Research Article

THREAT-RELATED ATTENTIONAL BIASES: AN ANALYSIS OF THREE ATTENTION SYSTEMS

Tracy A. Dennis, Ph.D.,[1]* Chao-Cheng Chen, M.S.,[1] and Bruce D. McCandliss, Ph.D.[2]

It is unclear how threat-related attentional biases affect multiple attention systems. This study used a new modification of a reaction time paradigm to examine whether inter-trial task-irrelevant fearful faces influenced the efficiency of alerting, orienting, and executive attention, and whether effects varied with level of state anxiety. Participants, 63 non-disordered adults (17 males and 46 females), reported on their subjective state anxiety and completed a modified version of the Attention Network Test in which fearful or neutral faces or control stimuli were presented briefly (50 ms) between trials of the task, but provided no task-relevant information. Across all participants, state anxiety was positively correlated with alerting, whereas fearful versus neutral faces were linked to decreased alerting efficiency. Contrasting high and low anxiety groups showed that fearful versus neutral faces reduced executive attention in the low state anxiety group only, suggesting decreased distraction by irrelevant stimuli in the high state anxiety group. Results document threat-related attentional biases that varied with attention system but failed to find enhanced bias effects among those with higher state anxiety in a typical range. This modification of the Attention Network Test, which added presentation of emotional distracters, provides a potentially useful new method for assessing the impact of task-irrelevant emotional stimuli on three aspects of attention performance. Depression and Anxiety 25:E1–E10, 2008. *Published 2008 Wiley-Liss, Inc.*†

Key words: ***threat-related attentional biases; attention systems; state anxiety***

INTRODUCTION

A prominent theme in research on attentional biases is the facilitated detection of stimuli that signify fear and threat [for a review see Bar-Haim et al., 2007; Bradley et al., 2000; Fox et al., 2002]. Within normative levels, this is an adaptive response because it is often linked to enhanced attention performance, which in turn may serve to prepare the individual to respond to threatening situations. Facilitated threat detection becomes less adaptive, however, when threats are irrelevant to current goals and serve as emotional distracters, thus resulting in attentional interference effects and compromised performance [Compton, 2003].

Enhanced detection of threat-related stimuli, such as human faces depicting fear, has been uniquely associated with elevated anxiety [Fox et al., 2001; Gasper and Clore, 2002; Keogh and French, 1999; Yiend and Mathews, 2001]. As shown in a recent meta-analysis,

[1]Department of Psychology, Hunter College, City University of New York, New York
[2]Sackler Institute for Developmental Psychobiology, Weill Medical College of Cornell University, New York, New York

Contract grant sponsor: NIH grants; Contract grant numbers: 5S06GM060654-04; 5 K01 MH075764-02; Contract grant sponsor: NSF grant; Contract grant number: REC-0337715; Contract grant sponsor: John Merck Scholars Program in the Biology of Developmental Disabilities in Children.

*Correspondence to: Tracy A. Dennis, Ph.D., Department of Psychology, Hunter College, City University of New York, 695 Park Avenue, New York, NY 10021.
E-mail: tracy.dennis@hunter.cuny.edu

Received for publication 4 August 2006; Revised 19 December 2006; Accepted 27 January 2007

DOI 10.1002/da.20308
Published online 12 June 2007 in Wiley InterScience (www.interscience.wiley.com).

however, these effects are somewhat modest [Bar-Haim et al., 2007]. This may be linked to several methodological issues, three of which are the focus of this study. First, reduced effect sizes may be attributable to method variance in the diverse ways attention is measured across studies; few if any simultaneously examine attentional biases in the multiple attention systems delineated by cognitive neuroscience, such as alerting, orienting, and executive attention [Callejas et al., 2004; Fan et al., 2002; Keogh and French, 1999]. Second, anxiety is also measured in multiple ways, including state, trait, and anxiety disorders. The degree to which bias effects are similar across different forms of anxiety might be due to elevated anxious states shared across most forms of anxiety [Compton, 2003]. Relatively few studies, however, focus on anxious states in relation to threat-related attentional biases [Rutherford et al., 2004]. Third, the task relevance of emotional stimuli varies across attentional bias studies. Some use emotional stimuli that are targets of attention during the task [Williams et al., 1996], whereas others use emotional stimuli that are task-irrelevant distracters [Bishop et al., 2004]. Task-irrelevant stimuli may capture an aspect of emotional processing that is particularly relevant for measuring attentional biases related to interference effects and emotional distractibility: these stimuli must be ignored because they provide no useful information about the task, and this requires the recruitment of attentional resources [Meinhardt and Pekrun, 2003; Mogg et al., 2000; Schupp et al., 2003]. The goal of this study was to address these three methodological issues—the measurement of attention, anxiety, and the nature of emotional stimuli—by examining threat-related attentional biases in relation to three attention systems, alerting, orienting, and executive attention, using a single reaction-time paradigm. We used task-irrelevant emotional stimuli (fearful versus neutral faces or control stimuli) to highlight the potential negative impact of emotional distracters on subsequent attention performance. We tested whether effects were enhanced or reduced in those with relatively high levels of state anxiety in a normative range.

ATTENTION SYSTEMS

Relatively few studies assess multiple aspects of attention in a single paradigm [Callejas et al., 2004; Fan et al., 2002]. This is a critical goal because emotional factors may differentially influence separable attention capacities, such as alerting, orienting, and executive attention [Fan et al., 2002; Posner and Petersen, 1990], and it is difficult to interpret whether conflicting results are linked to methodological variations across paradigms. *Alerting* is described as achieving and maintaining a state of awareness, and facilitates heightened readiness for perception and action. *Orienting* involves the preferential selection of some channels of information (i.e., an area of the left visual field) over others, and in the visual domain includes the ability to engage, disengage, and shift spatial attention. *Executive attention* involves several aspects of higher-level regulation of information flow, including the ability to resolve conflict among various competing responses, as illustrated by the engagement of this system in Stroop, Eriksen flanker, and other conflict tasks [Fan et al., 2003].

