral performance by influencing executive control functions. Anxiety is thought to strengthen this effect by enhancing threat's affective significance. To test these ideas directly, we examined the effects of low-level threat and experimentally induced anxiety on one executive control function, the efficiency of response inhibition. In Study 1, briefly presented stimuli that were mildly threatening (i.e., fearful faces) relative to nonthreatening (i.e., neutral faces) led to facilitated executive control efficiency during experimentally induced anxiety. No such effect was observed during an equally arousing, experimentally induced happy mood state. In Study 2, we assessed the effects of low-level threat, experimentally induced anxiety, and individual differences in trait anxiety on executive control efficiency. Consistent with Study 1, fearful relative to neutral faces led to facilitated executive control efficiency during experimentally induced anxiety. No such effect was observed during an experimentally induced neutral mood state. Moreover, individual differences in trait anxiety did not moderate the effects of threat and anxiety on executive control efficiency. The findings are partially consistent with the predictions of DCF in that low-level threat improved executive control, at least during a state of anxiety.

Keywords: low-level threat, executive control, state anxiety, trait anxiety, dual competition framework

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

One candidate attentional mechanism 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). An essential component of executive control is response inhibition, namely the ability to inhibit dominant or prepotent responses as needed (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Response inhibition may be critical for promoting adaptive functions following threat experiences. Imagine, for example, that you are having a conversation with a friend during a hike in the woods when suddenly you encounter a poisonous snake. The most advantageous response in this scenario would involve rapidly detecting the snake while also inhibiting previously planned actions related to the conversation. To explain how the executive control of attention influences the effect of threat on behavior, Pessoa (2009) proposed dual competition framework (DCF).

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 perceptual processing, its effect on executive control depends dramatically on the level of threat (e.g., high/extreme, low/mild). Specifically, DCF leads to the prediction that a high-threat stimulus places a premium on processing of the threat and, thus, reduces the executive resources that are available to manage responses to stimuli other than the threat itself (i.e., "hard prioritization"). A low-threat stimulus, on the other hand,

This article was published Online First November 7, 2011.

Jeffrey L. Birk and Heather L. Urry, 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.

We thank Tufts University for their assistance in funding this work via two Graduate Student Research Awards to J. L. Birk. We also 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. Finally, we 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 Heather L. Urry, Department of Psychology, Tufts University, 490 Boston Avenue, Medford, MA 02155. E-mail: heather.urry@tufts.edu

places a smaller premium on processing of the threat and, thus, has minor effects on the availability of executive resources to manage responses to stimuli other than the threat (i.e., "soft prioritization"). In fact, according to DCF, low-level threats prioritize subsequent processing at the location of the threat "as part of additional information gathering" (p. 161) and thus should enhance subsequent task performance at that same location.

Several studies have provided evidence for the conclusion that threat can improve executive control function (Blanchette, 2006; Cohen, Henik, & Mor, 2011; Öhman, Flykt, & Esteves, 2001; Schimmack, 2005; but see Krysko & Rutherford, 2009). However, missing from these studies is a consideration of state-dependent influences (e.g., mood state). Indeed, DCF proposes that the executive enhancement seen in response to low-level threat should be especially pronounced for people in an elevated state of anxiety because elevated anxiety heightens the perceived affective significance of the threat. Consistent with this idea, the presentation of low-threat stimuli (i.e., fearful faces) relative to neutral stimuli (i.e., neutral faces) improved subsequent executive control efficiency for people with high levels of naturally occurring state anxiety but not for people with low levels of anxiety (Dennis, Chen, & McCandliss, 2008). Similarly, a second study found that higher levels of executive control efficiency following presentation of fear-evoking stimuli (e.g., pictures of sharks) but not neutral stimuli (e.g., pictures of fish) were correlated with higher levels of naturally occurring state anxiety (Finucane & Power, 2010). However, because naturally occurring state anxiety might covary systematically with unmeasured/unknown extraneous variables (e.g., arousal, intelligence, personality traits), it is possible that a third variable might explain the moderating effects of state anxiety that were observed in these two studies.

Finally, a shared limitation of existing studies is their focus on one, unpleasant arousing mood state, namely anxiety. It may be that 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, which is an aroused, positively valenced mood state, 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), as compared with a neutral state (but see Finucane, Whiteman, & Power, 2009). Finucane (2011) demonstrated that experimentally induced fearful and angry mood states improved executive control efficiency relative to a neutral mood state, but to our knowledge, only one study has directly compared effects of experimentally induced anxious and positive ("nonanxious") moods on executive control efficiency (Pacheco–Unguetti, Acosta, Callejas, & Lupiáñez, 2010). In that study, there was no effect of induced mood state on executive control efficiency. It is important that neither Finucane (2011) nor Pacheco–Unguetti et al. (2010) evaluated the effect of threat.

In what follows, we present the results of two studies, for each of which the goal was to determine whether low-level threat stimuli would, as predicted by DCF, facilitate subsequent executive control efficiency in the context of an experimentally manipulated state of anxiety. In Study 1, we compare the effect of threat during experimentally manipulated anxiety to the effect of threat during experimentally manipulated happiness. In Study 2, we compare the effect of threat during experimentally manipulated anxiety to the effect of threat during an experimentally manipulated neutral mood state. Because there is some indication that experimental demonstrations of threat-related attentional capture may reflect an interaction between state and trait anxiety (for a review, see Williams, Mathews, & MacLeod, 1996), we also examine whether effects of low-level threat and manipulated anxiety depend on individual differences in trait anxiety.

In both studies, 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. To measure the executive control of attention, participants completed a modified version of the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) following the mood-induction procedure. In this variant of the ANT (Dennis et al., 2008), each trial was preceded by a threat-related (fearful face) or nonthreat-related (neutral face) stimulus. Fearful faces constitute low-level threat stimuli because they do not directly jeopardize one's survival, but they nevertheless clearly signify the potential presence of danger. For each cell of the design, we calculated a conflict score—a behavioral index of the efficiency with which a person uses executive control to inhibit a dominant response. As a test of specificity, we also calculated an alerting score, a behavioral index of the efficiency with which one achieves a state of readiness to act. 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).

Study 1

In Study 1, we tested the hypothesis that the presentation of a fearful face relative to a neutral face increases executive control efficiency in response to target stimuli presented subsequently at the same spatial location. Given the well-established link between anxiety and threat, it was possible that the facilitative effect of low-level threat on executive control efficiency would occur only for people in an anxious mood state and not for people in a happy mood state. However, if the effect of an anxious mood state is explained by arousal, then a similar effect would be observed during the equally arousing happy mood state. Finally, although our primary focus was to determine whether low-level threat would facilitate subsequent executive control, we also examined whether threat would influence attention more broadly, in which case we would also observe effects of low-level threat on alerting.

