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The Impact of Uncertain Threat on Affective Bias: Individual Differences in Response to Ambiguity

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Individuals who operate under highly stressful conditions (e.g., military personnel and first responders) are often faced with the challenge of quickly interpreting ambiguous information in uncertain and threatening environments. When faced with ambiguity, it is likely adaptive to view potentially dangerous stimuli as threatening until contextual information proves otherwise. One laboratory-based paradigm that can be used to simulate uncertain threat is known as threat of shock (TOS), in which participants are told that they might receive mild but unpredictable electric shocks while performing an unrelated task. The uncertainty associated with this potential threat induces a state of emotional arousal that is not overwhelmingly stressful, but has widespread—both adaptive and maladaptive—effects on cognitive and affective function. For example, TOS is thought to enhance aversive processing and abolish positivity bias. Importantly, in certain situations (e.g., when walking home alone at night), this anxiety can promote an adaptive state of heightened vigilance and defense mobilization. In the present study, we used TOS to examine the effects of uncertain threat on valence bias, or the tendency to interpret ambiguous social cues as positive or negative. As predicted, we found that heightened emotional arousal elicited by TOS was associated with an increased tendency to interpret ambiguous cues negatively. Such negative interpretations are likely adaptive in situations in which threat detection is critical for survival and should override an individual's tendency to interpret ambiguity positively in safe contexts.

Keywords: threat of shock, anxiety, ambiguity, individual differences, bias

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Individuals such as military personnel and first responders are required to operate in highly stressful, often uncertain environments. When a source of threat is unclear, it can be adaptive to view potentially dangerous or unpredictable (i.e., ambiguous) stimuli as threatening until contextual information proves otherwise. Indeed, previous research suggests that unpredictability is aversive (Weiss, 1970; Grillon, Baas, Lissek, Smith, & Milstein, 2004; Herry et al., 2007) and elicits heightened responses to ambiguous stimuli in brain regions associated with threat detection (Davis, Neta, Kim, Moran, & Whalen, 2016). Additionally, attention toward threat-related information is prioritized when an individual is faced with threat (Cornwell et al., 2011), but it is not yet known how people process ambiguous emotional cues in potentially threatening contexts.

One way to mimic a threat context in a controlled laboratory setting is using a threat-of-shock (TOS) paradigm, in which participants receive mild electric shocks that are unpredictable and unrelated to their performance on a given task. This manipulation induces a state of hyperarousal that is not overwhelmingly stressful but has widespread—both adaptive and maladaptive—effects on cognitive and affective function (see Robinson, Vytal, Cornwell, & Grillon, 2013b for a review). For example, TOS has been shown to facilitate sustained attention and response inhibition (e.g., Cantelon, Eddy, Mahoney, Taylor, & Davis, in preparation; Cornwell, Mueller, Kaplan, Grillon, & Ernst, 2012; Robinson, Krimsky, & Grillon, 2013a). In the affective domain, TOS appears to partially model the effects of anxiety disorders (Monk et al., 2006; Telzer et al., 2008), resulting in a hypervigilance to threat (Mogg & Bradley, 2005; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007) and abolished positivity bias (Grillon & Charney, 2011; Robinson, Letkiewicz, Overstreet, Ernst, & Grillon, 2011; Robinson, Charney, Overstreet, Vytal, & Grillon, 2012). Importantly, in some situations (e.g., walking home alone at night), this hyperarousal can promote an adaptive state of improved vigilance and defense mobilization (Grillon & Charney, 2011).