Recently, chronometric analyses of each of these networks have been combined into a single assessment with fully randomized conditions within blocks called the Attention Network Test (ANT). This cued reaction-time task produces reliable estimates of the efficiency of each attention network [Fan et al., 2002; Fossella et al., 2002a,b], and recent neuroimaging efforts have created mappings between these effects and three separate anatomical networks supporting alerting, orienting, and executive attention [Fan et al., 2003]. This study modifies the ANT by inserting intertrial emotional faces. This provides a potentially useful new method for assessing the impact of task-irrelevant emotional stimuli on subsequent attention performance, and could set the stage for subsequent attentional bias studies involving a range of emotional stimuli and emotional states.

THREAT-RELATED ATTENTIONAL BIASES AND ANXIETY

Threat-related biases have been shown to both facilitate and interfere with attention. Facilitation effects are most clearly supported in the case of alerting. For example, human faces displaying fear are detected and responded to more rapidly [Eastwood et al., 2001, 2003; Eysenck and Calvo, 1992; Fenske and Eastwood, 2003; Fox et al., 2001, 2002; Mathews and MacLeod, 1985; Schupp et al., 2003]. In combination with these threat-related biases, high levels of anxiety within a typical range also appear to be positively correlated with heightened attentional processes related to alerting, such as vigilance and detection [Compton, 2003; Keogh and French, 1999; Mogg et al., 1992].

When threat-related stimuli are emotional distracters rather than targets of an attention task, however, facilitated emotional processing tends to be associated with decrements in attention [Compton, 2003]. For example, fearful stimuli are more difficult to disengage from once attention is captured, particularly among those showing elevated anxiety, leading to compromised alerting and orienting [Derryberry and Reed, 2002; Fox et al., 2001, 2002; Georgiou-Karistianis et al., 2003; Pollak and Tolley-Schell, 2003; Yiend and Mathews, 2001]. This attention capture may also be linked to executive attention deficits documented in conflict interference tasks and the Emotional Stroop [Fenske and Eastwood, 2003; Simpson et al., 2000; Williams et al., 1996]. Consistent with resource allocation models, such interference effects appear to be related to the recruitment of attentional resources away from a target task, and are enhanced when emotional states like anxiety exceed an optimal range or cognitive demands are already high [Easterbrook, 1959; Hanoch and Vitouch, 2004; Leith and Baumeister, 1996; Meinhardt and Pekrun, 2003; Wood et al., 2001].

Tasks assessing attentional biases in anxiety capitalize on two characteristics of individuals who are anxiety prone. First, anxious individuals, although often performing a primary attention task as well as low anxious individuals, show attention deficits when there is a secondary or dual task-relevant demand [Wood et al., 2001]. This suggests that depletion of general cognitive resources has detrimental effects on attention, but does not speak to whether threat-related attention interference effects are due to increased processing of the affective stimuli [Compton et al., 2003; Easterbrook, 1959; Ellis and Ashbrook, 1989; Hanoch and Vitouch, 2004; Kliegel et al., 2003; Mogg et al., 2000; Rokke et al., 2002; Schupp et al., 2003; Vuilleumier and Schwartz, 2001]. Task-irrelevant stimuli have the advantage of more directly assessing this possibility: they are not targets of the task, and are completely unrelated to task performance. Interference effects linked to these stimuli are likely to reflect emotional distractibility and capture of attention. This study used task-irrelevant stimuli (fearful and neutral faces, and non-emotional control stimuli) that occurred before the target attention task, and gave no information about the timing or content of the upcoming trial.

A second characteristic is that anxious individuals give priority to threat-relevant stimuli [Mathews and MacLeod, 1994]. These threat-related biases might be linked to evolutionarily adaptive rapid detection and avoidance of potential danger [Mathews, 1990]. Another possibility is that anxious states are associated with reductions in inhibitory control, in particular the inhibition of threat-related and emotionally salient information that is task-irrelevant [Fox et al., 2001; Wood et al., 2001]. It is unclear whether state anxiety within a typical range is linked to reduced inhibition of threat-related distracters (in this study, fearful faces), and whether this has an impact on subsequent alerting, orienting, and executive attention performance. This study's use of a design in which task-independent emotional stimuli precede the measure of attention dissociates the assessment of threat-related bias and attention, thus reducing measurement ambiguity.

Investigations of alerting, orienting, and executive attention are typically studied in separate paradigms (one per attention system) and use task-relevant emotional stimuli that serve as targets or cues [Bush et al., 2000; Williams et al., 1996]. A task that assesses multiple aspects of attention simultaneously has the potential to strengthen the inference that emotions have distinct effects on each attention system. For example, affective factors that have an impact on cognitive load, such as emotional distracters and emotional states outside a typical range, might have an enhanced negative impact on aspects of attention that require more conscious control, such as executive attention [Bush et al., 2000; Compton et al., 2003; Wood et al., 2001]. In one study, for instance, anxiety was associated with reduced effortful inhibition of threat-related stimuli only when mental load was increased or when anxiety was beyond an optimal level [Wood et al., 2001].

Emotional context is another important factor to consider when interpreting previous studies' results. The significance of stimuli may vary depending on the larger emotional and cognitive context [Compton, 2003; Scerif et al., 2006]. The event-related potential literature suggests, for instance, that affective processing of positive or pleasant stimuli is enhanced when paired with negative stimuli [Cacioppo et al., 1993; Schupp et al., 2003]. This study tested whether the impact of neutral faces on attention would be most dissimilar to that of fearful faces (i.e., the pleasant attributes of the neutral faces would be enhanced) if the neutral faces were presented along with fearful faces versus control stimuli. Thus, focusing on the effects of fearful face processing, we expected that fearful faces would be linked to stronger attention interference effects in contrast to neutral faces presented alternately with the fearful faces versus neutral faces presented in a non-emotional control context.