Method

Participants

Sixty-one undergraduate students from Tufts University (35 female; mean $[M]_{age}$ = 20.10 years, standard deviation $[SD]_{\mathrm{age}}$ = 1.76) participated for course credit or monetary compensation. Participants were 67.2% Caucasian, 19.7% Asian or Asian American, and 8.2% Black or African American; 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 manipulation. 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 31 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 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). 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 12 pictures with associated storyline text, and lasted 4 min. Each picture was presented with text at the top of the screen for 12 s and then without text for another 8 s. 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, since 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 EMG activity over the corrugator supercilii muscle region. Relative to a neutral baseline, greater corrugator activity is observed for unpleasant emotions, whereas 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 1,000 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 further smoothed with a 1-s prior moving average filter. These steps were completed in part with Matlab software (Mathworks, Natick, MA) using ANSLAB routines (Wilhelm & Peyk, 2005). Corrugator activity was averaged across the 4-min duration of 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 ANT (Fan et al., 2002) similar to that used by Dennis and colleagues (2008). The modified ANT allowed us to measure the efficiency of the 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). Since the effects of induced mood could be time limited, we excluded trials from the original ANT that measure the efficiency of the orienting network. We reasoned that this would minimize the time it would take to complete the task while at the same time maximizing our ability to test hypothesized effects on executive control efficiency and to examine specificity by retaining trials that assess alerting efficiency.

To assess executive control efficiency, 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 were generated by subtracting congruent-flanker reaction time from incongruent-flanker reaction time for correct trials. Smaller conflict scores indicate greater efficiency of executive control, specifically response inhibition.

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 reaction time from no-cue reaction time for correct trials.

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

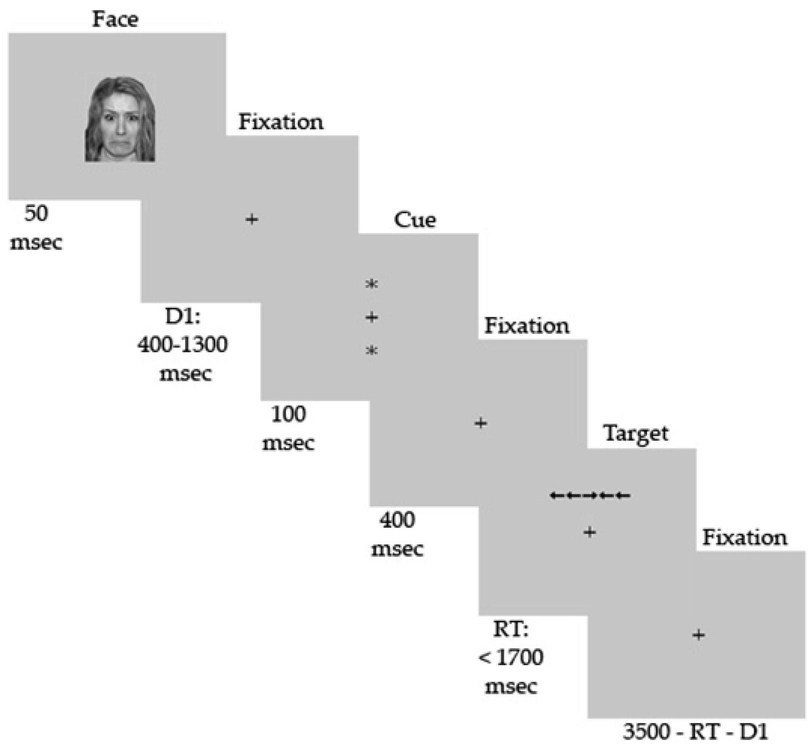

Figure 1. Trial structure for the modified Attention Network Test. In this example trial, the participant saw a fearful face which was followed by a fixation cross and then a double cue (which will tend to increase alerting efficiency relative to trials with no cue). The double cue was followed by another 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.

Higher alerting scores indicate greater efficiency in achieving a state of action readiness.

To examine the influence of threat on subsequent efficiency 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. Following Dennis et al. (2008), the delay between the offset of the face and the onset of the target varied randomly between 900 ms and 1800 ms (see Figure 1). Faces from 12 actors were selected from the NimStim collection (Tottenham et al., 2009). Greater 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 for each mood group. Accuracy data will not be reported for Study 1 or Study 2 because the ANT was designed to measure efficiency, which is our primary dependent variable of interest. Furthermore, the accuracy data are not normally distributed.

Procedure

Participants completed the tasks in the following order: 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 reaction time and accuracy feedback. A total of 192 no-feedback trials were then 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

For each reaction time measure (conflict score and alerting score), Mahalanobis distance was computed for each participant across levels of the within-subjects independent variables to identify multivariate outliers. 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). In the general linear model (GLM) analyses below, we report results of multivariate F statistics ($\alpha = .05$) and follow-up Fisher's least significant difference tests as needed to interpret significant results.

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

GLMs were performed within each group to examine the effects of arousal (arousing, nonarousing) and period (preinduction, postinduction) on self-reported PA and NA from the PANAS. In addition, paired samples *t* tests were performed within each group to compare the arousing (anxious, happy) conditions to the nonarousing (neutral) condition on mean corrugator activity, a second index of mood valence.

In the happy group, a significant interaction of Arousal × 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, postinduction PA was higher for the arousing (happy) than the nonarousing (neutral) condition ($p < .001$), but there was no such difference in preinduction PA ($p = .291$). In addition, mean corrugator activity was significantly lower (i.e., less "frowning") during the arousing (happy $M = 0.60$, $SD = 0.33$) than during the nonarousing (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 × 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, postinduction NA was higher for the arousing (anxious) than the nonarousing (neutral) condition ($p < .001$), but there was no such difference in preinduction NA ($p = .562$). In addition, mean corrugator activity was significantly greater (i.e., more "frowning") during the arousing (anxious $M = 0.69$, $SD = 0.34$) than during the nonarousing (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 to examine the effects of arousal (arousing, nonarousing) and period (preinduction, postinduction) on self-reported arousal from the PANAS. As expected, there were significant Arousal × 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, postinduction arousal was higher for the arousing (anxious or happy) than the nonarousing (neutral) condition in both groups (both *p*s $< .001$), but there was no such difference in preinduction arousal in either the happy ($p = .954$) or anxious group ($p = .890$).

