5-2023

# What Cognitive Processes Drive Attentional Bias, and How Does Stress Affect Them?

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## Citation

Hunter, C. L. (2023). What Cognitive Processes Drive Attentional Bias, and How Does Stress Affect Them?. *Graduate Theses and Dissertations* Retrieved from https://scholarworks.uark.edu/etd/5051

# What Cognitive Processes Drive Attentional Bias, and How Does Stress Affect Them?

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts in Psychology

by

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Harding University
Bachelor of Science in Cognitive Neuroscience, 2020

May 2023
University of Arkansas

This thesis is approved for recommendation to the Graduate council.

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# Abstract

Attentional biases toward or away from emotionally evocative stimuli have been well documented and related to clinical outcomes such as social anxiety. Some work has suggested that stress modulates attentional biases, but there are a number of inconsistencies in this literature regarding the direction of that modulation, highlighting a need to examine moderators of that effect. Sex differences in stress effects could potentially explain this inconsistency, as acute stress can affect males and females differently. It is also possible that stress differentially influences multiple component processes underpinning attentional bias, but these processes have not been well character, and to date no study has examined this possibility. We addressed these gaps by examining the effects of an acute stressor on attentional bias and its component processes, quantified by computational cognitive modeling, as well as potential sex differences in these effects. We found that overall participants were significantly biased towards threat, but biases did not differ by stress condition or sex. Additionally, we found evidence that attentional bias to threat is a function of both automatic and controlled attentional processes, but that stress did not influence these processes within the context of this task. These findings help to clarify the existing discrepancy in the literature, as differences in methods may differentially affect controlled and automatic attentional processes. Additionally, these findings provide a new avenue of researching attention to threat and the automatic processes that drive it.

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# What Cognitive Processes Drive Attentional Bias, and How Does Stress Affect Them?

Today more than ever, people are exposed to an incredible amount of information and stimuli almost constantly (Bohn & Short, 2012).Consequently, our minds must be selective about the stimuli to which we choose to give our finite attentional resources. These biases in attention and perception can be influenced by motivations, goals, personality traits, and other factors (Helzer et al., 2009). For example, many studies have found that we preferentially attend to threatening stimuli, and this is especially true for individuals with anxiety-related disorders (Fani et al., 2012; McHugh et al., 2010; Roy et al., 2008). However, attentional bias (i.e., the tendency for people to focus on certain stimuli while avoiding others ) is something that can vary depending on the specific context in which the stimuli are presented and individual differences, with differences being potentially explained by both people being more aware of threatening stimuli as a defense mechanism and intentional avoidance of those stimuli as an emotion regulation tactic (Bar-Haim et al., 2010; Morales et al., 2015; Robinson et al., 2012; Stirling et al., 2006). There is a gap in the literature concerning how attentional biases vary in response to an acute stressor. This study addresses that gap by examining the effects of an acute stressor on attentional bias and its component processes, as well as considering sex differences as a possible explanation.

## Attention and the Bases of Its Biases

The mechanisms responsible for attentional biases are naturally tied to the mechanisms for attention. According to the functional component theory of attention, four processes contribute to attention: saliences filtering, competitive selection, working memory, and top-down sensitivity control (Knudsen, 2007). Information from the world is filtered based on salience before representations of that information are selected by competitive processes for entry into working memory. Working memory, via controlled top-down processes, is then thought to modulate sensitivity control of neural representations of outside information (Desimone & Duncan, 1995; Miller & Cohen, 2001). Salience filters are considered to be a *bottom-up process* (i.e., data-driven processes that emphasize the raw experience of the stimulus itself), automatically responding differently to frequent or novel stimuli. In contrast, the remaining three processes largely contribute to *top-down* (i.e., schema-driven processes that emphasize previous knowledge, experiences, and expectations) attention (Wallbott & Ricci-Bitti, 1993). Competitive selection of observed information allows selection of stimuli that are pertinent at a given moment, while working memory contributes to and enhances sensitivity of the neural circuits that represent the information (Knudsen, 2007). The stimuli people are exposed to are automatically filtered based on salience, before controlled processes help determine what information is most useful at a given time and contribute ultimately to decision-making. Thus, these mechanisms illustrate multiple places where attentional biases may arise within the process of attention. More salient (e.g., threatening) information make it through salience filters to a greater extent—thus entailing an automatic attentional process—or an individual could attend to threatening stimuli if those stimuli are deemed more pertinent based on past experiences, which would be a controlled goal-oriented process.

Attentional bias plays a major role in how people perceive the world and process information, with threat-related attentional biases in particular being important in processing and assessment of emotional negative information (Azriel & Bar-Haim, 2020). Since the 1980s, research examining abnormalities in emotional processing has focused more and more on attentional biases to threat, especially in individuals experiencing anxiety and stress (Beck et al., 2005; Clark, 1986).These biases may be more pronounced in anxious individuals because seeing threat where it does not actually exist will presumably lead to a constant state of anxious arousal (Carver & Blaney, 1977; Stapinski et al., 2010). Although attentional biases toward physical danger and life-threatening stimuli is highly adaptive, the stress response is highly conserved across various types of stressors (Calabrese et al., 2007; Fredrickson et al., 2015), which could possibly lead to persistent differences in attentional biases.

## Stress and Attentional Bias

In support of the idea that stressors unrelated to physical danger may lead to persistent changes in attentional biases, attentional biases are known to differ within the context of life stressors (Mogg et al., 1990, 1994). How exactly stress influences attentional biases, however, is less clear. For example, some studies have found that acute stress reduces attentional bias towards threats (Bar-Haim et al., 2010; Brüne et al., 2013; Jiang et al., 2017). These studies generally attribute this effect to as a sort of recognition that one does not have the necessary cognitive resources to handle additional emotional regulation and therefore try to (i.e., intentionally) avoid negative threatening stimuli as much as possible. Conversely, other studies have found that acute stress enhances attentional biases toward negative stimuli (Carr et al., 2016; Roelofs et al., 2007; Rued et al., 2019; Tsumura & Shimada, 2012). Specifically, these studies have found that acute stress is, and elevated levels of cortisol are, associated with increased attentional bias towards negative stimuli including angry faces and depression-related words. These increases in attention to threat may be attributable to time-dependent effects of cortisol on emotional processing. In particular, Tsumura and Shimada (2012) proposed that cortisol facilitates emotional information processing in the early stages of stress response and inhibits it in the later stages of stress response. This proposed mechanism may help to account for the differences found in the literature in the direction of the effect of stressors on attentional bias. However, the mechanism proposed by Tsumura and Shimada is based on the assumption that the effects of stress change over time. Stress can have varying effects based on timing, due in part to two types of cortisol receptors: mineralocorticoid receptors and glucocorticoid receptors (Oitzl et al., 2010). Early stress effects work through membrane bound mineralocorticoid receptors, which cause rapid non-genomic physiological and behavioral effects. In contrast, slower stress effects are enacted through intracellular mineralocorticoid receptors and glucocorticoid receptors. These two kinds of receptors exert complimentary genomic effects in response to stressors, resulting in maintenance of neuronal integrity and facilitation of recovery through energy metabolism (Oitzl et al., 2010). However, cortisol has been found to enhance emotion regulation both shortly after and a long time after exposure to a stressor (Kinner et al., 2014; Langer et al., 2020, 2021), meaning there is evidence for stress consistently improving emotion regulation over time rather than a shift from enhancement to inhibition.

Additionally, the explanation given by Tsumura and Shimada (2012) still assumes attentional bias is always the result of automatic processes, and, as described above, emotional attentional biases may be driven by controlled processes, such as intentional avoidance. Indeed, attention is often driven by both automatic (Theeuwes, 1994, 2004, 2010; Yantis, 2000) and controlled (Folk et al., 1992; Hickey et al., 2006) cognitive processes. Although threatening stimuli capture attention faster than other stimuli (Fox et al., 2002; Pitica et al., 2012)—suggesting that attentional bias by threatening stimuli may be an automatic process (Ohman, 2007)—controlled goal-oriented processes can also contribute to attentional biases (Gladwin, 2017; Vromen et al., 2016). Together, these results suggest that attentional bias may be the result of a combination of both controlled and automatic processes. To date, however, no study has tested this possibility by separating controlled and automatic attentional processes in emotional attentional bias task performance via computational modeling. Moreover, if attentional bias is not solely an automatic process, discrepancies in the stress and attentional bias literature are not well explained by Tsumura and Shimada's theory, entailing that the basis of heterogeneity in this literature remains unknown.