Much of the work examining threat detection using TOS paradigms has compared responses with negative and neutral stimuli (Robinson et al., 2013b for a review). One unique way of probing these effects, however, is by examining responses to ambiguity. In the cognitive domain, ambiguity research has demonstrated that TOS increases risk avoidance during gambling tasks in which probabilities are unknown (ambiguous; Clark et al., 2012). In the affective domain, responses to ambiguity can be examined using social cues, such as facial expressions of emotion, which provide important information about the environment and are often used to guide behavior. Specifically, some facial expressions are associated with clearly positive (happy) or negative (angry) outcomes, whereas others are ambiguous in that they can predict both positive and negative outcomes (surprised). When presented without contextual information to disambiguate the valence of surprise, these expressions can be used to delineate an individual's valence bias: some individuals tend to interpret the expression negatively, whereas others interpret them more positively (Kim, Somerville, Johnstone, Alexander, & Whalen, 2003; Neta, Norris, & Whalen, 2009). Not surprisingly, we have shown that these valence interpretations are sensitive to subtle contextual manipulations (Kim et al., 2004), including a temporal context of clearly valenced faces (Neta, Davis, & Whalen, 2011), time perspectives (Neta, Tong, & Henley, 2017), and predictability (Davis, Neta, Kim, Moran, & Whalen, 2016).

In the present study, we leveraged the ambiguity of surprised expressions to test the effects of TOS on valence bias. Given that TOS is a context in which individuals might experience hypervigilance toward threat, we predict that TOS will elicit heightened emotional arousal that will be associated with more negative interpretations of surprised expressions. In other words, although it may be adaptive to adopt a more positive or optimistic outlook in safe environments, it is likely not adaptive to maintain this positive outlook under TOS and may instead be adaptive to identify potential threat.

Materials and Methods

Participants

Sixty-four participants were recruited for this experiment. Three were excluded from all analyses; one for technical issues resulting in missing data, two for noncompliance, in which one participant failed to make responses during the entire safe block, and another reporting low quality of participation, and reported inaccurate performance via randomly pressing buttons as quickly as possible (see Appendix for debriefing form). Thus, the final sample included 61 participants (40 females; age range = 18–33 years; mean (*SD*) age = 20.72 (3.13); race = 36 White, 11 Asian, 3 African American, 5 Hispanic, 6 Other). Because our first analysis, which examined the shift in ratings from safe to TOS (see *Effect of Threat of Shock* section in *Results*), was dependent on the experimental manipulation (i.e., TOS), we excluded three participants who explicitly told us they did not believe our experimental manipulation. Belief in shock was assessed on completion of the experiment (see Appendix for full debriefing form) by asking participants to indicate how much they expected to be shocked on a scale of 1 (*low belief*) to 10 (*high belief*). One participant gave a rating of 4, and two gave a rating of 2, so these three were removed because they were deemed unlikely to experience transient stress. The final sample in this analysis included 58 participants (38 female; mean [*SD*] age = 20.76 [3.10] years). However, all other analyses were less dependent on whether participants believed the experimental manipulation, so these participants were not excluded from any other analyses. All participants received monetary compensation and were Tufts University students or community members recruited via Craigslist. Participants provided written, informed consent in accordance with the Tufts University Social, Behavioral and Educational Research Institutional Review Board and secondary approvals from the funding agency (U.S. Army Human Research Protections Office).

Stimuli and Paradigm

Stimuli were 36 surprised faces (19 male) drawn from three stimulus sets (Ekman & Friesen, 1976; Lundqvist, Flykt, & Ohman, 1998; Tottenham et al., 2009). Faces were converted to gray scale, aligned vertically with the middle of the pupils and horizontally with the nose in the center, and matched on contrast/brightness. Using data from a pilot study, faces were divided into two sets matched on valence ratings, $t(34) = 0.03$, $p > .9$. One set was presented in the shock and the other in the safe condition, with order (shock/safe) and face sets counterbalanced across participants. Each face was presented three times per block (54 total presentations per block) and one block per shock/safe condition.

Before the task, participants completed a shock work-up procedure (described below). They were told that they would view a series of faces, and they were to rate each face as positive or negative, responding as quickly as possible based on gut instinct. Using Psychopy version 1.81.03 (Peirce, 2007), faces were presented on a black background for 500-ms with a 1000-ms interstimulus interval.