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 postinduction arousal score was higher in the anxious group than in the happy group, $t(59) = 2.11$, $p = .039$. However, the preinduction arousal score was also marginally higher in the anxious group than in the happy group, $t(59) = 1.80$, $p = .077$. Taking this preinduction difference into account (i.e., by subtracting preinduction levels of arousal from postinduction levels), the group difference was no longer significant, $t(59) = .086$, $p = .932$. Collectively, these arousal results suggest that the happy and anxious mood states were achieved with an equivalent degree of arousal in the two groups.

Hypothesis Testing

Executive control. GLMs were conducted for the arousing mood conditions to assess the effects of threat (fearful face, neutral face), mood group (happy, anxious), and time (early [blocks 1–2], late [blocks 3–4]) on conflict scores. 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 × Threat, $F(1, 58) = 6.07$, $p = .017$, $\eta_p^2 = .095$. For early trials, which occurred soon after 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 late 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 × Mood Group interaction, $F(1, 58) = 4.37$, $p = .041$, $\eta_p^2 = .070$. 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 × Threat × 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 to examine the effects of threat and flanker (incongruent, neutral,

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

	Preinduction		Postinduction	
	Arousing mood	Nonarousing mood	Arousing mood	Nonarousing 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 $p < .05$.

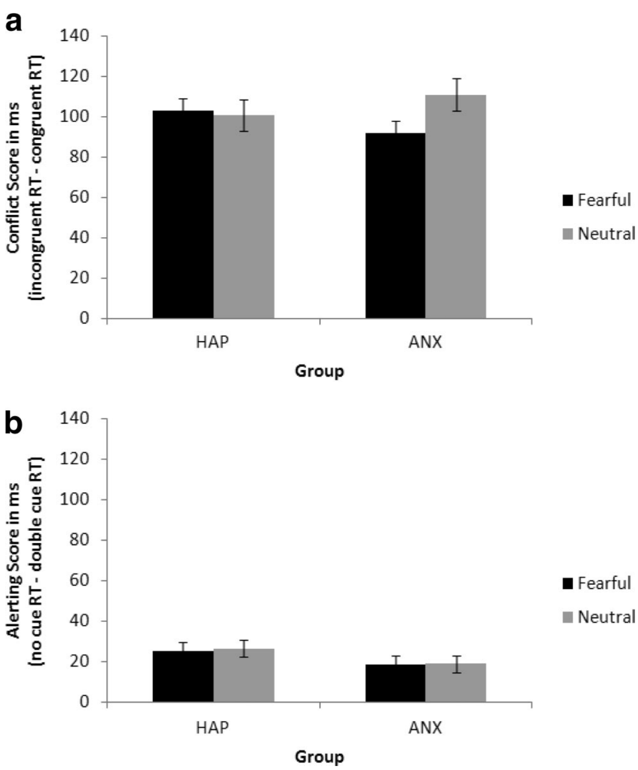

Figure 2. These two panels depict attention network efficiency scores in Study 1 for reaction time (RT) differences as a function of happy (HAP) and anxious (ANX) mood states for trials preceded by fearful faces (black bars) and neutral faces (gray bars). The top figure shows conflict scores (incongruent—congruent) and the bottom figure shows alerting scores (no cue—double cue). Note that conflict scores are inversely related to executive control efficiency. Error bars represent ± 1 standard error.

congruent) on raw reaction times. An interaction of Threat × Flanker, $F(2, 27) = 7.46$, $p = .003$, $\eta_p^2 = .356$, indicated that RT were faster to 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, $p = .072$. RT were also significantly slower for neutral-flanker trials preceded by fearful faces ($M = 494.15$ $SD = 47.88$) versus neutral faces ($M = 486.11$, $SD = 49.74$), $p = .044$. 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 RT in the incongruent condition and a marginal threat-related slowing in the congruent condition. Thus, the attentional effect of threat among people in an anxious mood is not simply a threat-related enhancement of attention to the central location or a threat-related increase in general effort, which would be manifested as faster responses for trials preceded by fearful faces relative to neutral faces irrespective of flanker type.

To examine the effect of arousing mood alone, separate paired *t* tests were conducted for each mood group to compare conflict scores for the arousing (anxious or happy) condition to the nonarousing (neutral) condition. For the anxious group, conflict scores did not differ between the arousing (anxious $M = 101.34$, $SD = 33.86$) and nonarousing (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 arousing (happy $M = 102.01$, $SD = 32.12$) and nonarousing (neutral $M = 99.55$, $SD = 29.16$) conditions, $t(30) = 0.61$, $p = .545$. These results show that arousing mood alone was not sufficient to influence executive control efficiency for either group.

Alerting. GLMs were conducted for the arousing mood conditions to assess the effects of threat (fearful face, neutral face), mood group (happy, anxious), and time (early, late) on alerting scores. 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 late relative to the early trials, all other Fs < 1.89. Thus, there was no threat-related facilitation of alerting efficiency in either group (see Figure 2b), which suggests specificity in the threat-related facilitation of executive control efficiency in the anxious group.

To examine the effect of arousing mood alone, separate paired *t* tests were conducted for each mood group to compare alerting scores for the arousing (anxious or happy) condition to the nonarousing (neutral) condition. For the anxious group, alerting scores did not differ between the arousing (anxious $M = 18.66$, $SD = 21.82$) and nonarousing (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 arousing (happy $M = 25.93$, $SD = 18.68$) and nonarousing (neutral $M = 28.17$, $SD = 20.60$) conditions, $t(29) = -0.65$, $p = .521$. These results show that arousing mood alone was not sufficient to influence alerting efficiency for either group.

Discussion

Using a novel, multimodal mood-induction procedure, we found that threat-related stimuli facilitated subsequent executive control efficiency during experimentally induced state anxiety. There was no parallel effect of threat on alerting efficiency, which suggests that threat had a specific effect on executive control. 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 experimentally induced state anxiety cannot be explained by arousal. These findings indicate that state anxiety may potentiate the facilitative effect of low-level threat on subsequent executive control efficiency.