Differences in the literature regarding the effects of stress on attentional bias may be due to methodological differences rather than a gap in theory. First, three cited studies that found that stress enhances attentional bias did not include a no-stress control group (Carr et al., 2016; Roelofs et al., 2007; Tsumura & Shimada, 2012). All three of these studies compared performance pre-stressor with performance post-stressor (Carr et al., 2016; Roelofs et al., 2007; Tsumura & Shimada, 2012). These studies confound stress with practice effects and in doing so prohibit inference about what changed attentional bias from the first to second assessment (Shields, 2020)[1]. This split, coupled with the lack of a control group, places considerable doubt on the results of these three studies. Additionally, the fourth study that found an enhancing effect of attentional bias used an unconventional stressor, having the stressor occur during the attention task rather than prior to, which could potentially impact the results (Rued et al., 2019). In contrast, two studies that found a decrease in attentional bias in the stress condition (Brüne et al., 2013; Jiang et al., 2017) all found it when participants were randomly assigned to either a stress or control condition and attentional bias was assessed only after the stressor. Importantly, however, both of these studies that found a decrease in attentional bias when using random

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[1] Additionally, in the two studies that compared pre-stressor and post-stressor attentional bias, enhanced bias was only found after splitting cortisol response, a continuous variable, into "high" and "low" groups, with participants with "low" cortisol reporting reduced attentional bias and participants with "high" cortisol reporting enhanced attentional bias. However, dichotomizing a continuous variable using a median split, like was done in these two studies, can often produce spurious effects (MacCallum et al., 2002)

assignment exclusively tested male participants (Brüne et al., 2013; Jiang et al., 2017); it is possible that stress differentially influences attentional bias in men and women, which could lead to discrepancies between prior work. Notably, the previously mentioned studies that found an enhancing effect of stress on attentional bias all recruited both males and females, and one of those studies found that stress increased in attentional bias towards threat specifically in female participants (Carr et al., 2016). Stress has been found to differentially affect other cognitive processes, including memory performance, working memory, and emotion regulation, in men and women (Gupta & Chattarji, 2021; Kinner et al., 2014; Schoofs et al., 2013). Given the role of long-term memory in informing schema-driven processes (i.e. top-down attention) (Wallbott & Ricci-Bitti, 1993), executive functions in attenuating attention to threat (Loeber et al., 2009; McNally, 2019),  and emotion regulation in processing threatening and stressful stimuli (Cisler & Koster, 2010; Todd et al., 2012), sex differences should be explored as a potential explanation for the discrepancy in the literature.

## Current Research

The current study aims to address the gap in the literature in both the effects of stress on attentional biases and the cognitive processes that drive attentional biases and explore whether the gap in the literature can be attributed to theoretical or methodological differences. We used the Trier Social Stress Test (Kirschbaum et al., 1993) to induce acute stress in a sample of 176 undergraduate participants. We then assessed attentional bias using a modified facial dot-probe task that utilizes angry, happy, and neutral faces. Finally, we fit the modified dot-probe task data to the Diffusion Model for Conflict Tasks (DMC), an elaborated diffusion model that models controlled cognitive processes with a constant drift rate and automatic cognitive processes with a superimposed gamma function (Figure 1, adapted with permission from Shields et al., 2020).

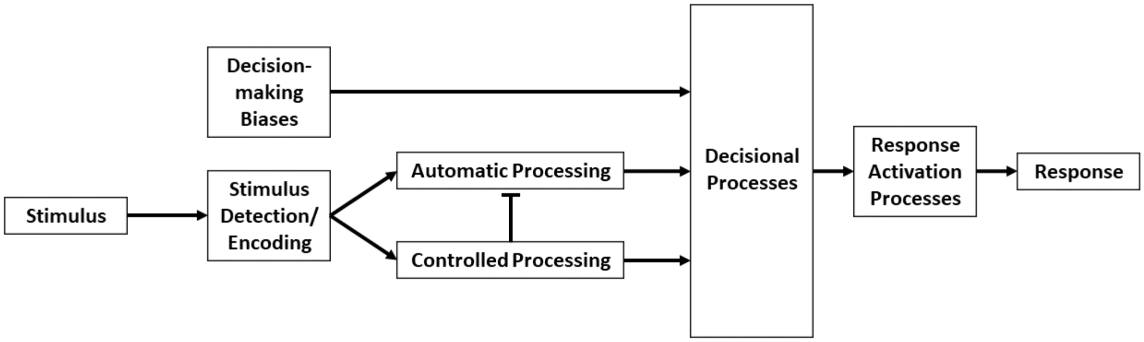

**Fig. 1**. Theoretical framework for the DMC. Responses to tasks are modeled as an additive result of automatic and controlled processes in decision-making.

# Method

## Participants

An a priori power analysis was conducted to determine the sample size necessary to detect the effects of interest in this study. Assuming a medium-sized effect ($d$=0.50), 176 participants (88 in each group) are necessary to achieve 95% power in a one-tailed test. To oversample in case of error, 187 participants were recruited from the university psychology subject pool and were compensated for their participation with course credit. Individuals were ineligible to participate in the study if they were using hormonal contraceptives, had a major physical health disorder, had current insulin-dependent diabetes, had a history of strokes or seizures, were currently pregnant or nursing, had been diagnosed with Post-Traumatic Stress Disorder, were taking inhaled beta-agonists, had taken oral or parenteral corticosteroids within the past 3 months, had had any major sleep disturbances in the past six weeks, had been sick or ill within the past week, or drink more than 8 caffeinated beverages in a day. Forty-six participants were excluded based on attention checks, low-effort responses, or computer error. As a result, 141 participants' data were analyzed ($M_{age}$=19.07, $SD$=1.77, 59.6% female). Participants were randomly assigned to either the stress condition ($N$=69, 57.9% female) or the control condition ($N$=72, 61.1% female). Of this sample, 81.56% identified as White, 6.38% as Hispanic, 6.38% as Asian, 4.96% as Black, and 0.71% as Native Hawaiian or Pacific Islander.

## Materials

### *Stress*

Acute stress was manipulated using a modified Trier Social Stress Test, adapted for Zoom (see also Gunnar et al., 2021), which includes both a stress induction experimental condition and a non-stressful control condition. Participants in the stress condition were given 4 minutes to prepare a speech in which they described their qualifications for a hypothetical job. This speech was then presented in front of a panel of two neutral evaluators via Zoom. Participants were required to speak for a full 10 minutes. If they stopped before the full 10 minutes had elapsed, the evaluator instructed them to continue speaking. Evaluators were instructed to stare into their webcams rather than look at the computer screens so that participants felt as if the evaluators were looking directly at them Evaluators also wore either lab coats or formal attire that looked psychologically cold and distant and were sat in front of a solid black background. Afterwards, participants were then asked to count backward from 2934 in steps of 13. Participants were periodically instructed to count faster, and if they made a mistake or stopped counting for too long, they were instructed to start over from 2934. During the mathematics task participants were told to count faster after 90 seconds, 180 seconds, and 240 seconds had elapsed. The task ended after 4 minutes had elapsed. In contrast, participants in the control condition were instructed to sit in silence for 4 minutes, before being instructed to speak quietly to themselves, unobserved, for 10 minutes. They were then instructed to count to 30 to themselves as often as they would like for 4 minutes.

### *Negative Affect*

Immediately prior to and after the stress or control task, participants self-reported their current affect using the Positive and Negative Affect Schedule (Watson et al., 1988). Items pertaining to negative affect (i.e., distressed, upset, guilty, scared, hostile, irritable, ashamed, nervous, jittery, and afraid) were summed to create a negative affect composite. Baseline affect was assessed ($\alpha$=.73) along with affect immediately following the stressor ($\alpha$=.87).

### *Cortisol*

Participants provided two saliva samples (baseline and post-manipulation) using the passive drool method. Following collection, saliva samples were stored in a -20°C or -80°C freezer (depending upon space available) until assayed using high-sensitivity Salivary Cortisol ELISA Kits from Salimetrics according to manufacturer instructions. Inter- and intra-assay coefficients of variation were less than 10%. All controls were within the expected range. Assay sensitivity is <0.007ug/dL. Values were converted to nmol/L for consistency with most stress and cognition literature.

### *Attentional Bias*

Attentional bias was assessed via a modified facial dot-probe task. Sixty images were taken from the NimStim Set of Facial Expression (Tottenham et al., 2009). These images consisted of 20 individuals, each posing with happy, angry, and neutral expressions. Images were selected based upon whether 80% of a sample correctly identified the emotion shown in the image, based upon ratings obtained by Tottenham et al. Each happy and angry face was paired with a neutral face from the same model to create Happy-Neutral and Angry-Neutral pairs. Additionally, five models were chosen to have neutral faces paired with a neutral face. The location of faces (i.e., left or right) in a pair was randomly determined. The faces were presented on a white background. The task consisted of 20 Angry-Neutral pairs, 20 Happy-Neutral pairs, and 5 Neutral-Neutral pairs randomly presented on a white background and repeated 3 times, for a total of 135 trials. Each trial began with a fixation cross presented for a random interval between 500 and 1000ms in the center of the screen. The face pair then appeared and was displayed for a random interval between 1400 and 1700ms. These presentation timings were determined from piloting the task; during piloting, these timings best produced indices of attentional bias given other task parameters. The faces then disappeared and were replaced with a small X or K centered on the face image location, with the X or K being randomly placed behind either the left or right face. Participants were told to press the “A” key if the X was on the left side of the screen and the “L” key if the X was on the right side of the screen. Trials where the X was behind the neutral face are referred to as “emotion-incongruent” and trials where the X was behind the emotional face are referred to as “emotion-congruent”. Additionally, interference variables were created for emotional trials by subtracting the mean reaction time for correct congruent trials for a given emotion from the mean reaction time for correct incongruent trials, in order to assess how much interference was generated by the presence of a given face (Figure 2).