THE CURRENT STUDY

The goal of this study was to address methodological issues raised by previous research on threat-related attentional biases. We modified the ANT to include brief presentations of task-irrelevant fearful faces, neutral faces, or non-emotional stimuli before each trial. This single reaction-time paradigm assesses (a) attentional biases in terms of whether presentation of fearful versus neutral faces facilitates or interferes with the efficiency of three attention systems, alerting, orienting, and executive attention; and (b) whether these patterns vary with state anxiety. On the basis of studies which isolated individual aspects of attention within different tasks [e.g., Eastwood et al., 2003; Mogg et al., 2000], we expected that irrelevant threat-related stimuli (fearful faces) would interfere with attention, in particular executive attention which involves more controlled inhibitory processing. We tested for facilitation and interference effects related to higher levels state anxiety: we expected that anxious states would selectively enhance alerting, but might exacerbate interference effects on orienting and executive attention.

METHODS

PARTICIPANTS

Participants were 63 adults between the ages of 18 and 32 years (17 males, 46 females), recruited through the psychology participant research pool at an urban college in New York City. Participants were briefly asked to report identified psychological, attentional, or neurological impairments; no participants did so. Self-reported race/ethnicity was as follows: 16 Caucasian, 14 Hispanic, 9 Asian or Pacific Islander, 9 African American, and 15 "other."

PROCEDURES AND MEASURES

Participants completed the State Trait Anxiety Inventory [Spielberger, 1983] immediately before completing the ANT to assess state anxiety during the laboratory visit. State anxiety was assessed four additional times following each block of the attention task. Subsequent self-reports of state anxiety did not significantly differ from baseline and thus only baseline scores were used in analyses. Participants were categorized into low and high groups based on sample norms (50th percentile = 39, low $N = 35$, high $N = 28$). Division of the sample into three rather than two groups did not appreciably change the pattern of results, but by reducing the number of participants in each group did reduce power to detect significant group differences. Average state anxiety scores in the high anxiety group were $M = 47.04$, $SD = 5.71$, range 40–64; and $M = 33.17$, $SD = 4.84$, range 21–39 in the low anxiety group. Scores for the high anxiety group are similar to those reported for a sample of adults with anxiety disorders, $M = 49.02$, $SD = 11.62$ and consistent with cutoff scores of 40 used in previous studies of anxiety and attention [Richards and French, 1992; Wood et al., 2001]. Scores across the whole sample are consistent with those reported for a normative sample of adults and college students, $M = 36.47$, $SD = 10.02$ for males and $M = 38.76$, $SD = 11.95$ for females [Spielberger, 1983]. Scale reliability for all participants was $\alpha = .93$.

ATTENTION TASK

Subjects were then administered the ANT [Fan et al., 2002]. The ANT was modified in this study by inserting inter-trial fearful and neutral faces, or a control stimulus designed to provide no facial or emotional information (gray opaque squares) for 50 ms. The ANT was presented via E-Prime software on an IBM-compatible personal computer running Window XP, presenting to a 14-inch Dell monitor. Participants viewed the screen from a distance of 65 cm, and responses were collected via two buttons on the mouse.

The ANT, illustrated in Figure 1, combines a cued reaction time and flanker task [Eriksen and Eriksen, 1974]. It quantifies the efficiency of three attention systems by measuring how response times to the target flanker task are influenced by alerting and spatial cues and flankers. Following presentation of the inter-trial stimuli, a cue is presented, followed by the target arrow, which randomly appears either above or below the fixation cross and is surrounded on the left and right by four "flanker" stimuli. Participants indicate with one of the two alternative button presses whether the central target arrow points left or right.

Figure 1a shows the inter-trial stimuli and Figure 1b shows the cue conditions. Cues modulate whether subjects are alerted to the impending stimulus, and whether subjects are oriented ahead of time to the location of the target. Cues are no cues, double cues (asterisk appears above and below the fixation), center cues (asterisk appears superimposed over the fixation), and spatial cues (asterisk appears above or below the fixation to indicate the location of the subsequent target). Figure 1c shows the flanker stimuli: congruent flankers point in the same direction as the central target arrow, incongruent flankers point in the opposite direction, and neutral flankers have no directional information. Consistent with the classic flanker task, congruent and neutral flankers yield faster reaction times than incongruent flankers due to reduced conflict interference [flanker incongruence; Eriksen and Eriksen, 1974; Fan et al., 2002].

The experiment consisted of a 24-trial full-feedback practice block (reaction time, whether answer was correct, and cumulative success rate) followed by two blocks of 384 feedback-free trials each, with a brief break in each block after half the trials. Each block included exactly two types of stimuli: One block contained a random mix of fear versus neutral faces and the other block contained a random mix of neutral faces versus control stimuli (opaque gray squares). Stimuli were presented randomly without replacement within each block so that each stimulus type was presented for 50% of the trials within a block. Block order was counterbalanced across subjects. This design allowed us to examine both the transient effects of perceiving fearful faces on subsequent attention performance, and whether the effects of neutral faces differed depending on their emotional context: that is, whether they were in the presence of fearful faces or non-social-emotional stimuli. The non-face condition was not intended to isolate particular aspects of facial processing, but rather to study whether context effects would appear. The control stimulus therefore provided a contrast between a simple, non-social, non-emotional stimulus with a complex, facial, emotional stimulus. Also, throughout the experiment, the inter-trial faces and control stimuli were completely unrelated and uninformative for performance of the primary ANT task. Thus, this measure provides a simple but effective way to examine effects of task-irrelevant emotional stimuli on attention.