The surprise task instructions were as follows: "For this task you will be presented with a series of pictures of faces. Your goal is to determine if you think the face is positive or negative by pressing the keys marked P and N. The pictures will be presented quickly, so please make your response as quickly as possible by using your first impression or gut reaction to the picture. There will not be a practice for this task."

Shock procedure. Mild electric shocks were delivered to the index and middle fingers of the nondominant hand via a finger stimulator (Coulbourn Instruments LLC, Whitehall, PA). Each participant used a work-up procedure to set the shock at a level that was highly uncomfortable but not painful. They were told that they would receive 0–5 shocks that would be unrelated to the task or their performance. To reduce demand characteristics, participants were not given any information suggesting that the shock was being used as an anxiety or mood induction technique. During the shock condition each participant was shocked once before the task and once approximately 1 s after the final face presentation (to sustain arousal without interfering with task performance). During the safe condition, shock electrodes were removed and the participant was told that they would not receive any shocks.

The shock calibration instructions were as follows: "You will now set the level of shock. We will start with shock on the lowest setting and if you feel comfortable increasing the level of shock, you can let me know and I will increase it one level. We will continue increasing it until you reach a level that is highly uncomfortable but not painful to you. The shock will never go higher than the level you have set it at. Throughout the study there will be shock and safe conditions. I will inform you before we begin each task whether it is a shock or safe condition. If it is a safe condition, I will remove the electrodes; you will not be shocked during those tasks. If it is a shock condition, I will place the electrodes on your fingers and have you press the lever to remind yourself the level you have set it at. For the shock condition, you will be shocked between 0 and 5 times during the task and you can be shocked at any time when wearing the shock electrode. The shock is controlled by the computer program and is not dependent on task performance. Once I turn the lever to remote, the shock box will be controlled by the computer program and I will move the shock box closer to computer that will be sending the shock triggers."

Self-report questionnaires. Before each block, participants rated how anxious, happy, emotionally aroused/activated, relieved, and excited they felt on a scale from 0 (*not at all*) to 10 (*quite a bit*). Ratings were made after attaching the shock electrodes for the shock condition and without electrodes for the safe condition. At the end of the experiment, participants rated their performance using the following debrief form. Responses on this form were used as exclusion criteria.

Data Analysis

Analyses were performed using IBM SPSS version 22 (Armonk, New York). Paired-samples *t* tests were computed to evaluate differences in self-reported mood in the shock versus safe condition.

To determine whether uncertain threat influenced interpretations of surprised faces, we calculated valence bias scores in the safe (baseline) condition. The dependent measure used to represent valence bias was percentage negative ratings, calculated as the percent of trials on which a subject rated surprise negatively, of the total number of trials (excluding omissions). Given that individuals with a positive valence bias may be qualitatively different from those with a negative bias and that any manipulation of ratings may affect these groups differently, participants were divided into three equal groups, consistent with previous work on valence bias (e.g., Neta, Norris, & Whalen, 2009; Neta & Whalen, 2010; Neta & Tong, 2016): those who rated surprise most negatively (Negative group), those who rated surprise most positively (Positive group), and those in the middle (Middle group). We then calculated a difference score (percentage negative ratings in Shock-Safe conditions, indicating a shift in valence bias) for each participant and evaluated differences in bias shift between groups using Kruskal-Wallis and Wilcoxon's nonparametric tests.

Finally, to explore the hypothesis that bias shift might be associated with hyperarousal, we computed correlations between bias shift with self-reported changes in mood induced by TOS (emotional arousal, anxiety, happiness, relief, and excitement). Correlations were evaluated using Bonferroni-adjusted alpha levels of .01 (.05/5). Because TOS is traditionally used as a model for anxiety, we also performed a multiple linear regression analysis to determine whether anxiety or emotional arousal was a stronger predictor of bias-shift.