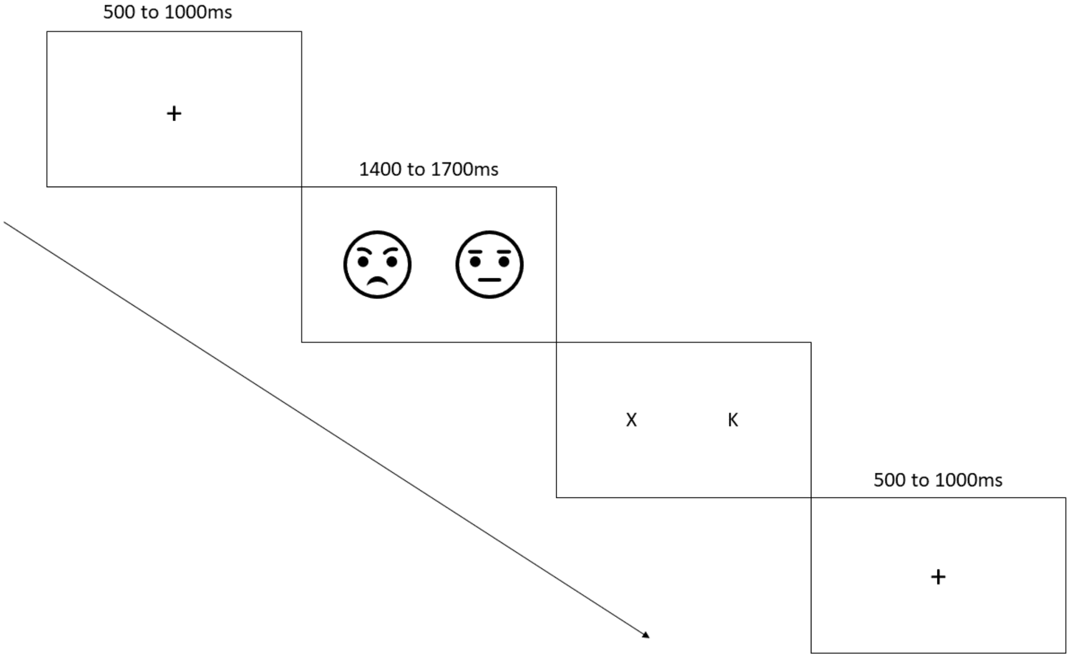

**Fig. 2.** An example angry congruent trial from the modified facial dot-probe task. Faces shown are a graphical representation of faces used. Photographs taken from the NimStim Set of Facial Expressions were used in the actual trials.

### ***Computational Model***

Modified facial dot-probe data were fit to the Diffusion Model for Conflict Tasks (without starting point variability) (Ulrich et al., 2015), which is a model designed to fit any response-competition task. The DMC proposes that decision making is driven by superimposed automatic and controlled processes. Automatic processes are modeled as a gamma function, as automatic processes exert their greatest influence early into a trial and gradually decline (Glaser & Glaser, 1982; Lu & Proctor, 2001), and controlled processes modeled as a standard diffusion function with constant drift rate. Additionally, the DMC includes parameters to account for variability across trials, including starting point in evidence accumulation and nondecision time. All in all, the Diffusion Model of Conflict includes the following parameters: A (amplitude of the gamma function), a (shape of the gamma function), τ (latency to peak onset of the gamma function), μC (controlled drift rate), μR (non-decision time), and σR (variability in non-decision time). Parameters that influence the gamma function (A, a, and τ) were focused on in particular as they inform the influence of automatic cognitive processes during a given trial. We extended the DMC to allow amplitude of the gamma function and controlled drift rate to be negative, as participants may avoid negative faces and focus their attention on happy faces. Additionally, a novel model was fit to the data that included parameters accounting for attention from neutral stimuli in trials (size, shape, and scale of the gamma function) to determine if neutral faces elicit automatic attentional activation and compared that model to the DMC, as we have previously done (Shields et al., 2019, 2020). Both models were fit to participant-level data using cumulative density functions (CDFs), which represent reaction time distributions, and conditional accuracy functions (CAFs), which represent proportion of errors. Parameters that influence the gamma function (A, a, and τ) were constrained to be greater than -40, 1, and 5 and less than 40, 3, and 300, respectively. Controlled drift rate (μC) was constrained to be between -1 and 1, non-decision time (μR) was constrained to be between 200 and 1000, and variability in non-decision time (σR) was constrained to be between 50 and 100, as per (Mackenzie & Dudschig, 2021). The observed and predicted CDFs and CAFs were fit by minimizing the $G^2$ fit statistic. Parameter values for each participant were obtained from the best fitting parameter for each participant and used in subsequent statistical analyses. The novel model was compared to the DMC by both directly comparing $G^2$ values between the two models and comparing Bayesian Information Criterion, a criterion for model selection based on the likelihood function.

## Procedure

Participants were brought into an isolated room in the lab and presented with an informed consent form after joining a Zoom call. They were then instructed to rinse their mouth out, as they would provide saliva samples during the study. They then completed various questionnaires for approximately 5 to 10 minutes in order to acclimate them to the laboratory environment. After the questionnaires were completed, a baseline saliva sample was collected via instructions from a remote research assistant, followed by the baseline affect assessment. Participants then completed either the Trier Social Stress Test or the control condition task. Both the experimental condition and control condition of the TSST took 18 minutes to complete. Post-stressor/control condition, participants first completed the post-manipulation affect assessment, followed by various questionnaires for 10 minutes, before another saliva sample was collected. Finally, participants completed various cognitive tasks, including a modified facial dot-probe task in which either a Happy-Neutral, Angry-Neutral, or Neutral-Neutral pair of faces was shown. The dot-probe task took place approximately 25min post-stressor. (Figure 3.)

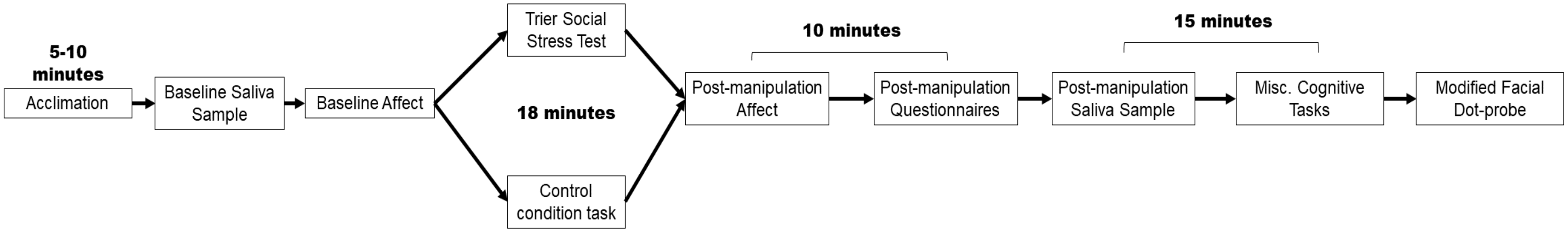

**Fig. 3.** General procedures and timing for the study.

### Data Analysis

Behavioral analyses examined whether there was a significant difference in interference (i.e., the difference between mean reaction time for congruent and incongruent trials for a given stimulus type) between stimulus types and whether the level of interference for each of the three stimulus types was significant different from zero. Additionally, ANOVAs were conducted to assess whether participant reaction time differed as a function of sex, stress condition, trial congruence, and stimulus type. ANOVAs were conducted both including and excluding trials with Neutral facial pairs, in order to determine whether their inclusion had a significant impact on the overall results. Participant data for angry and happy trials were fit together to the DMC on the level of distribution, with separate parameters for size, shape, and scale of the gamma function for happy and angry trials. Then, data were fit together to the novel model as it was for the DMC. Fit statistics and optimized parameter values were recorded for both model fits. All data analyses were conducted using R, version 4.1.2, with the diffusion models fit using the dfoptim package, version 1.6., and the ANOVAs conducted using the car package, version 3.0-12.

