



How Does Threat Modulate the Motivational Effects of Reward on Attention?

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Abstract. Studies on attentional bias have overwhelmingly focused on the priority of different stimuli and have rarely manipulated the state of the observer. Recently, the threat of unpredictable shock has been utilized to experimentally induce anxiety and investigate how negative arousal modulates attentional control. Experimentally induced anxiety has been shown to reduce the attentional priority afforded to reward-related stimuli while enhancing the efficiency of goal-directed attentional control. It is unclear which of these two influences might dominate when attending to reward-related stimuli is consistent with task goals and by extension what the scope of the modulatory influence of threat on attention is. In contrast to paradigms in the visual domain, a novel auditory identification task has demonstrated a robust influence of target-value associations on selective attention. In the present study, we examined how the threat of shock modulates the influence of learned value on voluntary attention. In both threat and no-threat conditions, we replicate prior findings of voluntary prioritization of reward-associated sounds. However, unlike in studies measuring involuntary attentional capture, threat did not modulate the influence of reward on attention. Our findings highlight important limitations to when and how threat modulates the control of attention, contextualizing prior findings.

Keywords: threat, reward, motivation, auditory attention



Object representation in higher order brain networks is the product of competition among sensory stimuli for attentional priority, with the priority gain of one object leading to a cost in another (e.g., Desimone & Duncan, 1995; Itti & Koch, 2001). Attentional priority can be *voluntarily* allocated to features, objects, or regions in space that match an observer's current task goals (e.g., Posner, 1980; Wolfe et al., 1989). In contrast, attention can also be *involuntarily* biased by physically salient, low-level features such as color and shape contrast (e.g., Theeuwes, 1991, 1992). Moreover, attention can be biased toward stimuli or locations that have previously been allocated attention in the past, referred to as experience-driven attention or selection history (e.g., Anderson et al., 2011; Geng & Behrmann, 2002; Jiang & Swallow, 2013; Kristjansson et al., 2002; Schmidt et al., 2015). In the case of reward history, as demonstrated in the value-driven attentional capture (VDAC) paradigm (Anderson et al., 2011), participants learn to associate a color stimulus with a reward in a training phase. In the subsequent test phase, participants complete a new task in which the previously reward-

associated color is utilized as a task-irrelevant distractor. Thus, attending to reward-associated stimuli is consistent with task goals in the training phase and inconsistent with task goals in the test phase, probing the motivational effect of reward and the involuntary consequences of reward history on the control of attention, respectively. Using this paradigm, previously reward-associated distractors have been consistently shown to draw eye movements (e.g., Anderson & Kim, 2019a, 2019b; Anderson & Yantis, 2012) and slow down the speed with which the target of visual search can be reported in the test phase (e.g., Anderson et al., 2011; Anderson & Halpern, 2017; Anderson & Yantis, 2013).

Studies on the mechanisms of attentional biases have overwhelmingly focused on determining which kinds of stimuli have high priority and have rarely manipulated the physiological state of the observer. In hungry individuals, food-related stimuli are allocated increased attentional priority compared to control stimuli (Hardman et al., 2013; Mogg et al., 1998; Placanica et al., 2002). Likewise, fear-related stimuli are more robustly attended in individuals with high trait anxiety (e.g., Bar-Haim et al., 2007; Quigley et al., 2012). The threat-of-shock paradigm (Grillon et al., 2004) can be utilized to experimentally induce anxiety. Using a threat-of-shock manipulation, it has been shown that previously reward-associated stimuli less robustly capture attention under threat, evidenced by fewer

distractor-evoked eye movements and less substantial distractor-related slowing of target report (Kim & Anderson, 2020a, 2020c), while goal-directed attentional control is facilitated in a visual search task, with participants more frequently employing an optimal search strategy and less frequently missing the target (Kim et al., 2021a). Potentially related to adaptations deprioritizing reward-related stimuli in favor of negatively valenced stimuli when threatened (Kim & Anderson, 2020a, 2020c), along with general improvements in goal-directed cognitive processes to promote survival (Kim et al., 2021a), it is clear that threat can have divergent effects on the control of attention. Relevant to a more comprehensive understanding of threat's influence on attention is determining the more dominant of the two mechanisms of modulatory control, which can be measured when reward-related stimuli are task-relevant under threat, with implications for the scope of threat-related modulations of attentional control.