Results

Self-Reported Mood and Anxiety

Paired-samples *t* tests showed that participants were more emotionally aroused/activated, $t(60) = 6.067$, $p < .001$, 95% confidence interval (CI) [0.912, 1.809], more anxious $t(60) = 8.005$, $p < .001$, 95% CI [2.398, 3.995]), less happy, $t(60) = -2.417$, $p = .019$, 95% CI [−1.168, −0.110], and less relieved, $t(56) = -3.351$, $p = .001$, 95% CI [−2.382, −0.601], and trending toward more excited, $t(60) = 1.958$, $p = .055$, 95% CI [−0.010, 0.928] in the shock versus safe condition.

Next, we used the Kruskal-Wallis to test differences in self-reported mood and anxiety between our three groups. There were no significant differences on most of the measures, including arousal/relief/excitement/happiness scores. We did observe a significant effect of reported anxiety during the shock condition ($p <$ .02), in which the Positive group was more anxious than the Negative group ($p < .01$) and a trend compared with the Middle group ($p < .06$), but there was no difference between the Middle and Negative groups ($p > .2$). Additionally, Kruskal-Wallis nonparametric tests revealed no significant group differences in age, gender, or the belief that they would be shocked, and a one-way ANOVA on shock intensity (Levene's $p > .4$) yielded no significant main effect of group, $F(2, 58) = .68$, $p > .5$.

Valence Discrimination

As expected, valence bias was significantly different between the three groups, $\chi^2(2) = 53.69$, $p < .001$. Interestingly, the Positive group ($N = 20$, mean (SD) = 58.3% [19.7%]) had a valence bias ranging from 7.4% negative (quite positive) to 76.8% negative (somewhat negative), which is a more negative valence bias than we observed in previous studies (Neta et al., 2009, 2011; Neta, Kelley, & Whalen, 2013). Despite that, the Positive group had a more positive bias than the other two groups (mean [*SD*], range): Middle group ($N = 20$, 83.2% [4.3%], 77.4–92.5% negative), Negative group: ($N = 21$, 97.5% [3.1%], 92.6–100% negative). To verify that the greater negativity bias was not due to order effects, we computed an independent-samples *t* test and found no difference between valence bias in participants exposed to the shock or safe condition first, $t(56) = 0.340$, $p > .7$. In previous studies (Neta & Whalen, 2010; Neta & Tong, 2016; Neta et al., 2009, 2017), we divided participants using a median split, but because our distribution of valence bias was more negative here, a median split yielded a Negative group whose ratings were close to ceiling, precluding our ability to measure changes in bias because of our manipulation. Using a tertiary split yielded a Middle group with a negative bias that was not at ceiling and therefore could be influenced by our manipulation.

Effect of Threat of Shock

When examining the main effect of group on bias shift (change in mean negative ratings), we found that the assumption of homogeneity of variance has been violated; therefore, we conducted a Kruskal-Wallis nonparametric test. This analysis excluded the three subjects that did not believe the experimental manipulation (because any bias shift may not be attributed to TOS; $N = 58$). These tests revealed a significant effect of group, $\chi^2(2) = 7.36$, $p < .03$, in which the Positive group showed a significantly greater bias shift than the Negative group, $\chi^2(1) = 4.46$, $p < .04$, and the Middle group, $\chi^2(1) = 4.73$, $p < .03$, but there was no difference between the Middle and Negative groups, $\chi^2(1) = 0.38$, $p > .5$; Figure 1. After removing one outlier (>3 *SD* above the mean in bias shift; shifting from 50–94.4% negative under TOS), the effects remained significant. To compare the ratings under shock and safe conditions for each group, we used a Wilcoxon's nonparametric test. We found a significant effect in the Positive group ($Z = -2.05$, $p < .05$), such that ratings were more negative for the shock than safe condition, but no significant effects in the Middle ($Z = -.83$, $p > .4$) and Negative groups ($Z = -1.62$, $p > .1$). When removing the outlier, the effect for the Positive group was at trend ($p = .07$). However, when comparing ratings across the entire sample (rather than by group), the mean negative ratings for the safe and shock conditions were similar: for the safe condition, the mean (*SD*) was 79.9% (20.0%) negative, and for the shock condition, the mean (*SD*) was 80.4% (21.6%) negative.