There were four important limitations to Study 1. First, among people with high trait anxiety, which is the dispositional tendency to be anxious, threat has been shown to have an inhibiting effect on executive control (Derakshan & Eysenck, 2009; Derryberry & Reed, 2002; Eysenck, Derakshan, Santos, & Calvo, 2007; Wood, Mathews, & Dalgleish, 2001). It may be that the threat-related facilitation of executive control efficiency observed during state anxiety in Study 1 would be absent or perhaps even reversed in participants with high trait anxiety. Second, although unlikely given random assignment of participants to conditions, 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. Third, although the anxious and happy moods were purposefully matched for arousal, the mood states might have differed in other undesirable ways. For example, happiness might be uniquely associated with alterations in self-focused attention (Green, Sedikes, Saltzberg, Wood, & Forzano, 2003) or a generally reduced cognitive capacity (Mackie & Worth, 1989). Fourth, although we confirmed that the mood manipulations induced arousing negative and positive moods using measures that were sensitive to valence and arousal, we could not specifically confirm that participants were anxious in response to the anxious mood manipulation. To address these four limitations while replicating the primary finding, we conducted Study 2.

Study 2

As in Study 1, we examined the effects of low-level threat and experimentally induced state anxiety on executive control efficiency as measured using our modified version of the ANT. Each trial of the ANT was preceded by a threatening or nonthreatening stimulus (fearful or neutral face, respectively). For this follow-up study, we added a measure of trait anxiety and a premood-induction ANT. This enabled us to test whether the effects of threat and state anxiety depend on level of trait anxiety, and to rule out the possibility that our two mood groups differed in attentional efficiency prior to the mood induction. Moreover, rather than using a happy mood induction as our comparison group, participants were randomly assigned to an anxious or neutral mood group. Finally, we replaced the valence and arousal mood-manipulation measures from Study 1 with specific self-report measures of anxiety before and after every mood induction. Consistent with the rationale for and findings from Study 1, we tested the hypothesis that the presentation of a fearful face relative to a neutral face would increase executive control efficiency in anxious people.

Method

The methods used for Study 2 were identical to those described for Study 1, except as noted below.

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, and 0.8% American Indian or Alaska Native; 3.3% declined to provide this information. Of the total sample, 14.9% endorsed being of Hispanic origin.

Materials

Trait Anxiety Groups

Participants completed the trait form (Y-2) of the State–Trait Anxiety Inventory for Adults (STAI; Spielberger, 1983). The total scores for the STAI 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).

Mood manipulation. Participants were randomly assigned to one of two groups. Sixty participants completed the anxious mood induction, and 61 participants completed the neutral mood induction.

Mood measures. In addition to recording corrugator activity, 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. 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 before and after each task using mood ratings that were modified from the adjective triplets used by Tamir, John, Srivastava, and Gross (2007). These ratings captured anxiety (e.g., *anxious, worried, fearful*) and general arousal (e.g., *active, alert, keyed up*) (see Nitschke, Heller, Palmieri, & Miller, 1999). They also included filler items corresponding to other negative and positive emotional states so as not to emphasize negative mood categories (and anxiety specifically) and thereby reduce demand characteristics (data not reported). Participants reported how strongly they felt each set of adjectives "right now, at this very moment" on a 7-point scale from 0, *not at all*, to 6, *very much*.

ANT. Before and after the mood induction, participants completed a two-block version of the ANT administered in Study 1 to assess the efficiency of executive control and alerting attention networks. Since the threat-related effects were strongest early in the task during Study 1, the overall length of the ANT was shortened in Study 2 to focus on attentional effects occurring close to the end of the mood induction. 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).

Procedure

Participants completed the tasks in the following order: a dot probe task (data not presented as they are not the focus of this report), demographic questionnaire and STAI, STICSA/triplets, baseline ANT, STICSA/triplets, mood induction (ANX or NEU), STICSA/triplets, experimental ANT, STICSA/triplets.

Results

Data Retention and Analysis

Using Mahalanobis distance, 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. One hundred fifteen participants were included in the manipulation checks that follow (34 anxious mood, low trait anxiety; 24 anxious mood, high trait anxiety; 26 neutral mood, low trait anxiety; 31 neutral mood, high trait anxiety). There was no significant difference in level of trait anxiety for participants assigned to the anxious ($M = 39.84$, $SD = 10.25$) and neutral ($M = 41.47$, $SD = 10.08$) mood conditions, $t(114) = 0.86$, $p = .392$, suggesting that state and trait anxiety were not confounded.

Manipulation Checks

To determine whether the mood manipulations were successful, GLMs were performed to assess the effects of mood group (anxious, neutral), trait anxiety group (low TA, high TA), and period (preinduction, postinduction) on the STICSA and on the anxiety-relevant adjective triplets from the mood ratings. In addition, a GLM was also performed to examine the effects of mood group (anxious, neutral) and trait anxiety group (low TA, high TA) on mean corrugator activity during the mood manipulations.

There was a trend toward a main effect of mood group, $F(1, 112) = 2.99$, $p = .087$, $\eta_p^2 = .026$, and a significant main effect of period on STICSA somatic anxiety scores, $F(1, 112) = 15.96$, $p < .001$, $\eta_p^2 = .125$. These effects were qualified by a significant Mood Group × Period interaction, $F(1, 112) = 34.82$, $p < .001$, $\eta_p^2 = .237$, which revealed that preinduction scores were not different for the anxious ($M = 14.52$, $SD = 3.41$) relative to the neutral ($M = 14.85$, $SD = 3.41$) group, $p = .620$, but postinduction scores were greater for the anxious ($M = 16.94$, $SD = 4.18$) relative to the neutral ($M = 14.30$, $SD = 4.07$) group, $p = .001$. As anticipated, there was a main effect of trait anxiety such that high TA participants had overall higher scores ($M = 16.06$, $SD = 3.52$) than low TA participants ($M = 14.19$, $SD = 3.63$), $F(1, 112) = 8.34$, $p = .005$, $\eta_p^2 = .069$. There were no other significant effects involving trait anxiety, however, indicating that the impact of the mood inductions on somatic anxiety did not differ as a function of trait anxiety.

The analysis of STICSA cognitive anxiety scores revealed only the expected main effect of trait anxiety group such that, as above, high TA participants had overall higher scores ($M = 17.00$, $SD = 4.50$) than low TA participants ($M = 12.70$, $SD = 4.50$), $F(1, 112) = p < .001$, $\eta_p^2 = .186$. There were no other significant effects or interactions, all other Fs ≤ 0.91.