As depicted in Figure 1d, each trial consisted of six events: (1) inter-trial stimulus (fear face, neutral face, control stimulus; 50 ms); (2) fixation period (variable 400–1300 ms); (3) cue condition (no cue, center cue, double cue, spatial cue; 100 ms); (4) fixation period (400 ms); (5) simultaneously presented target and flanker stimuli (terminated at response up to

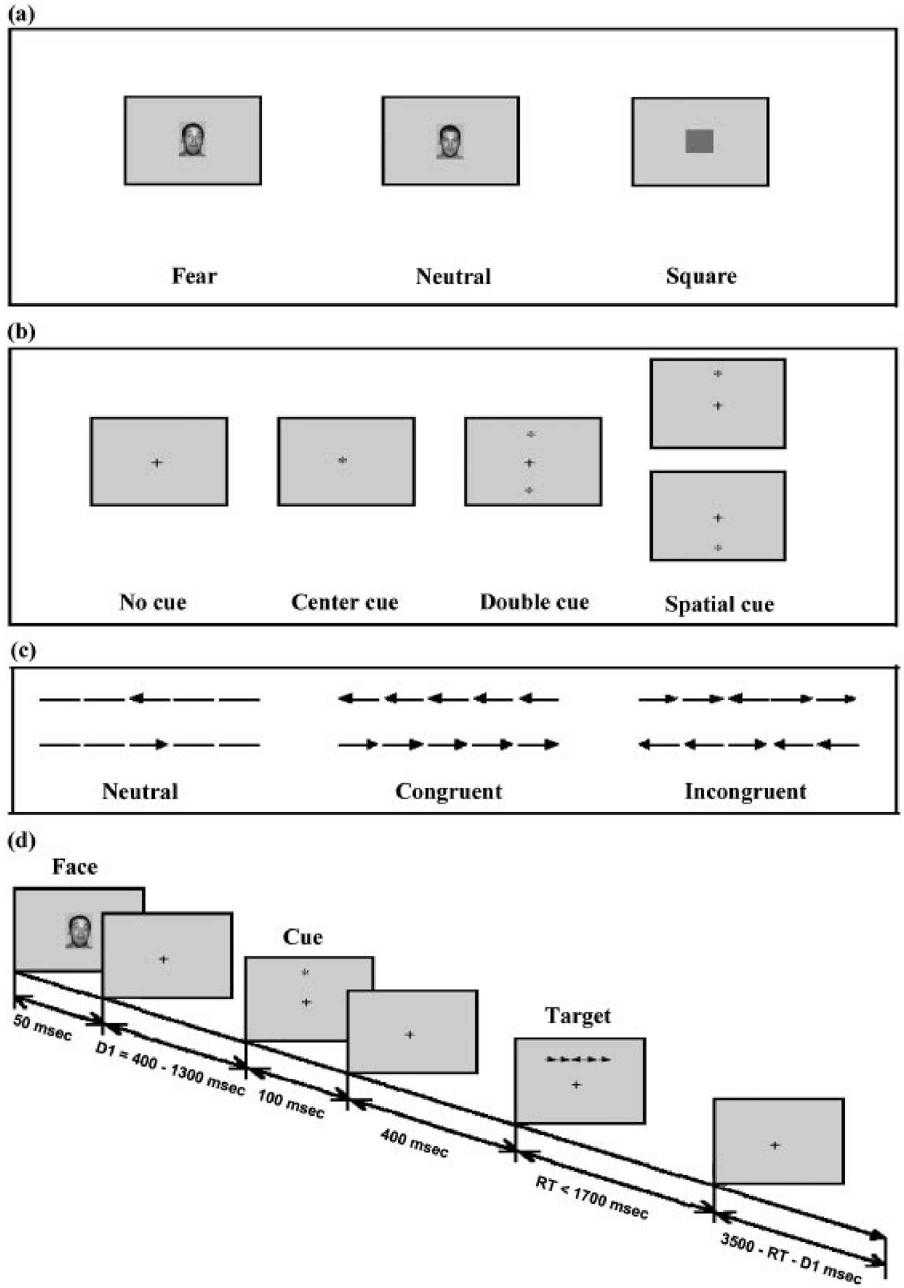

Figure 1. Diagram of the Attention Network Test [based on Fan et al., 2002].

1,700 ms); and (6) post-target fixation period (variable, based on the first fixation duration minus the reaction time for that trial). Each trial lasts for 4,050 ms. Subjects were encouraged to take a short rest between 192-trial blocks.

Efficiency of the three attentional networks, alerting, orienting, and executive attention, is determined by measuring how response times to the flanker displays are influenced by alerting cues, spatial cues, and flanker type [see Fan et al., 2002 for additional details]. Efficiency *alerting* is calculated as reaction time following no cue−reaction time double cue. The double cue was used because it diffuses attention between the two potential target locations while alerting the participant to the arrival of the target. Higher scores indicate greater alerting efficiency due to presence of cues. The efficiency of *orienting* is calculated as reaction time following center cue−reaction time spatial cue. Higher scores indicate greater orienting efficiency due to presence of spatially predictive information of one cue, whereas controlling for alerting effects in the other. The efficiency of *executive attention* is calculated as reaction time to incongruent flankers−reaction time to congruent flankers. Higher scores indicate greater conflict interference and thus less efficient executive attention.

Neutral flankers were retained in this study to confirm that the addition of the inter-trial stimuli did not change basic properties of the task (e.g., only small differences between reaction times for the congruent and neutral flanker conditions). This aspect of the design represented a replication of the stimulus protocol from the Fan et al. [2002] study. In this initial study, neutral flankers were included in hopes of capturing the specific benefit that congruent flankers provide, but unfortunately the initial study failed to capture any such effects. Therefore, in this replication and extension, the stimulation protocol was retained from the original study, but the design for the analysis and hypothesis testing was simplified to create a Conflict Interference score with only two levels (congruent and incongruent flankers). The neutral trials were retained in the design for the sole purpose of replication integrity.