Emotional Arousal and Bias Shift

As predicted, we observed a significant positive correlation between bias shift and self-reported emotional arousal across all participants ($r(60) = 0.403$, $p = .001$; Figure 2), in which individuals reporting greater arousal under TOS showed a greater bias shift (interpreting faces more negatively under TOS). No other correlations between self-report measures (anxious, happy, relieved, excited) survived correction for multiple comparisons using Bonferroni adjusted alpha levels of .01 (.05/5). These effects did not change after excluding two outliers, defined as bias shift greater than 3 *SD* from the mean.

Whereas it did not survive correction for multiple comparisons, we did observe a near-significant positive correlation between bias shift and self-reported anxiety ($r(60) = 0.312$, $p = .015$). Because previous work has used TOS as a model for anxiety (see Robinson, et al., 2013b for a review), we performed a multiple linear regression analysis to determine the relationship between anxiety and emotional arousal as predictors of bias shift. Preliminary analyses

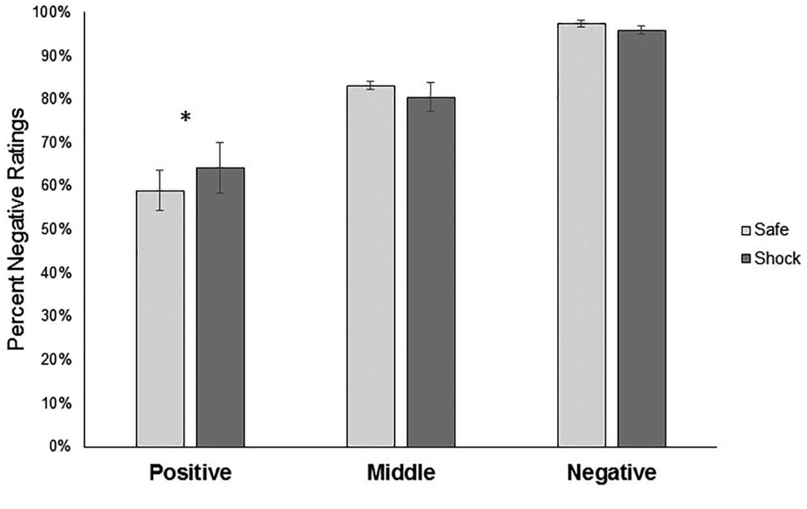

Figure 1. Shift toward negativity under threat of shock. Participants who showed the most positive valence bias at baseline interpreted surprise more negatively under the TOS compared with the safe condition. There was no significant change in ratings in the groups with a more negative bias at baseline. Error bars represent standard error of the mean. * $p < 0.05$.

suggest that the data met the assumptions of collinearity (anxiety, tolerance = 0.844, Variance Inflation Factor = 1.185; emotional arousal, tolerance = 0.844, 1.185) and independent errors (Durbin-Watson value = 2.194). The overall multiple regression model indicates that self-reported anxiety and emotional arousal explain a significant amount of the variance in bias shift ($F[2, 58] = 6.798$, $p = .002$, $R^2 = 0.190$, $R^2_{\text{Adjusted}} = 0.162$). Interestingly, whereas emotional arousal did significantly contribute to the model ($\beta = .332$, $t[58] = 2.578$, $p = .013$), anxiety did not account for any additional variance ($\beta = .181$, $t[58] = 1.181$, $p = .165$).

Comparing Bias Across Samples

The valence bias observed in the current sample is more negative than we have observed previously. Specifically, we compared these data to two separate studies: one study with a similar sample size ($N = 49$) and that used the cold pressor to induce a state of physiological stress. There was no significant difference in age ($p > .6$) or gender ($p > .1$) between these samples. However, the participants in the current report showed more negative ratings of surprised faces, $t(106.4) = 2.75$, $p < .01$, unequal variances assumed. Next, because there were slightly fewer participants in the cold pressor task, we compared our data with another study examining contextual manipulations of valence ratings of surprised faces with a larger sample size ($N = 75$; Neta, Davis, & Whalen, 2011). Again, there was no significant difference in age ($p > .4$) or gender ($p > .4$) between the samples, but again the TOS participants were more negative, $t(117.0) = 5.81$, $p < .001$, unequal variances assumed.