The influence of reward on attention has predominantly been investigated in the visual domain, and studies investigating attentional biases toward auditory stimuli are relatively limited (see Anderson, 2019; Parmentier, 2014, for reviews). While most studies investigating attentional biases by sounds have utilized a cross-modal approach that interfaces visual and auditory systems (e.g., Anderson, 2016b; McDonald et al., 2000; Sanz et al., 2018; Stormer et al., 2009), few have investigated the mechanisms of how learned value modulates auditory attention specifically (e.g., Asutay & Västfjäll, 2016; Folyi et al., 2016; Folyi & Wentura, 2019). Recently, the design of the VDAC paradigm has been translated into the auditory domain using solely auditory stimuli (Kim et al., 2021b) and has identified both robust voluntary attentional biases toward reward-associated targets in the training phase, indicated by faster report of high-value targets, and involuntary attentional capture by currently task-irrelevant but previously reward-associated distractors in the test phase, indicated by a slowing of target report in the presence of a previously high-value distractor. In contrast, typical approaches to studying VDAC in the visual domain often produce nonsignificant effects of reward during training in which the speed of target report is little influenced by the associated value (e.g., Anderson, 2016a; Anderson & Halpern, 2017; Kim & Anderson, 2020b). The VDAC paradigm in the auditory domain thus lends itself more naturally to an investigation of how threat modulates attention to reward-related but currently task-relevant stimuli.

In the present study, we investigated how experimentally inducing anxiety modulates voluntary attentional biases using the training phase of the VDAC paradigm in the auditory domain (Kim et al., 2021b). We utilized a between-subjects approach in which half of the participants

were exposed to unpredictable threat of electric shock while they performed the task (Kim & Anderson, 2020c). Of interest was whether the influence of threat on facilitating motivated or goal-directed attention would dominate, enhancing the priority of reward-related stimuli, or whether the influence of threat in blunting reward-related priority would dominate, resulting in weaker priority for high-value stimuli. A third possibility is that these two influences might offset, resulting in no net influence of threat, the likelihood of which could be assessed using Bayesian statistics.

Materials and Methods

Participants

Forty-eight participants (threat group: 12 female, 12 male; no-threat group: 15 female, 9 male), whose ages ranged from 18 to 34 years inclusive (threat group: $M = 20.8$, $SD = 3.1$; no-threat group: $M = 20.5$, $SD = 3.6$), were recruited from the Texas A&M University community. No significant mean differences were found in age between the two groups, $t(23) = 0.29$, $p = .771$, and a χ^2 test of independence showed that there was no significant association between gender and group, $\chi^2(1, 48) = 0.76$, $p = .561$. All participants were English-speaking and reported normal or corrected-to-normal visual acuity and normal color vision. All procedures were approved by the Texas A&M Institutional Review Board. Written informed consent was obtained for each participant, and all study procedures were conducted in accordance with the principles expressed in the Declaration of Helsinki. Participants were compensated with their earnings in the task.

Our sample size was based off a power analysis evaluating the effect of reward on response time (RT) in an identical version of the experimental task (Kim et al., 2021b), estimating a sample size of $n = 30$ to yield power $(1 - \beta) > .8$. In addition, we have previously measured the modulatory effect of threat on VDAC in a between-subjects design, but measuring involuntary attentional capture in the visual domain, and found a significant interaction effect of threat and reward with a sample size of 32 (Kim & Anderson, 2020c). Thus, given the novelty of the experimental design and to be conservative with our effect size, we decided to recruit and analyze complete datasets from 48 participants.

Apparatus

A Dell OptiPlex 7040 (Dell, Round Rock, TX, USA) equipped with MATLAB software (Mathworks, Natick, MA,

USA) and Psychophysics Toolbox extensions (Brainard, 1997) was used to present the stimuli on a Dell P217H monitor. The participants viewed the monitor from a distance of approximately 70 cm in a dimly lit room. Participants also wore Beyerdynamic DT 770 Pro 250 Ω professional studio headphones (Beyerdynamic, Heilbronn, Germany) to listen to all sounds. For participants in the threat condition, paired electrodes (BioPac Systems, Inc., Goleta, CA, USA) were attached to the left forearm of each participant and electric shocks were delivered through an isolated linear stimulator under the constant current setting (STMISOLA, BioPac Systems), which were controlled by custom MATLAB scripts. Motor responses to the auditory stimuli were made on a Millikey MH-5 response box (LabHackers Research Equipment, Halifax, Canada).

Auditory Stimuli

The auditory stimuli were the same as those used in Kim et al. (2021b). All auditory stimuli were recorded using a Spark SL condenser microphone (Baltic Latvian Universal Electronics LLC, Westlake Village, CA, USA), with an Arrow audio interface (Universal Audio Inc., Scotts Valley, CA, USA), on a 2017 MacBook Pro (Apple Inc., Cupertino, CA, USA). The recordings were sampled and modified using the built-in functions on the Logic Pro X software (Apple Inc.). The spoken letters used were U, I, and O, and the spoken numbers used were 1, 2, 3, and 4. These letters and numbers were chosen based on their phonetics (not rhyming and similar intonation). All recorded samples of the numbers and letters were cut to begin at exactly the same time, compressed to make the sound intensity equal, and condensed to be 300 ms in duration to ensure acoustic similarities across all stimuli.