## Results

### Preliminary Analyses

We first examined whether negative affect and salivary cortisol changed from baseline to post stressor, and whether that change differed between conditions. In a 2x2 repeated-measures ANOVA predicting negative affect from Condition (stress, control) and Time (baseline, post-manipulation), significant main effects of Condition, $F(1, 137)=20.83$, $p<.001$, and Time, $F(1, 137)=27.98$, $p<.001$, emerged, along with a significant Condition×Time interaction, $F(1, 137)=55.58$, $p<.001$. Examining the main effect of Condition in greater detail, participants in the stress condition (*M*=17.0, *SE*=0.491) had significantly more negative affect than participants in the control condition (*M*=13.9, *SE*=0.480), *t*(137)=4.56. Examining the main effect of Time in greater detail, baseline negative affect (*M*=14.1, *SE*=0.342) was significantly lower than post-manipulation negative affect (*M*=16.8, *SE*=0.495), *t*(137)=5.29. Finally, examining the Condition×Time interaction we found that participants in the stress condition had significantly greater negative affect post-manipulation (*M*=20.2, *SE*=0.707) than baseline (*M*=13.8, *SE*=0.488), *t*(137)=-8.92, *p*<.001. In contrast, participants in the control condition had no significant change in affect from baseline to post-manipulation, *t*(138)=1.55, *p*=.124. Raw change in salivary cortisol was then examined. In a 2x2 repeated-measures ANOVA predicting salivary cortisol from Condition and Time, a significant main effect of Condition emerged, *F*(1, 122)=4.27, *p*=.041, and a significant Condition×Time interaction emerged, *F*(1, 122)=14.91, *p*<.001. Examining the main effect of Condition in greater detail, participants in the stress condition (M=9.66, SE=0.70) had significantly higher cortisol than participants in the control condition (M=7.61, SE=0.70), t(122)=2.07. Examining the Condition×Time interaction, we found that participants in the stress condition (M=10.71, SE=0.727) had significantly higher cortisol post-manipulation than participants in the control condition (M=7.01, SE=0.727), *t*(122)=3.60, *p*<.001. In contrast, baseline cortisol did not significantly differ between the two conditions, *t*(122)=0.346, *p*=.730 (Figure 4).

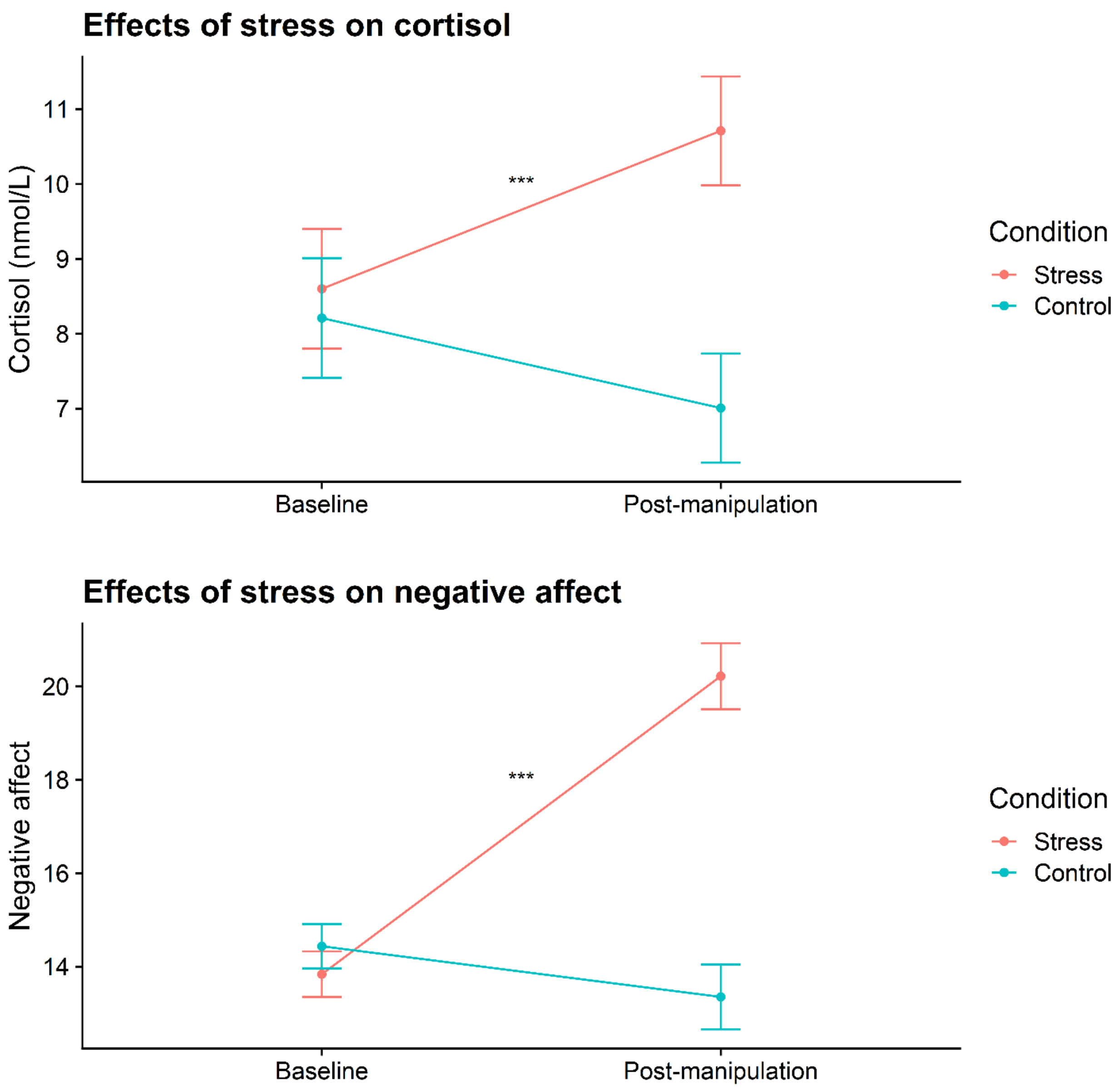

**Fig. 4.** Change in cortisol and negative affect from baseline to post-manipulation by stress condition. Participants in the stress condition had significantly higher cortisol and significantly more negative affect post-manipulation than at baseline, while participants in the control condition had no significant change. ****p* < .001, ***p* < .01, **p* < .05

### Behavioral Analyses

Interference values for angry and happy faces were analyzed to determine whether they significantly differed from zero and significantly differed from one another. Angry interference

($M_{\text{angry}}$=10.90, $SE_{\text{angry}}$=4.63) was significantly different from zero, $t(138)=2.36$, $p=.019$, such that participants responded 10.90ms faster when the angry face was target-congruent than when the neutral face was target-congruent. Happy interference ($M_{\text{happy}}$=-4.66, $SE_{\text{happy}}$=4.16) however was not significantly different from zero, $t(138)=-1.03$, $p=.306$. Furthermore, interference from angry faces was significantly greater than interference from happy faces, $t(138)=2.34$, $p=.021$. When comparing stimulus interference by stress condition, there was no significant difference between stress groups for angry interference and happy interference, $p$s>.215. Finally, when comparing stimulus interference by both stress condition and sex, there was no significant effect of stress on angry interference, $F(1, 135)=0.17$, $p=.683$, or happy interference, $F(1, 135)=1.41$, $p=.238$, and there was no significant effect of sex on angry interference, $F(1, 135)=0.01$, $p=.952$, or happy interference, $F(1, 135)=0.67$, $p=.415$. Furthermore, there was no significant interaction effect between stress and sex on angry interference, $F(1, 135)=1.59$, $p=.210$, or happy interference, $F(1, 135)=.006$, $p=.937$ (Figure 5).