Discussion

Here we used TOS to examine the effects of uncertain threat on individual differences in valence ratings of emotional ambiguity (i.e., surprised facial expressions). As predicted, participants interpreted surprise more negatively under the threat versus safe conditions but only those individuals with a more positive valence bias at baseline. This is consistent with previous work that has shown that manipulations of valence ratings of surprised faces are more successful in individuals with a positive valence bias than those with a negative bias (Neta & Whalen, 2010; Neta & Dodd, 2017). Indeed, the emphasis of this effect in the positive group is consistent with our initial negativity hypothesis (Neta & Whalen, 2010; Neta, Davis, & Whalen, 2011; Neta & Tong, 2016), which suggests that negative responses to ambiguity are more automatic and that positivity may require some regulatory process. Thus, many experimental manipulations that have examined a shift in valence bias have done so by disrupting this regulatory mechanism, which would affect the bias only in the positive group who were putatively regulating their automatic negative responses at baseline (Neta & Whalen, 2010). Here again this regulatory process was disrupted by TOS, shifting these individuals toward the prepotent negative interpretation. Additionally, across all participants, individuals reporting heightened emotional arousal under uncertain threat interpreted surprised faces more negatively than those reporting lower emotional arousal. These effects are consistent with previous work showing that context (Kim et al., 2004), including a temporal context of clearly valenced faces (Neta, Davis, & Whalen, 2011) and unpredictability or uncertainty (Davis, Neta, Kim, Moran, & Whalen, 2016), influences interpretations of ambiguity. This is also consistent with findings suggesting that hypervigilance toward threat promotes anxiety-like behaviors (Shackman et al., 2011), including increased amygdala activity (Davis, Neta, Kim, Moran, & Whalen, 2016) that drives valence bias toward negativity (Robinson, Charney, Overstreet, Vytal, & Grillon, 2012). Interestingly, self-reported emotional arousal was a stronger predictor of bias shift than anxiety, supporting the assertion that TOS is a useful tool to model certain aspects of anxiety such as hypervigilance toward threat (see Robinson et al., 2013b for a review).

Adaptive Effects of Emotional Arousal

The TOS paradigm is a unique stress-induction procedure that can be used to simulate some of the cognitive and emotional demands faced in highly stressful, threatening, or uncertain conditions (e.g., military combat). Notably, in such circumstances, individuals must maintain peak cognitive performance while simultaneously monitoring the environment for unidentified threat.

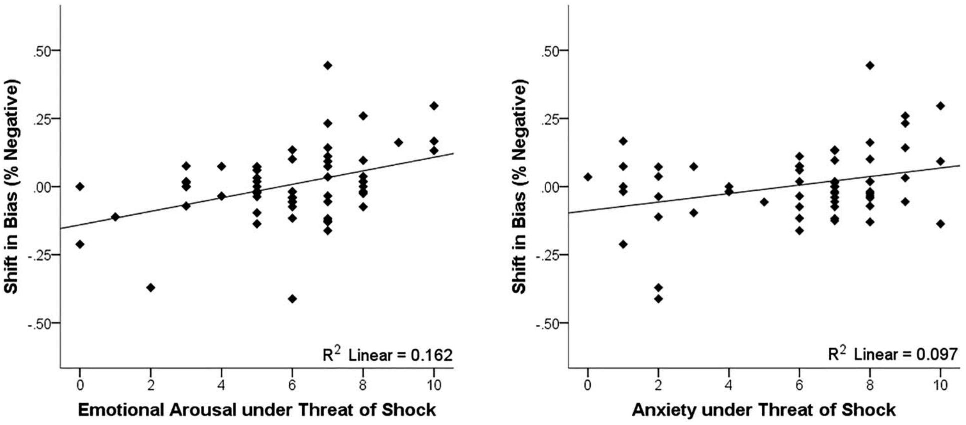

Figure 2. Shift toward negativity associated with emotional arousal. Heightened emotional arousal under threat of shock (TOS) was associated with a greater shift in bias to interpret surprised faces negatively.