FEARFUL AND NEUTRAL FACES

Stimuli were fearful and neutral faces taken from a battery developed by the Research Network on Early Experience and Brain Development, which contains 646 facial expressions posed by actors of varying ethnicities [Tottenham et al., 2002]. Faces used in this study were selected based on normative ratings of the faces for fearful and neutral facial expressions. Faces were presented between trials of the attention task. Half of the participants were presented with 16 neutral and 16 fearful faces, posed by 16 actors (one neutral and one fearful face from each actor). Twelve instances of each face were used in each block of 192 trials. Given potential concerns with frequency of presentation effects (neutral faces were seen in twice as many trials as fearful faces across all four blocks) the second half of the sample was run with a modified subset of 24 faces, which were selected to form three groups of faces: eight fear (from eight actors), and two groups of eight neutral (from 16 actors), counterbalanced across blocks.

RESULTS

We first tested whether the modified ANT replicated previous results of the ANT task by conducting a Cue (no, center, double, spatial) × Flanker (congruent, incongruent, neutral) analysis of variance on reaction times. We next conducted a multivariate analysis of variance to examine the impact of state anxiety and the four face-type conditions (fearful, neutral-f (neutral with fear faces), neutral-c (neutral with control stimuli), and control stimulus) on the efficiency of alerting, orienting, and executive attention. Table 1 presents mean reaction times for all Cue and Flanker conditions, error rates, and attention efficiency scores separately by face type and low and high state anxiety groups. Patterns of results were identical between the two sets of face stimuli, and thus data were combined. No significant gender differences appeared for any of the variables in this study. Thus, gender was not included in subsequent analyses.

Consistent with the unmodified ANT [Fan et al., 2002, 2003], there was a main effect of Cue showing that reaction times were fastest for spatial versus all other cues, $F(3,60) = 111.44$, $P<.001$, and a main effect of Flanker showing that reaction times were fastest for congruent and neutral versus incongruent flankers, $F(2,61) = 275.06$, $P<.001$, all follow-up *t*-tests $P<.05$. The significant interaction between Cue and Flanker, $F(6,57) = 13.93$, $P<.001$, is depicted in Figure 2. Following all cueing conditions, reaction times were increased for incongruent flankers compared with

TABLE 1. Means and standard deviations for reaction times and attention scores

	Fear	Neutral-f	Neutral-c	Squares	Total	Low anxiety	High anxiety
Reaction times							
No cue	551.68 (62.86)	560.01 (66.03)	559.05 (62.77)	563.70 (61.55)	558.61 (60.73)	562.23 (70.97)	554.09 (45.71)
Double cue	527.37 (59.54)	525.30 (60.13)	527.52 (56.33)	533.77 (62.15)	528.49 (57.00)	534.32 (63.19)	521.20 (48.31)
Center cue	534.40 (63.81)	535.80 (65.04)	538.21 (66.14)	546.07 (69.12)	538.62 (62.83)	544.12 (72.48)	531.74 (48.60)
Spatial cue	495.07 (60.84)	497.95 (66.72)	503.46 (71.16)	502.85 (66.88)	499.83 (63.83)	503.66 (71.52)	495.04 (53.59)
Congruent	492.53 (52.84)	499.99 (61.25)	499.56 (58.12)	498.76 (63.91)	498.82 (55.74)	503.88 (65.04)	492.50 (41.63)
Incongruent	603.61 (78.44)	604.25 (78.66)	607.43 (78.34)	607.67 (83.92)	606.99 (76.85)	610.00 (82.80)	603.21 (70.01)
Neutral	489.03 (54.51)	490.61 (55.66)	494.46 (54.86)	493.59 (56.94)	492.99 (52.55)	498.56 (61.40)	486.01 (38.77)
Attention efficiency							
Alerting	24.31 (27.74)	34.71 (31.42)	31.53 (26.89)	29.93 (28.09)	30.12 (17.50)	27.91 (18.24)	32.89 (16.44)
Orienting	39.32 (32.46)	37.84 (27.90)	35.06 (34.76)	43.22 (35.16)	38.79 (24.82)	40.45 (26.38)	36.70 (23.02)
Executive attention	111.09 (46.09)	104.26 (41.45)	107.87 (41.96)	109.44 (36.62)	108.16 (36.48)	106.12 (30.48)	110.71 (43.29)
Accuracy rates (%)	97.73 (2.34)	97.45 (2.48)	97.46 (3.10)	97.22 (3.03)	97.47 (2.56)	97.89 (2.04)	96.94 (3.05)

Congruent, incongruent, and neutral refer to flanker types.

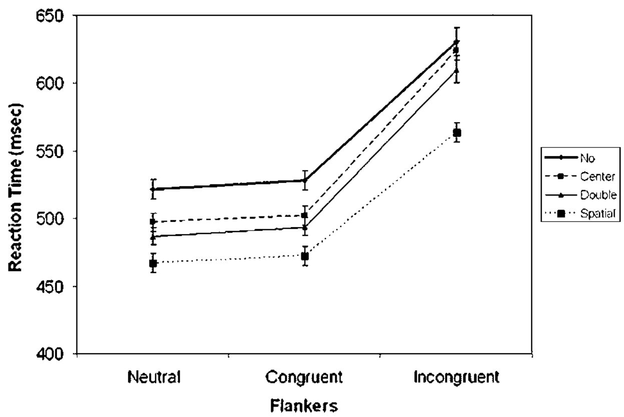

Figure 2. Reaction times for neutral, congruent, and incongruent flankers following each cue type.