The parallel analysis on scores for the *anxious, worried, fearful* and *active, alert, keyed up* triplets revealed significant Mood Group × Period interactions, $F(1, 112) = 39.21$, $p < .001$, $\eta_p^2 = .259$ and $F(1, 112) = 28.59$, $p < .001$, $\eta_p^2 = .203$, respectively. Preinduction scores were not different for the anxious relative to the neutral group, ps $> .05$ but postinduction scores were greater for the anxious relative to the neutral group, ps $< .05$. There were no interactive effects involving trait anxiety. However, high TA participants endorsed feeling more *anxious, worried, fearful* ($M = 2.16$, $SD = 0.91$) than the low TA participants ($M = 1.56$, $SD = 0.91$), $F(1, 112) = 12.47$, $p = .001$, $\eta_p^2 = .100$. High TA participants also endorsed feeling less *active, alert, keyed up* ($M = 3.11$, $SD = 1.37$) than the low TA participants ($M = 3.92$, $SD = 1.36$), $F(1, 112) = 10.05$, $p = .002$, $\eta_p^2 = .082$.

In the analysis of mean corrugator activity during the mood manipulations, contrary to expectations, there was no effect of mood group, $F(1, 112) = 0.13$, $p = .719$, $\eta_p^2 = .001$, and no interaction of mood group and trait anxiety, $F(1, 112) = 1.80$, $p = .182$, $\eta_p^2 = .016$. No significant difference existed between the anxious and neutral mood groups for low TA, $p = .223$, or high TA, $p = .496$, participants. There was also no main effect of trait anxiety, $F(1, 112) = 0.810$, $p = .370$, $\eta_p^2 = .007$. Therefore, despite the evidence of the self-report measures and unlike Study 1, participants in the anxious mood induction did not exhibit greater expressive "frowning" behavior, as compared with participants in the neutral induction.

Accounting for Individual Differences in the Effectiveness of Induced Mood

Given the great importance of the corrugator measure as an index of the mood manipulation success that is relatively free of demand characteristics, the absence of a mood effect on corrugator activity suggests that anxious mood may not have been successfully induced in all participants. We therefore retained only those participants for whom the target mood was manipulated to a sufficient degree in subsequent analyses. Specifically, participants in the anxious mood group were retained only if they displayed at least a 50% increase in corrugator activity. Participants in the neutral mood group were retained only if they displayed less than a 50% increase in corrugator activity. Proportional change in corrugator activity was computed by subtracting the average activity during the 5-s period at the start of the induction (baseline) from the average activity during the 5-s period at the end of the induction and dividing this difference by the baseline.

In total, 70 participants were retained for 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). As intended, the STAI scores for retained participants were similar to scores in the full sample (low TA group: $n = 36$; $M = 32.56$, $SD = 4.78$, range: 22–39; high TA group: $n = 34$; $M = 49.65$, $SD = 6.46$, range: 40–65). In addition, there was no significant difference in TA level for participants assigned to the anxious ($M = 39.68$, $SD = 10.29$) and neutral ($M = 41.64$, $SD = 10.31$) mood conditions, $t(68) = 0.781$, $p = .437$, suggesting again that state and trait anxiety were not confounded. Participants who were retained based on the criteria above did not differ from participants who were not retained in TA, overall conflict scores, or overall alerting scores, all ps $\geq .220$.

Hypothesis Testing

Executive control. A GLM tested the effects of threat (fearful face, neutral face), mood group (neutral, anxious), trait anxiety group (low TA, high TA), and period (preinduction, postinduction) on conflict scores.[2] As in Study 1, there was a main effect of threat, $F(1, 66) = 19.91$, $p < .001$, $\eta_p^2 = .204$, such that conflict scores for trials preceded by fearful faces ($M = 88.02$, $SD = 43.09$) were lower than conflict scores for trials preceded by neutral faces ($M = 106.94$, $SD = 45.68$). There was also a main effect of period, $F(1, 66) = 7.44$, $p = .008$, $\eta_p^2 = .101$, such that conflict scores were lower during the postinduction ANT than during the preinduction ANT. No other main effects or interactions were significant, all

[2] Unlike in Study 1, a factor of Time (i.e., early vs. late trials) is not included in the analyses because each ANT consists only of blocks 1 and 2, which are together equivalent to the early trials for which the facilitation effect was discovered in Study 1.

Fs $\leq$ 1.78, all ps $\geq$ .187. However, the critical Threat $\times$ Mood Group $\times$ Period interaction was significant, $F(1, 66) = 8.61$, $p = .005$, $\eta_p^2 = .115$.

To interpret this interaction, we ran separate GLMs testing the effects of threat, mood group, and trait anxiety group on preinduction and postinduction conflict scores. As expected, the preinduction analysis revealed no main effects or interactions, all Fs $\leq$ 1.67, all ps $\geq$ .200. In contrast, the postinduction 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 $\times$ Mood Group, $F(1, 66) = 9.37$, $p = .003$, $\eta_p^2 = .124$. For the anxious mood group, conflict scores for trials preceded by fearful faces ($M = 68.34$, $SD = 41.96$) were lower than conflict scores preceded by neutral faces ($M = 111.90$, $SD = 53.44$), $p < .001$. However, for the neutral mood group, conflict scores for trials preceded by fearful faces ($M = 90.52$, $SD = 41.22$) were not significantly different from conflict scores for trials preceded by neutral faces ($M = 94.89$, $SD = 52.43$), $p = .587$. 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, we computed a follow-up GLM to examine the effect of threat and flanker (incongruent, neutral, congruent) on raw RT. An interaction of Threat $\times$ Flanker emerged, $F(2, 26) = 12.64$, $p < .001$, $\eta_p^2 = .493$. As in Study 1, RT were faster to incongruent-flanker trials preceded by fearful faces ($M = 561.12$, $SD = 105.20$) versus neutral faces ($M = 585.79$, $SD = 96.20$), $p = .007$. RT were marginally slower for congruent-flanker trials preceded by fearful faces ($M = 490.30$, $SD = 92.81$) versus neutral faces ($M = 473.29$, $SD = 83.92$), $p = .077$. RT were also significantly slower for neutral-flanker trials preceded by fearful faces ($M = 485.53$, $SD = 81.59$) versus neutral faces ($M = 466.71$, $SD = 78.68$), $p = .019$. As in Study 1, this pattern of results suggests that the attentional effect of threat among people in an anxious mood is not simply a threat-related enhancement of attention to the central location or a threat-related increase in general effort, which would manifest as faster responses for trials preceded by fearful faces relative to neutral faces for all three flanker types.