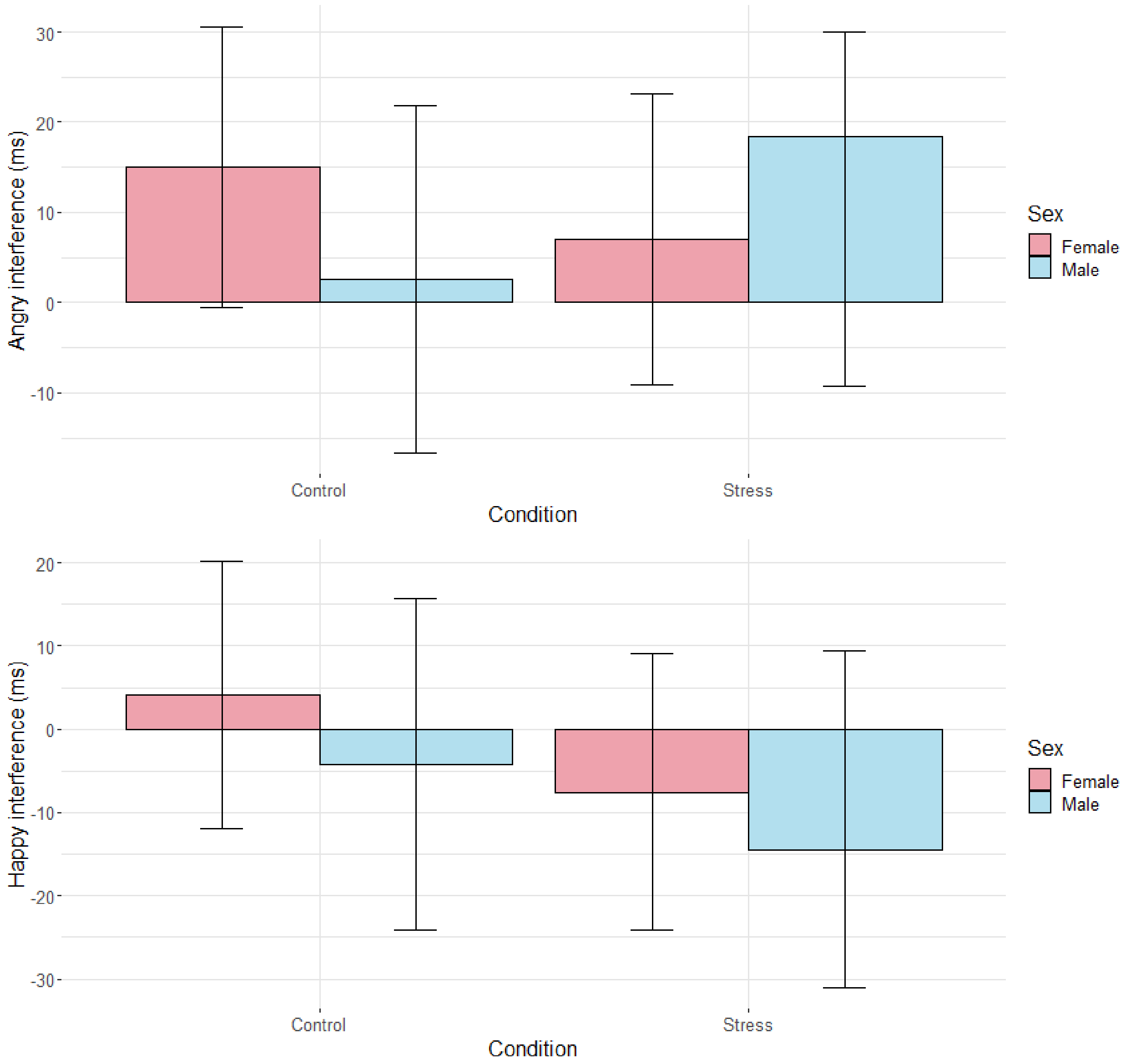

**Fig. 5.** Interference from angry faces and happy faces by stress condition and sex. No significant main effect of condition or sex, or a significant interaction between the two, was observed for angry interference or happy interference.

We next examined response time as a function of the within-subjects factors of Trial Congruence (congruent, incongruent) and Face Expression (angry, happy), and the between-subjects factors of Condition (stress, control) and Sex (male, female). Reported values are estimated marginal means. There was a significant interaction between Trial Congruence and Face Expression, $F(2, 20540)=5.40$, $p=.020$. Examining this interaction in greater detail, congruent trials with angry faces (*M*=643, *SE*=9.79) were significantly faster than incongruent trials with angry faces (*M*=651, *SE*=9.79), *z*=-2.15, *p*=.031. No significant difference was observed between congruent trials with happy faces and incongruent trials with happy faces, *p*=.259 (Figure 6).

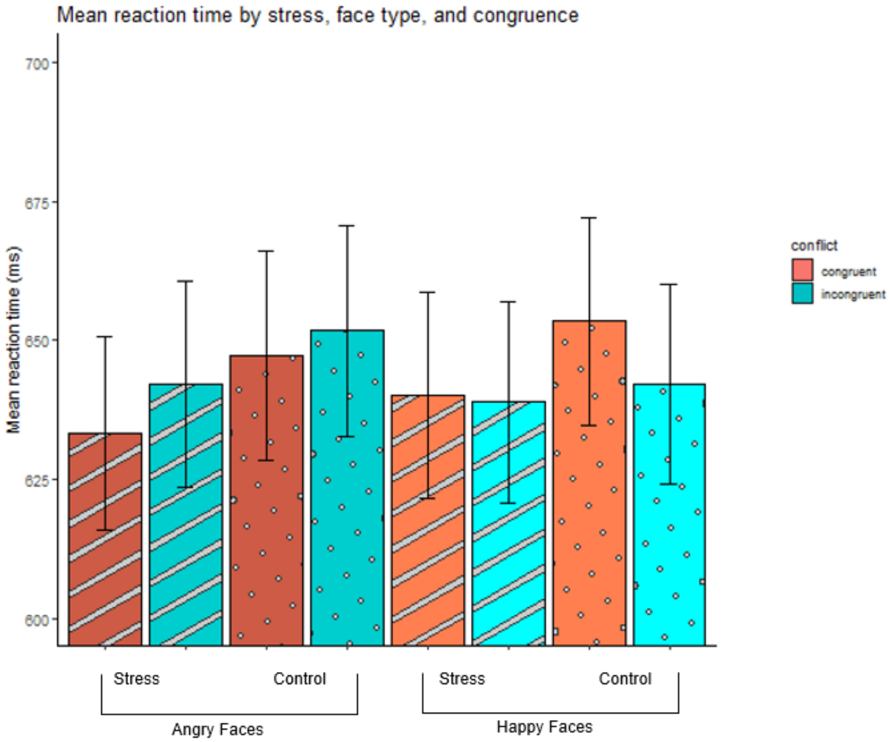

**Fig. 6.** Mean reaction time by stress group, face type, and face-probe congruence. Congruent trials with angry faces had significantly faster reaction times than incongruent trials with angry faces, while no such difference was observed between congruent trials with happy faces and incongruent trials with happy faces.

Finally, change in cortisol was examined as a predictor of angry interference and happy interference. Four different approaches were used to quantify change in cortisol: raw difference scores between baseline and post-manipulation, log transformed difference scores, residuals of post-manipulation cortisol regressed on baseline cortisol, and residual of log transformed post-manipulation cortisol regressed on log transformed baseline cortisol. Raw change in cortisol, *r*=-.100, *p*=.136, log transformed difference scores, r=-.040, *p*=.277, residuals of post-manipulation cortisol regressed on baseline cortisol, *r*=-.084, *p*=.694, and residual of log transformed post-manipulation cortisol regressed on log transformed baseline cortisol, *r*=-.086, *p*=.724, were all not significant predictors of angry interference. For happy interference, raw change in cortisol, *r*=.053, *p*=.247, log transformed difference scores, r=.043, *p*=.272, residuals of post-manipulation cortisol regressed on baseline cortisol, *r*=.040, *p*=.370, and residual of log transformed post-manipulation cortisol regressed on log transformed baseline cortisol, *r*=.060, *p*=.233, were all not significant predictors of happy interference.

## Computational Modeling Analyses

Model parameters and fit statistics were generated for each participant for both the Diffusion Model for Conflict Tasks and the proposed novel model. $G^2$ for each model was compared across participants using a paired t-test, with the DMC (*M*=23.91, *SE*=0.95) being a significantly better fit than the proposed novel model (*M*=26.93, *SE*=0.79), *t*=4.91, *p*<.001. Additionally, comparing Bayesian Information Criterion for each model indicated that the DMC (*BIC*=43.30) was a better fit than the proposed novel model (*BIC*=49.32). Given these results, subsequent model analyses were conducted using the DMC.

Model parameters generated for each participant were then examined to determine whether they differed as a function of the between-subjects factors of Condition (stress, control) and Sex (male, female). Ten model parameters were fit: A (amplitude of the gamma function), a (shape of the gamma function), and τ (latency to peak onset of the gamma function) were each estimated separately for trials with angry and happy stimuli. Additionally, μC (controlled drift rate), b (decision threshold), μR (non-decision time), and σR (variability in non-decision time) were constrained to equality across face expression trial type (Figure 7).