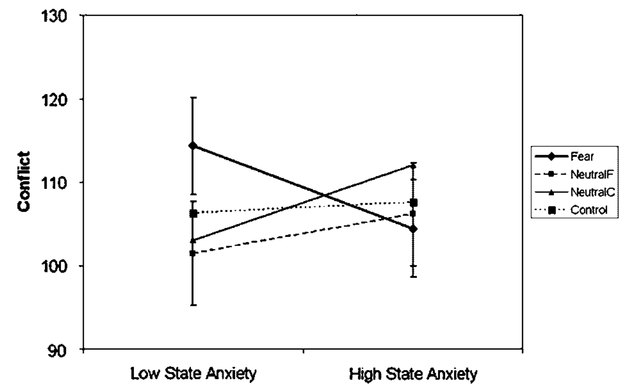

Figure 3. Effects of face type and state anxiety on executive attention. Error bars are presented for fearful and neutral-f faces only. Executive attention efficiency was reduced in the low state anxiety group following fearful versus neutral-faces.

congruent and neutral flankers, though this effect of incongruent flankers was reduced (reaction times were faster) following spatial cues. Patterns of correlation among attention system were also consistent with those reported for the unmodified ANT: alerting and orienting were not significantly correlated with executive attention ($r = .14$ and $-.01$, respectively). Unlike previous studies, alerting and orienting showed a significantly positive correlation ($r = .31$, $P < .05$) suggesting attentional interdependence as well.

To test for the effects of emotional Face Type and State Anxiety group on attention, separate analyses were conducted for each attention system. We were interested in how main effects within each attention network may be influenced by state anxiety and emotional context, rather than exploring potentially complex patterns across all attention systems, which would have required a much greater number of participants to resolve. In addition, efficiency scores are on different scales (e.g., the flanker effect used to calculate conflict results in much larger numbers than that for alerting or orienting) and thus cannot be easily compared.

The analysis of the orienting scores showed that there were no significant effects of State Anxiety or Face Type on orienting (all Ps $> .30$).

The analysis of the alerting scores revealed a main effect of Face Type, $F(3, 59) = 3.57$, $P < .06$, which just missed significance, but suggested that fearful faces interfered with achieving an alert state: Alerting was reduced following fearful versus neutral-f faces, $t(62) = -2.12$, $P < .05$, ($M = 24.31$, $SE = 3.50$ for fearful faces and $M = 34.71$, $SE = 3.96$ for neutral-f faces). No other comparisons reached significance ($M = 31.53$, $SE = 3.39$ for neutral-c faces and $M = 29.93$, $SE = 3.54$ for control stimulus).

Lastly, the analysis of the executive attention scores showed a significant interaction between Face Type and State Anxiety, $F(3, 59) = 4.15$, $P < .05$, which also showed interference effects of fearful faces, but for the low anxiety group only. As seen in Figure 3, within the low state anxiety group, executive attention was reduced (i.e., higher conflict interference) following fearful versus neutral-f faces, $t(34) = 2.26$, $P < .05$. Interestingly, reaction times for control stimuli were second only to fearful faces, suggesting the incongruence or salience of the control stimuli may have captured attention. The differences among fearful and neutral-c faces and control stimuli did not reach significance, and conflict scores for low versus high state anxiety groups did not significantly differ.

Although the effect of State Anxiety group on alerting did not reach significance, state anxiety was positively correlated with alerting across all emotion conditions, $r = .33$, $P < .01$, but was not significantly correlated with orienting or conflict.

DISCUSSION

This study introduced a novel modification of the ANT. The modification adds presentation of task-irrelevant emotional and non-emotional stimuli in between trials of this cued reaction-time task designed to simultaneously generate measures of three attention systems, alerting, orienting, and executive attention. This provides a potentially useful new method for assessing the impact of task-irrelevant emotional stimuli on subsequent attention performance, and could set the stage for additional attentional bias studies involving a range of emotional stimuli and emotional states. In this study, we examined threat-related attentional biases related to state anxiety. Results complement previous research by demonstrating that even briefly presented task-irrelevant fear stimuli selectively compromise distinct attention systems [Callejas et al., 2004; Öhman et al., 2001]. In addition, state anxiety and the presence of fearful faces had unique influences on each attention system, suggesting that attentional biases may have specific rather than generalized enhancement and interference effects depending on attention systems.

Alerting was compromised for all participants following presentation of fearful versus neutral-f faces—that is, for those blocks of trials in which fearful and neutral faces alternated. Although some studies show facilitation of alerting by fearful and negative faces [e.g., Eastwood et al., 2001], when threat-related stimuli are emotional distracters rather than targets of an attention task, as in this study, interference effects may emerge [Compton, 2003]. One explanation for this is that individuals, regardless of anxious state, found it more difficult to disengage from the salient fearful faces [Derryberry and Reed, 2002; Fox et al., 2002]. Cognitive control may have been recruited to ignore fearful faces and thus diverted resources away from attention performance on the subsequent task [Wood et al., 2001]. This is consistent with resource allocation models which hypothesize that facilitation of emotional processing can divert attentional resources to the detriment of other cognitive processes [Compton, 2003; Easterbrook, 1959; Meinhardt and Pekrun, 2003]. This is also consistent with competition models of the interaction between affective processing and executive attention: functional imaging studies, for example, document reciprocal suppression between brain activity related to negative emotion and frontally mediated executive attention processes [Bush et al., 2000; Mayberg, 1997; Williams et al., 1996].

In contrast, results differed from typical resource allocation accounts of anxiety and attention which posit that anxiety beyond an optimal level should exacerbate threat-related attentional biases [Compton, 2003; Easterbrook, 1959]. We detected a more complex pattern of results: higher state anxiety was associated with enhanced alerting, and within the low state anxiety group only executive attention was less efficient (greater conflict interference) following fearful versus neutral-f faces. These findings differ from previous studies that document disruptive effects of threat stimuli in groups showing relatively high anxiety [e.g., Bush et al., 2000; Fox et al., 2002; Williams et al., 1996]. Because state anxiety was within a typical range, even relatively high anxiety may fall within an optimal level of arousal and thus serve to increase alertness and decrease distraction by irrelevant stimuli. That is, if relatively anxious participants felt more anxious about performing well on the task, this might serve to enhance general alertness toward the task rather than the distracting faces. The low anxiety group might have shown state anxiety below optimal levels, and thus not benefited from factors serving to increase task focus. Facilitation is arguably more likely when emotional distracters are not the target of the task. This methodological characteristic of the modified ANT is critical to consider when comparing patterns of results with those using paradigms in which emotional stimuli are targets of the task [Bishop et al., 2004; Compton, 2003].