Alerting. A GLM was conducted to examine the effects of threat (fearful face, neutral face), mood group (neutral, anxious), trait anxiety group (low TA, high TA), and period (preinduction, postinduction) on alerting scores. There were no significant main effects or interactions, all Fs $\leq$ 2.27, all ps $\geq$ .137. Consistent with Study 1, this suggests specificity in the threat-related facilitation of executive control efficiency in the anxious group. See Figure 3b for a presentation of the alerting scores for all levels of threat, mood group, and trait anxiety group for the postinduction ANT.[3]

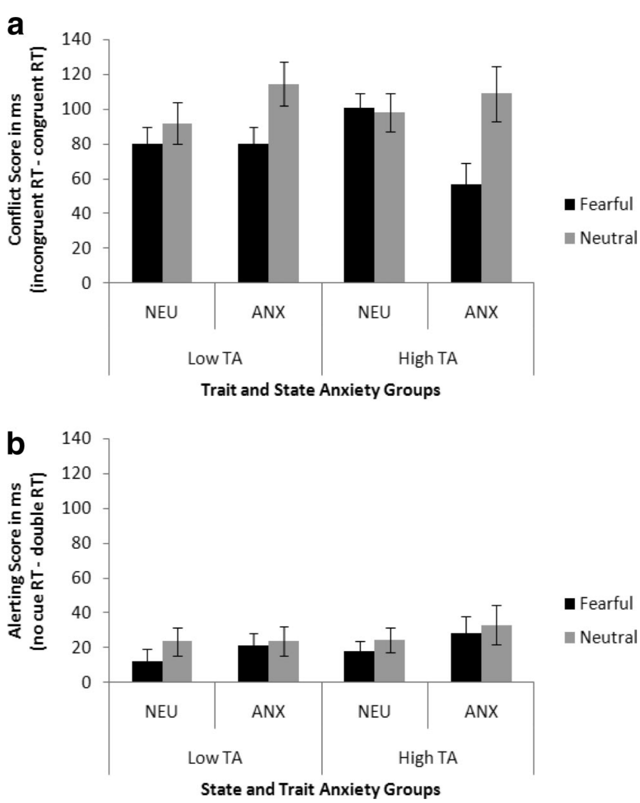

Figure 3. These two panels depict attention network efficiency scores in Study 2 for reaction time (RT) differences as a function of neutral (NEU) and anxious (ANX) mood states and low and high trait anxiety (TA) for trials preceded by fearful faces (black bars) and neutral faces (gray bars). These results pertain to participants for whom the mood inductions were effective. 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 efficiency. Error bars represent ± 1 standard error.

Discussion

Consistent with our hypothesis, participants effectively induced into an anxious mood state demonstrated facilitated efficiency of executive control following stimuli that were mildly threatening relative to nonthreatening. No such effect was present for participants effectively induced into a neutral mood state and there were no threat-related or overall effects involving state anxiety on alerting efficiency. Moreover, there were no effects of trait anxiety on executive control efficiency. In fact, not only did the facilitative effect of threat as a function of experimentally manipulated state anxiety not depend on trait anxiety, trait anxiety also did not affect executive control as a main effect. In sum, these results suggest that an attentional boost follows threat during an anxious state, regardless of one's level of anxious disposition (at least within a normal range); this attentional benefit specifically takes the form of improved efficiency of executive control.

General Discussion

Taken together, and consistent with DCF, the present studies demonstrate a replicable, threat-driven improvement in executive

[3] In order to test for possible effects of trait anxiety as a continuous measure, the five analyses for the manipulation check were conducted again as GLMs with STAI score as a covariate instead of TA Group as a two-level factor. Similarly, for the final set of retained participants, the three GLMs for conflict reaction time scores and the GLM for alerting reaction time scores were repeated with STAI score as a covariate. Apart from the same four main effects of trait anxiety reported in the original analyses (i.e., STICSA somatic; STICSA cognitive, *anxious, worried, fearful* triplet; *active, alert, keyed up* triplet), there were no other significant effects involving trait anxiety in any of these nine GLMs, all Fs $\leq$ 1.64, all ps $\geq$ .204.

control efficiency as a function of low-level threat during state anxiety. Study 1 reveals that this effect is not simply due to the arousing nature of anxiety; Study 2 reveals that this effect does not depend on the level of trait anxiety. Both studies suggest that threat-related facilitation of attention during an anxious state is specific to executive control efficiency as no such effect was observed for alerting efficiency.

Although previous 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, Russo, Bowles, & Dutton, 2001), few have addressed the combined effects of threat and state anxiety on the efficiency of executive attention specifically, and to date those studies have only examined individual differences in anxious mood (Dennis et al., 2008; Finucane & Power, 2010). In the present studies we randomly assigned participants to mood conditions in order to eliminate the influence of potentially confounding extraneous variables (e.g., enduring personality characteristics that systematically predispose particular people to experience state anxiety). This point is especially important when attempting, as we did, to disentangle the effects of state and trait anxiety.

It is interesting that experimentally manipulated anxiety failed to independently facilitate executive control in these studies, which is consistent with findings of Pacheco–Unguetti and colleagues (2010). This null result for anxiety seems at odds with studies suggesting that other negative emotions, specifically fear and anger, can facilitate executive control even in the absence of threat (Finucane, 2011). However, Gable and Harmon–Jones (2010a; 2010b) have suggested that any emotion that engenders sufficiently high levels of motivational intensity—that is, "impetus to act"—should enhance attentional focusing (Gable & Harmon–Jones, 2010a; Gable & Harmon–Jones, 2010b). Although attentional focusing is not isomorphic with executive control, it may be that our experimental manipulation of anxiety only engendered sufficient motivational intensity to enhance executive control when coupled with threat, a notion that is reminiscent of DCF's consideration of affective significance.

Implications for Dual Competition Framework

According to DCF, threat-related stimuli carry affective significance, which alters behavior by strengthening sensory representations at the perceptual level and by prioritizing attention at the executive level. The present findings are entirely consistent with this formulation, at least with regard to manipulated anxiety. We speculate that the mechanism for threat-related facilitation of executive control during state anxiety was a soft prioritization of perceptual processing, specifically processing the spatial location of threat. In other words, experimentally manipulated state anxiety led participants to pay greater attention to the spatial location of fearful faces than neutral faces, which facilitated executive control efficiency. However, we have no direct measure of attention to threat in the ANT. In future work, it would be useful to manipulate the validity with which the faces predict the spatial location of the target. If fearful faces were invalid cues for the spatial location of the target, DCF would predict threat-related hampering (certainly not threat-related facilitation) of executive control.