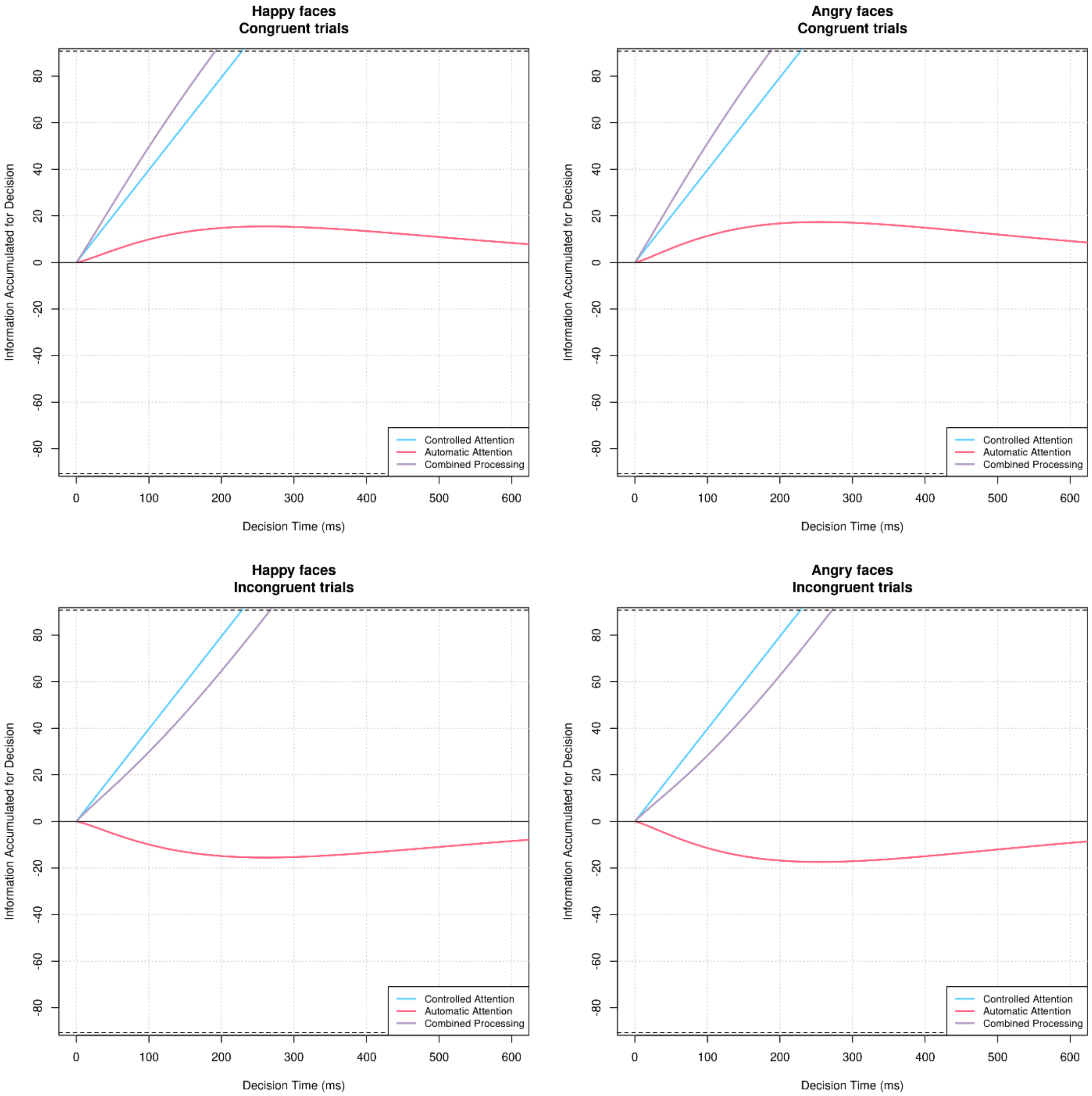

**Fig. 7.** Expected controlled and automatic drift distributions based upon fit parameters generated. Expected drifts are grouped by face type and face-probe congruence to illustrate drift for the four trial types in the task.

First, controlled drift rate and amplitude of the gamma function for angry trials were both examined for correlations with angry interference scores, in order to determine whether attentional bias towards angry faces is driven by controlled or automatic processes. Amplitude of the gamma function for angry trials (*r*=.267) was significantly correlated with angry interference, *p*=<.001. Additionally, controlled drift rate (*r*=-.201) was significantly correlated with angry interference, *p*=.019. Controlled drift rate and amplitude of the gamma function for happy trials were both then examined for correlations with happy interference scores. Amplitude of the gamma function for happy trials (*r*=.423) was significantly correlated with happy interference, *p*<.001. In contrast, controlled drift rate (*r*=.036) was not significantly correlated with happy interference, *p*=.676 (Figure 8).

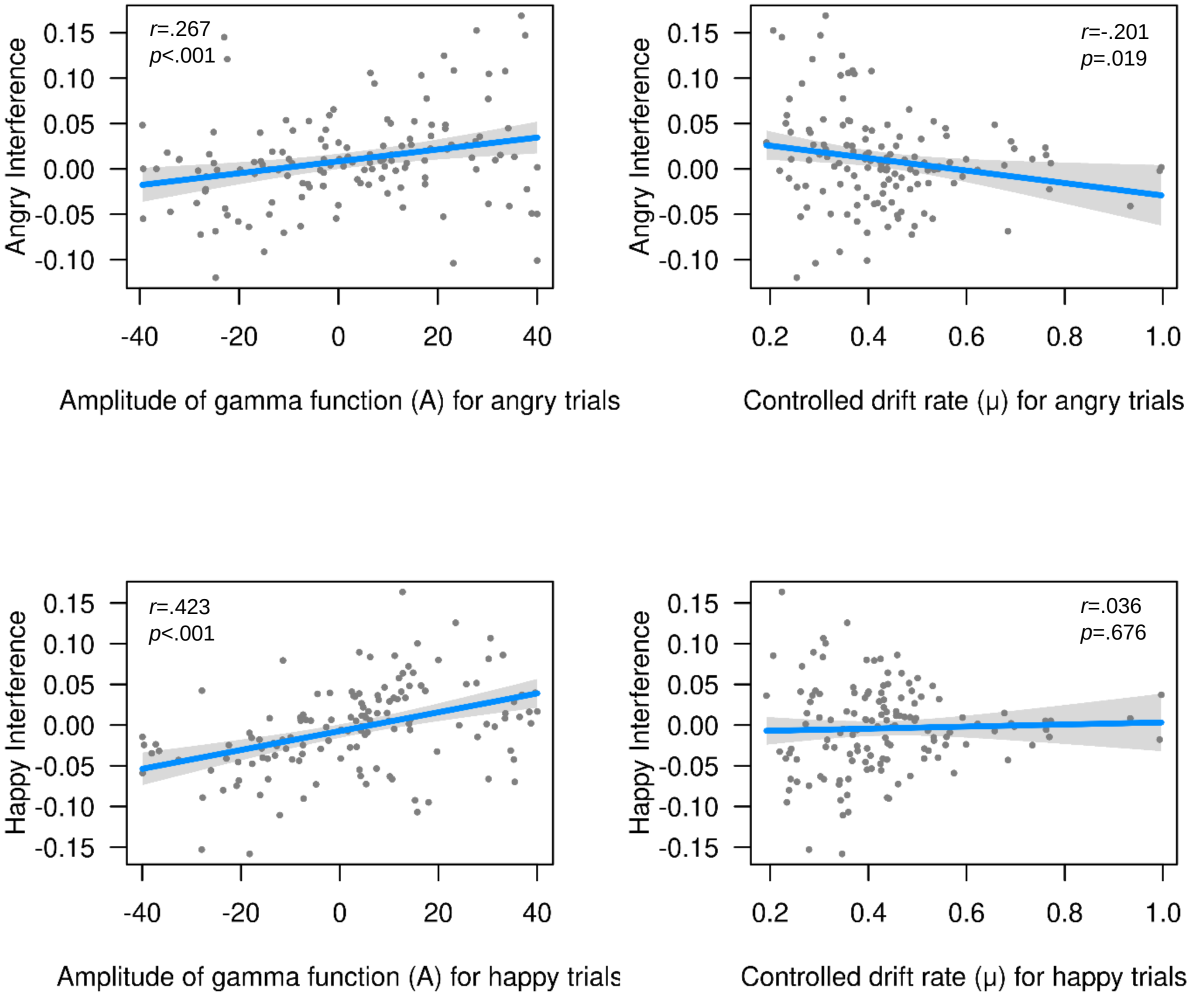

**Fig. 8.** Associations of angry interference and happy interference with amplitude of the gamma function (an automatic attention parameter) and controlled drift rate (a controlled attention parameter). Both automatic and controlled attentional parameters were associated with angry

interference, while only automatic attentional parameters were associated with happy interference.

However, automatic attention parameter recovery has been found to be somewhat poor (White et al., 2018) while conjunction automatic attention parameters show good recovery. Because of this, scores for the predicted drift rate of the superimposed process for angry congruent trials were calculated for each participant by summing values of the gamma function for the DMC across 1000ms to create total strength of automatic attention from optimized model parameters (see Equation 7, Ulrich et al., 2015)[2]. An ANOVA with Condition (stress, control) and Sex (men, women) then examined whether stress or sex influenced automatic attention strength to angry faces. The main effect of Condition, Sex, and the Condition×Sex interaction were not significant, *p*s>.140. We next examined the relation between automatic attention to angry faces and angry interference (i.e., attentional bias to threat), and we found that greater automatic attention total drift rate for angry faces was a significant predictor of angry interference, $r$=.531, $p$<.001. Additionally, we examined the relation between automatic attention to happy faces and happy interference (i.e., attentional bias to happy faces), and we found that greater automatic attention total drift rate for happy faces was a significant predictor of happy interference, $r$=.388, $p$<.001 (Figure 9).

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[2] Additional analyses were conducted using automatic attention activation (see Equation 6, Ulrich et al., 2015) rather than total expected value. An ANOVA with Condition (stress, control) and Sex (men, women) then examined whether stress or sex influenced automatic attention activation to angry faces. The main effects of Condition and Sex, along with the interaction, were not significant, *p*s>.199. Repeating this ANOVA with automatic attention activation to happy faces, we again observed no significant main effect of Condition or Sex, and no significant interaction, *p*s>.166.