Consistent with previous research, emotional context had an impact on results [Cacioppo et al., 1993]. The influence of fearful faces was only significant in comparison with trials preceded by neutral faces alternating with fearful faces in the same block of trials. The differences between fearful and neutral-c faces (which alternated with non-emotional control stimuli) did not reach significance. This suggests that the immediate emotional context, rather than the emotional content alone, is relevant to threat-related attentional biases. Results suggested a lack of "emotional contagion" in which the effects of neutral-f faces would resemble that of fearful faces. Future research should examine facilitation as well as interference effects in contrasting emotional contexts, as well as the potential for particularly powerful emotional stimuli to override the effects of less emotionally intense stimuli within the same context.

This study's emotional stimuli were not highly salient: exposure to them did not increase self-reported state anxiety post baseline, did not greatly increase perceptual or cognitive load, and was independent of the target task. This implies that even very brief emotional information can create an emotional context that constrains attention and prepares individuals for action. By bringing these various factors of emotion and attention together into a single reaction time experiment, this study was able to directly compare the emotional modulation of three distinct attention systems in a non-clinical sample, and contrast the impact of emotional individual differences (state anxiety) and emotional stimuli (fearful faces).

There were several methodological limitations and issues. First, the small sample size limited the power and generalizability of results. Second, by modifying the ANT, we may have influenced its psychometric properties. For example, we found that alerting was correlated with orienting, perhaps reflecting the modifications of the timeline of the task or an overall increase in alerting levels associated with the face stimuli. This is inconsistent with initial research on the ANT [Fan et al., 2002, 2003], but one study reported such inter-correlations when the ANTwas modified to include a modification in which an independent variable is used to measure alerting and a non-predictive spatial cue to measure orienting [Callejas et al., 2004]. An interesting possibility is that interdependence among attention systems is enhanced by the presence of an emotional manipulation. That is, one function of emotion may be to coordinate cognitive functions to facilitate adaptation to environmental challenges [Lewis, 2005]. Third, a question raised by the methodological design is whether emotional effects on attention are reducible to arousal effects. Because we did not compare faces that held arousal constant, it is not possible to assess this question. Future work could address this issue by exploring valence versus arousal effects, and utilizing measures that capture the rapid time course of emotional processing, such as event-related brain potentials.

This study introduced a potentially useful modification of an existing attention task that produces simultaneous measures of three attention systems defined by cognitive neuroscience, alerting, orienting, and executive attention [Fan et al., 2002]. It addressed a gap in the literature on threat-related attentional biases by combining three factors that have received relatively little empirical attention: state anxiety, task-irrelevant emotional stimuli, and measurement of multiple attention systems in a single reaction time paradigm. In contrast to previous literature, the clearest threat-related attentional biases were present among those reporting relatively low levels of state anxiety; the high state anxiety group appeared more impervious to emotional distracters. Although much future research is needed, results suggest that state anxiety and perception of fearful faces had an effect on attention, but that these effects played out differently as facilitation or interference depending on attention system. Findings are relevant for understanding relations among state anxiety, attentional biases, and distinct attention functions, and may provide a basis for better understanding the vulnerabilities associated with clinical anxiety disorders.

Acknowledgments. This work was supported in part by NIH grants 5S06GM060654-04 (T.A.D.) and 5 K01 MH075764-02 (T.A.D.), NSF grant REC-0337715 (B.D.M.), and the John Merck Scholars Program in the Biology of Developmental Disabilities in Children (B.D.M.).

REFERENCES

Bar-Haim Y, Lamy D, Pergamin L, Bakermans-Kranenburg MJ, van IJzendoorn MH. 2007. Threat-related attentional bias in anxious and non-anxious individuals: A meta-analytic study. Psychol Bull 133:1–24.

Bishop S, Duncan J, Brett M, Lawrence AD. 2004. Prefrontal cortical function and anxiety: Controlling attention to threat-related stimuli. Nat Neurosci 7:184–188.

Bradley BP, Mogg K, Millar NH. 2000. Covert and overt orienting of attention to emotional faces in anxiety. Cogn Emotion 14:789–808.

Bush G, Luu P, Posner MI. 2000. Cognitive and emotional influences in the anterior cingulate cortex. Trends Cogn Sci 4:215–222.

Cacioppo JT, Crites SL, Berntson GG, Coles MG. 1993. If attitudes affect how stimuli are processed, should they not affect the event-related brain potential? Psychol Sci 4:108–112.

Callejas A, Lupiàñez J, Tudela P. 2004. The three attentional networks: On their independence and interactions. Brain Cogn 54:225–227.

Compton RJ. 2003. The interface between emotion and attention: A review of evidence from psychology and neuroscience. Behav Cogn Neurosci Rev 2:115–129.

Compton RJ, Banich MT, Mohanty A, Milham MP, Herrington J, Miller GA, Scalf PE, Webb A, Heller W. 2003. Paying attention to emotion: An fMRI investigation of cognitive and emotional Stroop tasks. Cogn Affect Behav Neurosci 3:81–96.

Derryberry D, Reed MA. 2002. Anxiety-related attentional biases and their regulation by attentional control. J Abnorm Psychol 111: 225–236.

Easterbrook JA. 1959. The effect of emotion on cue utilization and the organization of behavior. Psychol Rev 66:183–201.

Eastwood JD, Smilek D, Merikle PM. 2001. Differential attentional guidance by unattended faces expressing positive and negative emotion. Percept Psychophys 63:1004–1013.

Eastwood JD, Smilek D, Merikle PM. 2003. Negative facial expression captures attention and disrupts performance. Percept Psychophys 65:352–358.

Ellis HC, Ashbrook PW. 1989. The 'state' of mood and memory research: A selective review. J Soc Behav Pers 4:1–21.