The current paradigm taps into this process and shows that interpretations of ambiguous social cues, which provide important information about the environment and are often used to guide behavior, become more negative under threatening and uncertain conditions. This negativity, which is correlated with increased arousal, is likely adaptive in situations in which threat detection is critical for survival and should override an individual's tendency to interpret ambiguity positively in safe contexts.

Greater Negativity Bias in This Population

Across more than a dozen studies, we have demonstrated a wide range of individual differences in valence bias such that surprised faces are interpreted as positive by some people and negative by others. Even in our smallest experimental sample ($N = 29$; Neta & Whalen, 2010), bias ranged from 23% to 96% negative, with an average of 56% (see Neta and Brock., 2017). In contrast, bias in the current sample ranged from 7.4% to 100% negative but with an average of 80% (i.e., many more individuals with a negative bias). One potential explanation for this difference is that the experiment was conducted in the context of potential shock. In other words, even in the safe condition, when participants were not wearing shock electrodes, they may have been primed by the broader context in which, on some trials, such a threat would be present. Regardless, this difference does not appear to pose critical issues given that a) we did not observe order effects, and b) if anything, it may provide further evidence for our hypothesis that the TOS context shifts valence ratings in the negative direction.

Limitations

There are a number of potential limitations to this work. First, the shock condition is inherently negative, so it is possible that participants rated the faces more negatively because of demand characteristics, despite the fact that they were never explicitly told that the shock was being used as an anxiety or mood induction procedure. Additionally, we found a specific pattern of results whereby more negative ratings were reported only in the group of participants with a more positive bias, and we suggest that demand may be unable to explain this specific pattern of results. Future research could be repeat this experiment using morphed faces, which decreases demand characteristics and may be more robust design (see Adams, Penton-Voak, Harmer, Holmes, & Munafo, 2013).

Second, the variable that was used to split participants into groups is not independent of the dependent variable. This is atypical because much of the research on individual differences relates a trait measure (e.g., trait anxiety) with an outcome (differential behavioral performance). Here the trait measure and the outcome are inherently similar. However, extant research has shown that emotional responses to ambiguity vary as a function of valence bias or the tendency to interpret ambiguity as positive or negative (Neta et al., 2009; Neta & Whalen, 2010; Neta & Tong, 2016). Some research has used a different set of stimuli for identifying the baseline valence bias and for testing some experimental manipulation (Neta & Tong, 2016; Neta & Dodd, 2017; Brown, Raio, & Neta, 2017), but this was not possible in this experiment, given that our main prediction depended on the change in ratings between baseline and the manipulation. Future work might use the valence ratings from a third set of stimuli that is not used in the main experiment as the grouping variable.

Conclusions

Here we showed that hyperarousal elicited by uncertain threat leads to more negative interpretations of emotional ambiguity. This work complements previous research showing that TOS is associated with hypervigilance toward threat in paradigms that compare responses with negative (threatening) and neutral stimuli. Future research could examine psychophysiological and neural responses to ambiguity under threat to elucidate the biological underpinnings of this shift toward negativity and could be a useful link to previous work examining the effects of TOS on cognition and emotion (Robinson et al., 2013b).

Taken together, although adopting a more positive outlook may be more adaptive in safe environments, a negativity bias might be more adaptive for certain situations (high stress, danger). Future research testing populations who regularly operate in these highly uncertain contexts (e.g., military personnel, first responders) might provide further insight into the mechanisms supporting ambiguity processing. Such studies could evaluate the way that experience and training shape these automatic processes and whether they are specific to uncertain threat or generalize to other emotional (or safe) environments as well.

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