DCF is founded largely on neuroanatomical and functional neuroimaging findings such that each aspect of the model corresponds to one or more brain regions (Pessoa, 2009). Substantial evidence shows that the registration of affective significance is carried out by the amygdala (Vuilleumier, 2005). Perceptual competition in the visual domain is purported to occur in extrastriate regions (Pinsk, Doniger, & Kastner, 2004). Executive competition is purported to occur in frontal regions such as anterior cingulate cortex (ACC; Westlye, Grydeland, Walhovd, & Fjell, 2011), which is known to operate in conjunction with dorsolateral prefrontal cortex (DLPFC; Silton et al., 2010). We cannot confirm these neural mechanisms in this behavioral study; future studies must investigate whether the facilitated behavioral effect is accompanied by an amygdalar response to threat stimuli that correlates with activation in DLPFC or ACC. If so, the accumulated evidence would suggest that functioning in a prefrontal–amygdala circuit is the mechanism underlying the improved executive control following the perception of threat during anxiety.

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 et al., 2001). It may be that ambiguity as to source of threat in the context of anxiety was important in increasing perceived affective significance, which then signaled the need for executive control to resolve the ambiguity. Whalen (1998) has suggested that this type of ambiguity is mediated by the amygdala, which is consistent with DCF's suggestion that the amygdala tracks affective significance. 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 asterisk cues used in the modified ANT 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 in the anxious compared to the positive group. A stronger alerting manipulation may have been necessary to prompt a threat-related boost in alerting in the present study.

Notably, we did not observe facilitated executive control efficiency in response to threat in the happy and neutral mood states. This result is not fully consistent with the predictions of DCF or with previous studies (e.g., Cohen et al., 2011). Although the model posits that the effect of low-level threat on executive control should be greatest during anxiety, it also suggests that threat should influence executive control, though to a lesser degree, even for people not in an anxious state. Anxiety-related variations in the evaluation of affective significance may have played the key role in modulating executive control in the present studies; affective significance may have simply been too low for people in happy and neutral moods to produce an effect on executive attention.

The Role of Conflict Monitoring and Adaptation

In line with the conflict-monitoring hypothesis of the ACC (Botvinick, Cohen, & Carter, 2004), we propose that reduced conflict scores in the present studies reflect the outcome of enhanced conflict monitoring and resolution processes. We speculate that this enhancement is initiated by the amygdala, which signals the high affective significance of threat stimuli in the context of anxious mood. Next, the amygdala communicates with the ACC, which signals the need to recruit executive control such that DLPFC is engaged to facilitate subsequent conflict resolution. When the target finally appears, conflict is reduced, response inhibition is increased, and behavior on incongruent trials is speeded.

Consistent with this proposed causal sequence, a negative anxious mood has been shown to result in conflict adaptation (i.e., improved executive control following cognitive conflict) in comparison to positive moods (van Steenbergen, Band, & Hommel, 2010). The processing of threat in the present studies might entail cognitive conflict if the faces were perceived to be irrelevant to 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 et al., 2006) and because the face stimuli in this task may be conceived of as distracters, the appearance of the fearful relative to the neutral faces may increase the burden on the executive control system. That is, fearful but not neutral faces may involve conflict between an innate, automatic, and dominant response (i.e., to attend to threat) and the goal of performing the task well. If threatening faces are initially associated with greater cognitive conflict than nonthreatening faces, then our findings are fully consistent with those of van Steenbergen and colleagues. The improved executive control following threat 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 mood state.

Implications for Attentional Control Theory

On the surface, the results of the present studies might seem to contradict the predictions of attentional control theory (ACT), which posits that anxiety impairs executive control efficiency and that this impairment is most evident when threat is present and irrelevant to the task at hand (for a review, see Eysenck et al., 2007; Derakshan & Eysenck, 2009). In the present studies, neither state nor trait anxiety had an independent effect on executive control. In addition, threat facilitated rather than impaired executive control efficiency during state anxiety.

Notably, most of the studies supporting ACT use tasks in which threats and targets are concurrent or temporally adjacent (e.g., dot probe, emotional Stroop). In the dot probe task, for example, threatening words, faces, or pictures are followed immediately by the dot target and, in the emotional Stroop task, threat (threatening words) and target (color of the threatening words) are one and the same. In contrast, in the present studies, we focused on the effect of prior threat on subsequent executive control efficiency. In fact, in our modified ANT the elapsed time between the offset of the threat to the onset of the target was approximately 1,350 ms, a relatively long delay (but not so long that soft prioritization of the spatial location of threat would have dissipated). Biased attention to threat may have disrupted executive control in anxious people if the delay between onset of threat and target had been considerably shorter and/or if the threat stimulus had still been present when the target appeared. Future studies should systematically vary the threat-to-target delay to determine, for example, whether facilitation of executive control efficiency in response to low-level threat strengthens, disappears, or remains unchanged at shorter (e.g., 0 to 500 ms) and longer (e.g., more than 1,800 ms) durations than the ones studied here.

Moreover, there is one sense in which our results may dovetail nicely with the predictions of ACT, which also posits that anxiety might facilitate executive control efficiency when threat is present and relevant to the task at hand. Although monitoring the fearful and neutral faces was unnecessary to make the correct behavioral response to the subsequent target, and thus not strictly task relevant, the fearful and neutral faces roughly predicted when and where the subsequent target would appear. In that looser sense, and contrary to the aforementioned possibility regarding conflict adaptation, the faces might be considered task relevant. In that case, one might interpret the facilitation of executive control by threat during a state of anxiety as being consistent with ACT. Future research should determine whether manipulating task relevance by, for example, establishing a contingency between face type and subsequent arrow flanker type, produces stronger or weaker facilitation of executive control efficiency following threat.

Implications for Clinical Theory and Practice

It is surprising that we did not observe any effect of trait anxiety on executive control efficiency, threat-related or otherwise. One account of these null findings has to do with the introduction of a delay between threat and target. As discussed above, most studies examining trait anxiety's effect on executive control use tasks with no delay between threat and target. It could be that the delay in our studies masks trait anxiety's effects on executive control for reasons that are unclear. Another, clinically relevant account of these null findings is that trait anxiety levels may not have been adequately extreme in the present sample. The mean STAI total score for the high trait-anxious group was approximately one standard deviation above the validated mean for normal college students (Spielberger, 1983). Although some studies have had comparable means for STAI total scores for participants considered to be highly trait anxious (e.g., Fox, Russo & Dutton, 2002), the average scores for participants with high trait anxiety in other studies have been considerably higher (e.g., Yiend & Mathews, 2001). Given that trait anxiety levels in the present study may have been low even for a nonclinical population, it is unclear whether threat-related effects on subsequent executive control efficiency would also emerge for people with clinical anxiety (e.g., social anxiety disorder, generalized anxiety disorder). It is possible that threat-related attentional benefits may be smaller in magnitude or perhaps even impossible to elicit in these clinically anxious populations.