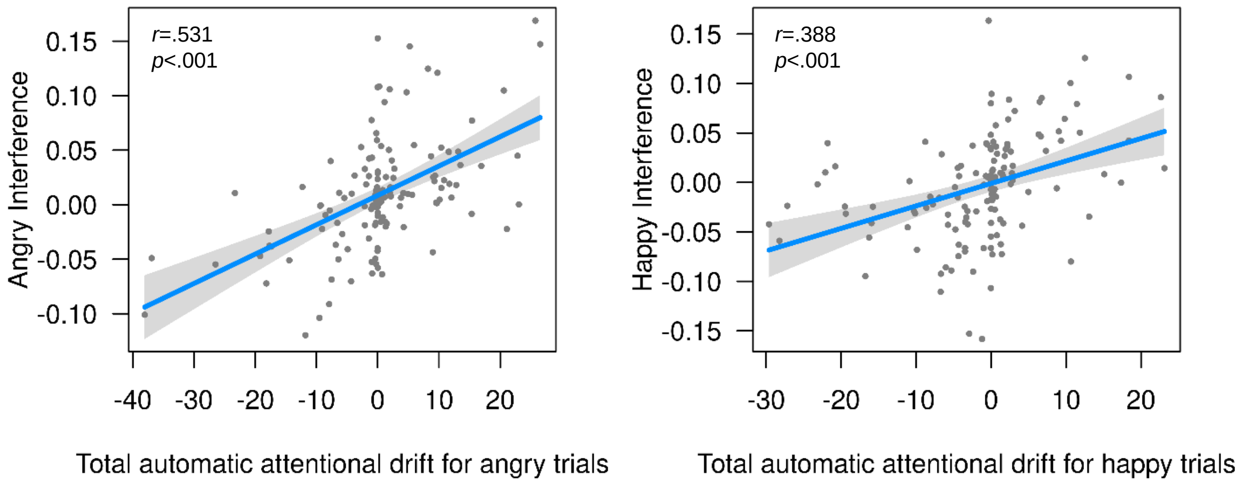

**Fig. 9.** Associations for angry and happy interference with total automatic attentional drift. Angry interference was positively associated with automatic attentional drift and happy interference was negatively associated with automatic attentional drift.

The remaining parameters (e.g., controlled attention, decision threshold) were then examined as a function of both stress condition and sex. Shape of the gamma function for men (*M*=2.43, *SE*=.081) was significantly greater than for women (*M*=2.22, *SE*=.068), *F*(1, 133))=4.032, *p*=.047. None of the other parameters differed by condition, sex, or their potential interaction, *p*s>.117.

Finally, associations between attentional bias, total automatic attentional drift, and parameter values and raw change in salivary cortisol were examined. Change in salivary cortisol did not significantly predict any change in attentional bias to angry faces, *p*=.300. Similarly, change in salivary cortisol did not significantly predict any change in attentional bias to happy faces, *p*=.332. There was a marginal significant association between change in cortisol and total automatic attentional drift on angry trials, *r*=-.155, *p*=.089. Similarly, there was a marginal significant association between change in cortisol and total automatic attentional drift on happy trials, *r*=.163, *p*=.075 (Figure 10). Finally, the shape of the gamma function was marginal significantly associated with change in salivary cortisol, *r*=-.171, *p*=.061. No other parameter values were significantly associated with raw change in cortisol, *p*s>.183.

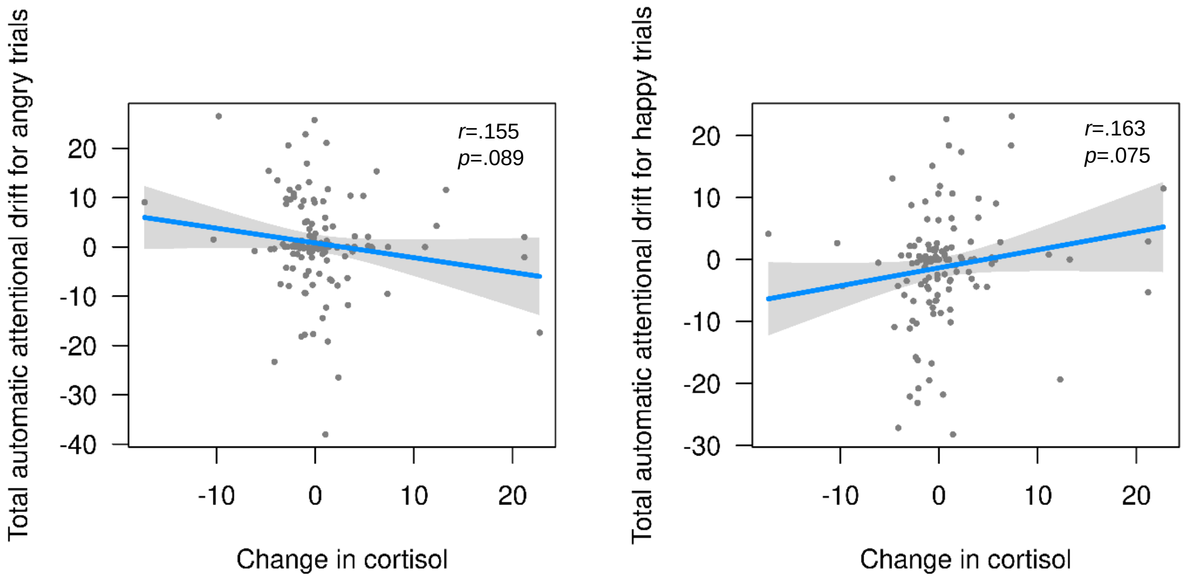

**Fig. 10.** Association between total automatic attentional drift and change in salivary cortisol on angry and happy trials. There was a marginal negative association between total automatic attentional drift and change in cortisol on angry trials and a marginal positive association on happy trials.

## Exploratory Analyses

Cortisol secretion has been found to differ significantly by time of day (Van Cauter et al., 1996; Veldhuis et al., 1989; Weitzman et al., 1971). As a result, exploratory analyses were conducted analyzing whether the time of day that a participant completed the study (i.e., morning or afternoon) was a significant predictor of our variables of interest. Stress did not interact with time of day to predict attentional bias, nor were there any higher-order interactions between stress, time of day, and other variables in predicting attentional bias. All time-of-day analyses are presented in the Supplemental Material.

Finally, exploratory analyses examining reported general anxiety and ADHD were conducted in relation to attentional bias in the stress and control conditions. Results were largely nonsignificant and are presented in the Supplemental Material.

## Discussion

The purpose of this study was twofold: (1) to investigate how exposure to an acute stressor affects attentional bias to threat, and (2) to evaluate whether these potential biases are primarily driven by automatic or controlled cognitive processes. Although we found evidence for attentional bias towards angry faces, we did not find that stress affected attentional bias in either men or women. However, we did find evidence that both automatic and controlled attentional parameters were associated with attentional bias to threat, but only automatic attentional parameters were associated with attentional bias to happy faces. Finally, we found no evidence that stress differentially affected automatic and controlled attentional processes.

Attentional bias to threat is a finding that is well documented throughout the literature (Azriel & Bar-Haim, 2020; Beck et al., 2005; Clark, 1986). This study thus replicated prior work finding that people respond faster to targets when they occur where an angry face was located than when they occur where a neutral face was located. Additionally, the present study only found evidence of attentional bias towards threatening stimuli (i.e., angry faces), not for happy faces paired alongside neutral faces. This finding suggests that individuals are specifically biased towards threat rather than just emotionally salient stimuli.

Furthermore, additional research examining interpretation biases found that it was predicted by trait anxiety (MacLeod & Cohen, 1993; Richards & French, 1992), a finding that the present study failed to replicate. The studies conducted by MacLeod & Cohen and Richards & French both used neutral and threat-related written stimuli, as opposed to facial stimuli as we did, which may explain this discrepancy. State anxiety has consistently been found to predict preferential attention to various threatening stimuli, as opposed to neutral (Bradley et al., 2000; Fox et al., 2001; Koster et al., 2006; Nelson et al., 2015; Quigley et al., 2012), while trait anxiety typically only predicts attention to threat for linguistic stimuli or non-facial pictures (Armstrong & Olatunji, 2012; Bar-Haim et al., 2007). Individuals seem to show preferential attention towards *relatively* threatening faces, regardless of trait anxiety, with both state anxiety and social anxiety possibly modulating that effect. Although our attempt to create a social anxiety measure from other scales included in the present study did not significantly predict attentional bias, it should be noted that it is a composite of items from other measures that had poor internal consistency. Future research examining attentional bias towards relative threats should include previously validated measures of social anxiety as potential predictors of attentional bias.