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

Eysenck MW, Calvo MG. 1992. Anxiety and performance: The processing efficiency theory. Cogn Emotion 6:409–434.

Fan J, McCandliss BD, Sommer T, Raz A, Posner MI. 2002. Testing the efficiency and independence of attentional networks. J Cogn Neurosci 14:340–347.

Fan J, Flombaum JI, McCandliss BD, Thomas KM, Posner MI. 2003. Cognitive and brain consequences of conflict. NeuroImage 18: 42–57.

Fenske MJ, Eastwood JD. 2003. Modulation of focused attention by faces expressing emotion: Evidence from flanker tasks. Emotion 3:327–343.

Fossella J, Posner MI, Fan J, Swanson JM, Pfaff DW. 2002a. Attentional phenotypes for the analysis of higher mental function. Sci World J 2:217–223.

Fossella J, Sommer T, Fan J, Wu Y, Swanson JM, Pfaff DW, Posner MI. 2002b. Assessing the molecular genetics of attention networks. BMC Neurosci 3:14.

Fox E, Russo R, Bowles R, Dutton K. 2001. Do threatening stimuli draw or hold visual attention in subclinical anxiety? J Experimental Psychol: General 130:681–700.

Fox E, Russo R, Dutton K. 2002. Attentional bias for threat: Evidence for delayed disengagement from emotional faces. Cogn Emotion 16:355–379.

Gasper K, Clore GL. 2002. Attending to the big picture: Mood and global versus local processing of visual information. Psychol Sci 13:34–40.

Georgiou-Karistianis N, Howells D, Bradshaw J. 2003. Orienting attention in obsessive-compulsive disorder. Cogn Behav Neurol 16:68–74.

Hanoch Y, Vitouch O. 2004. When less is more: Information, emotional arousal and the ecological reframing of the Yerkes-Dodson law. Theory Psychol 14:427–452.

Keogh E, French CC. 1999. The effect of trait anxiety and mood manipulation on the breadth of attention. Eur J Pers 13: 209–223.

Kliegel M, Horn AB, Zimmer H. 2003. Emotional after-effects on the P3 component of the event-related brain potential. Int J Psychol 38:129–137.

Leith KP, Baumeister RF. 1996. Why do bad moods increase self-defeating behavior? Emotion, risk tasking, and self-regulation. J Pers Soc Psychol 71:1250–1267.

Lewis MD. 2005. Bridging emotion theory and neurobiology through dynamic systems modeling. Behav Brain Sci 28:169–245.

Mathews A. 1990. Why worry? The cognitive function of anxiety. Behav Res Ther 28:455–468.

Mathews A, MacLeod C. 1985. Selective processing of threat cues in anxiety states. Behav Res Ther 23:563–569.

Mathews A, MacLeod C. 1994. Cognitive approaches to emotion and emotional disorders. Ann Rev Psychol 45:25–50.

Mayberg HS. 1997. Limbic-cortical dysregulation: A proposed model of depression. J Neuropsychiatry Clin Neurosci 9:471–481.

Meinhardt J, Pekrun R. 2003. Attentional resource allocation to emotional events: An ERP study. Cogn Emotion 17:477–500.

Mogg K, Mathews A, Eysenck M. 1992. Attentional bias to threat in clinical anxiety states. Cogn Emotion 6:149–159.

Mogg K, Millar N, Bradley BP. 2000. Biases in eye movements to threatening facial expressions in generalized anxiety disorder and depressive disorder. J Abnorm Psychol 109:695–704.

Öhman A, Lundqvist D, Esteves F. 2001. The face in the crowd revisited: A threat advantage with schematic stimuli. J Pers Soc Psychol 80:381–396.

Pollak SD, Tolley-Schell SA. 2003. Selective attention to facial emotion in physically abused children. J Abnorm Psychol 112:323–338.

Posner MI, Petersen SE. 1990. The attention system of the human brain. Ann Rev Neurosci 13:25–42.

Richards A, French CC. 1992. An anxiety-related bias in semantic activation when processing threat/neutral homographs. Q J Experimental Psychol A: Human Exp Psychol 45A:503–525.

Rokke PD, Arnell KM, Koch MD, Andrews JT. 2002. Dual-task attention deficits in dysphoric mood. J Abnorm Psychol 111:370–379.

Rutherford EM, MacLeod C, Campbell LW. 2004. Negative selectivity effects and emotional selectivity effects in anxiety: Differential attentional correlates of state and trait variables. Cogn Emotion 18:711–720.

Scerif G, Worden MS, Davidson M, Seiger L, Casey BJ. 2006. Context modulates early stimulus processing when resolving stimulus-response conflict. J Cogn Neurosci 18(5 (Print)): 781–792.

Schupp HT, Junghöfer M, Weike AI, Hamm AO. 2003. Attention and emotion: An ERP analysis of facilitated emotional stimulus processing. Neurorep: Rapid Commun Neurosci Res 14: 1107–1110.

Simpson JR, Öngür D, Akbudak E, Conturo TE, Ollinger JM, Snyder AZ, Gusnard DA, Raichle ME. 2000. The emotional modulation of cognitive processing: An fMRI study. J Cogn Neurosci 12:157–170.

Spielberger CD. 1983. State-Trait Anxiety Inventory Manual. Redwood City, CA: Mind Garden, Inc.

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

Vuilleumier P, Schwartz S. 2001. Emotional facial expressions capture attention. Neurology 56:153–158.

Williams JMG, Mathews A, MacLeod C. 1996. The emotional Stroop task and psychopathology. Psychol Bull 120:3–24.

Wood J, Mathews A, Dalgleish T. 2001. Anxiety and cognitive inhibition. Emotion 1:166–181.

Yiend J, Mathews A. 2001. Anxiety and attention to threatening pictures. Q J Exp Psychol A: Hum Exp Psychol 54:665–681.