Finally, although we examined anxiety as a cause of differences in attention, it is worth noting, as suggested by MacLeod, Koster, and Fox (2009), that attention can also be the cause of differences in anxiety. Indeed, 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, a contention that has received considerable empirical support (Dunning & Hajcak, 2009; Hajcak, Dunning, & Foti, 2009; Opitz, Rauch, Terry, & Urry, in press; Urry, 2010). The clinical relevance of these ideas is showcased in studies of cognitive bias modification training, in which it has been shown that manipulating attention to threat can alter levels of anxiety (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002; Schmidt, Richey, Buckner, & Timpano, 2009; See, MacLeod, & Bridle, 2009). While these studies have mostly manipulated orienting of attention to threat, the present work suggests that threat-related executive control might be an important element of attention to target in training.

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.

First, 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 this enhances the internal validity of our efforts, future projects should assess the effects of induced anxiety on threat-related attention using mood manipulations that have greater ecological validity (e.g., public speaking).

Second, although we had an objective confirmation of the valence of induced mood states (corrugator muscle activity) to supplement our self-report measures, 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 and that the anxious mood state was more arousing than the neutral mood state in Study 2.

Third, DCF proposes that low-level threat and high-level threat may actually have opposite effects on executive control function, but the present investigation did not test the effect of high-level threat. Future research should determine whether hindered executive efficiency occurs following highly threatening stimuli and whether dispositional anxiety is a key factor in predicting the occurrence of the effect.

Finally, although the conflict score has been shown to have a moderate-to-high level of reliability in a meta-analytic review, the alerting score has a relatively low level of reliability (MacLeod et al., 2010). It is possible that future research using a more reliable measure of alerting might reveal threat-related or anxiety-related effects akin to the effects on executive control reported in the two present studies.

Concluding Remarks

The present studies offer evidence that low-level threat can enhance subsequent executive control efficiency in anxious people. 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 are generally consistent with DCF. They are also consistent with ACT, that is, if one accepts that the low-level threat we studied here was perceived as task relevant. A challenge for both theories, however, is how to explain why experimentally induced state anxiety produced threat-related facilitation of executive control efficiency but trait anxiety did not. From a clinical standpoint, research that hones our understanding of 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). Such research may promote advances that aid in recovery from anxiety.

References

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

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Science, 8,* 539–546. doi:10.1016/j.tics.2004.10.003

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

Cohen, N., Henik, A., & Mor, N. (2011). Can emotion modulate attention? Evidence for reciprocal links in the Attentional Network Test. *Experimental Psychology, 58,* 171–179. doi:10.1027/1618-3169/a000083

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

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology, 111,* 225–236. doi:10.1037/0021-843X.111.2.225

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

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. (2011). The effect of fear and anger on selective attention. *Emotion, 11,* 970–974. doi:10.1037/a0022574

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

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

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, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition & Emotion, 16,* 355–379. doi:10.1080/02699930143000527

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

Gable, P., & Harmon-Jones, E. (2010a). The blues broaden, but the nasty narrows: Attentional consequences of negative affects low and high in motivational intensity. *Psychological Science, 21,* 211–215. doi:10.1177/0956797609359622

Gable, P., & Harmon-Jones, E. (2010b). The motivational dimensional model of affect: Implications for breadth of attention, memory, and cognitive categorization. *Cognition and Emotion, 24,* 322–337. doi:10.1080/02699930903378305

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. doi:10.1348/014466603763276171

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. doi:10.1037/0022-3514.74.1.224

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

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

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, FL: 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. doi:10.1037/0022-3514.57.1.27

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, 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

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,* 637–651. doi:10.1037/a0019803

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. doi:10.1146/annurev.neuro.24.1.167

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. doi:10.1111/1469-8986.3650628

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:10.1037/0096-3445.130.3.466

Opitz, P., Rauch, L. C., Terry, D. P., & Urry, H. L. (in press). Prefrontal mediation of age differences in cognitive reappraisal. *Neurobiology of Aging.*

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

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

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences, 13,* 160–166. 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

Pinsk, M. A., Doniger, G. M., & Kastner, S. (2004). Push-pull mechanism of selective attention in human extrastriate cortex. *Journal of Neurophysiology, 92,* 622–629. doi:10.1152/jn.00974.2003

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

Silton, R. L., Heller, W., Towers, D. N., Engels, A. S., Spielberg, J. M., Edgar, J. C., . . . Miller, G. A. (2010). The time course of activity in dorsolateral prefrontal cortex and anterior cingulate cortex during top-down attentional control. *NeuroImage, 50,* 1292–1302. doi:10.1016/j.neuroimage.2009.12.061

Spielberger, C. D. (1983). *State-Trait Anxiety Inventory for Adults manual.* Menlo Park, CA: Mind Garden, Inc.

Tamir, M., John, O. P., Srivastava, S., & Gross, J. J. (2007). Implicit theories of emotion: Affective and social outcomes across a major life transition. *Journal of Personality and Social Psychology, 92,* 731–744. doi:10.1037/0022-3514.92.4.731

Tottenham, N., Tanaka, J., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., . . . Nelson, C. A. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research, 168,* 242–249. doi:10.1016/j.drugalcdep.2010.05.004

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

Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Science, 9,* 585–594. doi:10.1016/j.tics.2005.10.011

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

Westlye, L. T., Grydeland, H., Walhovd, K. B., & Fjell, A. M. (2011). Associations between regional cortical thickness and attentional networks as measured by the attention network test. *Cerebral Cortex, 21,* 345–356. doi:10.1093/cercor/bhq101

Whalen, P. J. (1998). Fear, vigilance, and ambiguity: Initial neuroimaging studies of the human amygdala. *Current Directions in Psychological Science, 7,* 177–188. doi:10.1111/1467-8721.ep10836912

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. doi:10.1037/0033-2909.120.1.3

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

Yiend, J., & Mathews, A. (2001). Anxiety and attention to threatening pictures. *The Quarterly Journal of Experimental Psychology, 54*A, 665–681. doi:10.1080/02724980042000462

Received May 13, 2010
Revision received June 20, 2011
Accepted June 21, 2011 ■