Prior work had obtained discrepant findings regarding the effects of acute stress on attentional bias to threat, which we attempted to resolve with this study. We hypothesized that this discrepancy may be due to methodological differences in utilizing randomly assigned stress/control groups, using both male and female participants, and choice of task used to assess attentional bias. When using randomly assigned stress/control groups, recruiting both male and female participants—and exploring sex differences in our analyses—, and assessing attentional bias via a facial dot-probe task, we found no evidence that acute stress significantly affects attentional bias to threat, no evidence of significant sex differences in attentional bias, and no significant interaction between stress and sex. Hypothesized changes in methodology explain differences in results between the present study and prior studies that found an enhancing effect of stress on attentional bias. However, many of the studies that found a reduction in attentional bias following acute stress utilized random assignment to a stress or control group and assessed attentional bias post-stress using a dot-probe task (Brüne et al., 2013; Jiang et al., 2017). The present study provides evidence that discrepant findings within the literature may be in part due to methodological differences between studies examining attentional bias, though a discrepancy still exists between the findings in the present study and studies utilizing similar experimental design.

There are a number of factors that may explain the discrepancy between the results obtained in our study and the results of prior studies. First, prior studies obtained more nuanced results rather than direct effects of a stress condition on attentional bias, as did the current study. For instance, Jiang et al. (2017) specifically found evidence of attentional bias when using a modified facial dot-probe that contained go/no-go trials, with a difference in response accuracy being observed between congruent and incongruent trials in the control group but not in the stress group specifically on no-go trials. Given that the dot-probe used in the present study did not contain go/no-go trials, and that attentional bias was assessed via changes in reaction time, the difference in findings is more understandable. Additionally, Brüne et al. (2013) found attentional bias specifically regarding differences in visual fields, rather than an overall difference in reaction time. However, even when accounting for the position of the probe and the emotional face when presented, we failed to replicate the results obtained by Brüne et al.[3] Finally, one study in the literature (von Dawans et al., 2020) found no effect of acute stress on attentional bias to threatening faces. The study conducted by von Dawans et al. (2020) utilized a facial dot-probe task, random assignment, and included both male and female participants.

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[3] A type III repeated measures ANOVA was conducted to assess mean reaction for each combination of probe location and emotional face location There was no significant interaction between stress group, probe location, and emotional face location, *F*(1, 135)=.996, *p*=.320. Additionally, there was no significant four way interaction between sex, stress condition, probe location, and emotional face location, *F*(1, 135)=.402, *p*=.527, and no significant five way interaction between sex, stress condition, probe location, emotional face location, and face expression, *F*(1, 135)=.093, *p*=.761.

Additionally, their facial dot-probe task took place at a similar time as the one in the current study (approximately 25 minutes post-stressor). However, the study conducted by von Dawans et al. differed with ours in two key ways: the stressor used and the timing of facial stimuli during the dot-probe. While we used an individual TSST adapted for use over Zoom, von Dawans et al. used an in-person Trier Social Stress Test for Groups. Additionally, facial stimuli in the study conducted by von Dawans et al. were presented for approximately 500ms whereas our stimuli were presented for approximately 1600ms. While we obtained similar results, these methodological differences warrant further exploration. In a well-powered study utilizing a sufficient number of trials in a modified facial dot-probe task, we found no significant evidence main effect of acute stress on attentional bias to threat-related stimuli, even when accounting for potential differences in sex and visual field. A possible explanation may be that the attentional processes that stress affects are differentially affected when stimulus presentation time is long versus short, as the previously mentioned studies presented facial stimuli for 500ms or less while the present study presented facial stimuli for 1400ms to 1700ms. These differences in stimulus timing could mean varying attentional processes are being affected by the stressor (Mogg et al., 2004; Sass et al., 2010), possibly explaining the discrepancy between the results of the current study and the results in the literature. However, this explanation requires further study to address with certainty.

Finally, the present study sought to explore whether attentional biases to threat are driven by automatic or controlled attentional processes. Utilizing computational modeling, we found that the amplitude of the gamma function (an automatic attentional parameter), controlled drift rate (a controlled attentional parameter) and overall automatic attention strength were significantly associated with attentional bias to threat. Additionally, we found that only the amplitude of the gamma function and overall automatic attention strength were significantly associated with attentional bias to happy faces. This finding is consistent with previous work that found attentional processes in fear and anxiety-related responses to be the result of automatic processes (Cisler & Koster, 2010; Eysenck et al., 2007; Öhman, 2005). Fearful and threatening stimuli have been found to automatically activate certain physiological responses independent of conscious recognition of the stimulus, with the amygdala implicated as as neural mechanisms that may explain this automatic vigilance (Cisler & Koster, 2010; Öhman, 2005). Furthermore, attentional control theory suggests that attentional biases are the result of impairments in goal-directed attentional control and further resource allocation to stimulus-driven automatic processes (Eysenck et al., 2007). Our findings replicate the results in the literature by providing evidence that attentional bias to threatening faces is preferentially driven by automatic attentional processes. Additionally, our finding that greater controlled drift rate (i.e., goal-directed attention) was associated with reduced attentional bias to threat provides further evidence of attentional biases being the result of impairments in goal-directed attention. However, our findings also extend the literature by finding similar findings in a non-clinical population. As mentioned prevoiusly, research examining threat-related attentional biases and the processes that contribute to them have focused largely on individuals with anxiety. The present study provides evidence of attentional bias to threat, along with evidence that this bias is the result of automatic processes, in a non-clinical sample.

While this study has a number of strengths, there are also some limitations that should be mentioned. First, data collection was conducted during the COVID-19 pandemic, which has been found to impact stress resilience, mental health, and immune responses in a variety of ways (Manchia et al., 2022; Mattos dos Santos, 2020; Pfeifer et al., 2021). As a result, stress-related results should be considered in the context of social distancing during a global pandemic. Related, another potential limitation is the stressor used in this study. Because of COVID-19 protocols, we adapted the Trier Social Stress Test for use over Zoom, as has been done with adolescents (Gunnar et al., 2021). It may be possible that the in-person version of the TSST is perceived as more stressful, and results in a more severe stress response. This difference in severity could potentially account for the observed difference in findings between the present study and previous studies in the literature. Third, as described above, there may be specific task conditions necessary to eliciting stress-induced differences in attentional bias, and although these conditions, if they exist, are not entirely clear, we only assessed attentional bias using a single task that may have lacked these conditions. Finally, participants were recruited from university courses. As a result, the sample as a whole were relatively young and came from a Western, Educated, Industrialized, Rich, and Democratic (WEIRD) society (Henrich et al., 2010), which impacts the generalizability of our findings to larger samples.

## Conclusion

We found that participants randomized to the Trier Social Stress Test did not show significantly different attentional bias to threat than participants that completed a control paradigm, though we did find overall participants across groups were attentionally biased toward threat. Additionally, we found evidence that attention towards threat is driven primarily by automatic attentional processes and reduced by controlled attentional processes. Finally, our findings help to clarify the discrepancy in the prior literature, as methodological differences (i.e., differences in stress paradigm, attentional bias measure, procedures, etc.) may preferentially affect automatic vs controlled attentional processes, accounting for observed differences in the effects of acute stress on attentional biases across the literature. In short, attentional bias to threat seems to be driven by automatic attention towards threat and reductions in controlled attention, and stress seems to exert no effect on biases to threat or the processes that drive them.

Table 1

*Descriptive Statistics Among Computational Modeling Parameters by Stress Condition and Sex*

| | **Stress Men** | | **Stress Women** | | **Control Men** | | **Control Women** | |
|---|---|---|---|---|---|---|---|---|
| Variable | Mean | (SD) | Mean | (SD) | Mean | (*SD)* | Mean | (*SD*) |
| Amplitude of automatic attention function for angry trials | -3.16 | (18.45) | 8.13 | (19.72) | 2.33 | (22.52) | 1.39 | (19.99) |
| Scale of automatic attention function for angry trials | 2.34 | (0.58) | 2.30 | (0.62) | 2.43 | (0.63) | 2.29 | (0.58) |
| Peak latency of automatic attention function for angry trials | 226.28 | (76.92) | 171.07 | (97.38) | 219.93 | (91.12) | 208.38 | (88.86) |
| Amplitude of automatic attention function for happy trials | 2.05 | (22.14) | 0.63 | (16.76) | 0.12 | (20.15) | 9.05 | (20.03) |
| Scale of automatic attention function for happy trials | 2.39 | (0.59) | 2.16 | (0.68) | 2.56 | (0.45) | 2.22 | (0.61) |
| Peak latency of automatic attention function for happy trials | 210.78 | (89.55) | 199.37 | (83.36) | 165.63 | (108.17) | 204.70 | (83.21) |
| Strength of controlled attention | 0.45 | (0.15) | 0.41 | (0.10) | 0.46 | (0.15) | 0.41 | (0.18) |
| Decision boundary | 93.94 | (30.58) | 85.89 | (23.22) | 89.86 | (28.42) | 87.90 | (28.31) |
| Nondecision time | 405.68 | (71.57) | 411.40 | (71.79) | 392.25 | (47.99) | 422.93 | (61.57) |
| Standard deviation of nondecision time | 57.68 | (30.35) | 59.51 | (28.25) | 53.18 | (25.79) | 67.03 | (26.72) |

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