Experiment Procedure

The experiment began with a brief hearing test in which participants indicated when they perceived 5 tones of 300–700 Hz (sin wave form, increments of 100 Hz), which were presented at intervals that randomly varied between 3,000 and 11,000 ms (increments of 2,000 ms). Each tone was played to each ear separately, in random order, and volume was adjusted if needed until the participant was 100% correct in identifying the tones. The computer volume was originally set to ~56 dB, and all participants were 100% accurate in the hearing test without adjustment, resulting in the original intensity being retained for the entire experiment in all cases. Participants in the threat condition were then connected to the isolated linear

stimulator and underwent a shock calibration procedure to achieve a subjective intensity of shock that is “unpleasant, but not painful” (e.g., Kim & Anderson, 2020a, 2020c; Kim et al., 2021a). No mention of electric shock was given to participants in the no-threat condition. Then, participants practiced the upcoming experimental task for 12 trials. This practice script would repeat until participants achieved at least 80% accuracy. Finally, participants completed six runs of the task and were compensated the total monetary reward accumulated throughout the experiment.

Task Design

Each run of the auditory identification task consisted of 72 trials. Each trial began with a fixation display (1800 ms), followed by the auditory stimuli (300 ms), an interstimulus interval (ISI), auditory and visual feedback (1,500 ms), and an intertrial interval (ITI; see Figure 1). Throughout each trial, a fixation cross (0.7° × 0.7° visual angle) was presented at the center of the screen. During the presentation of the auditory stimuli, participants would simultaneously hear a spoken letter played to one ear and a spoken number played to the other ear. The possible letter–number combinations and what side they were presented on the headphones were fully counterbalanced, and the order of trials was randomized each run. Participants were instructed to listen for the *letter* they heard and press the respective button on the response box (learned during practice). For each participant, correct report of one target letter was associated with high reward (7 cents), another with low reward (1 cent), and a third with no reward (0 cents). The letter-to-value mapping was counterbalanced across participants. The ISI lasted for 1,500, 2,700, or 3,900 ms (equally often, order randomized). Next, participants were given feedback based on what button they pressed. If the participant did not respond before the end of the ISI, they were presented with the words “Too Slow” and their accumulated total earnings, while if they pressed the wrong button they were presented with the words “Incorrect” and their accumulated total earnings (no sound was presented during such feedback). For correct responses, participants were shown their corresponding reward earnings and their accumulated total earnings, in addition to an audible cue for 500 ms (sin wave form, high reward = 650 Hz, low reward = 500 HZ, and no reward = 350 Hz). An auditory cue was associated with each reward value so that participants would still be exposed to reward-related feedback even if they chose not to look at the computer screen (which was not necessary to perform the task accurately). Finally, the ITI lasted for 900, 2,700, or 4,500 ms (exponentially

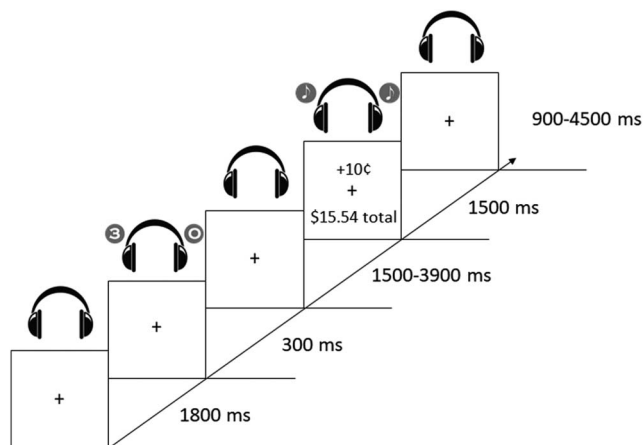


Figure 1. Sequence of trial events. Participants completed an auditory stimuli identification task in which one of three possible letters were associated with high, low, or no reward feedback. Half of the participants completed the entire experiment under threat of shock, while the other half were never introduced to threat of shock.

distributed, with the shorter time lengths being more frequent). The fixation cross disappeared for the last 200 ms of the ITI to indicate the participant that the next trial was about to begin.

Participants in the threat condition received a total of 10 electric shocks per run that was pseudo-randomly determined with the constraint that shocks were never administered on consecutive trials nor on the last trial of a run. Furthermore, electric shocks were evenly spaced out so that two shocks were administered every 15 trials to maintain a continuous state of elevated state anxiety (e.g., Kim & Anderson, 2020a, 2020c; Kim et al., 2021a). On shock trials, participants were administered the electric shock in place of hearing the auditory stimuli, and the ISI and reward feedback time were omitted for that trial.

Data Analysis

RT was measured from the onset of the auditory stimuli. Only correct responses were included in the RT analyses. RTs more than 3 *SDs* above and below the *M* for a given condition for a given participant were trimmed (e.g., Anderson & Yantis, 2013; Kim & Anderson, 2020a, 2020c; Kim et al., 2021b). Repeated-measures ANOVA analyses were conducted in SPSS (SPSS Statistics, IBM, Armonk, NY, USA). When the key interaction term for RT was nonsignificant using traditional null hypothesis testing, we also quantified the Bayes factor (BF) using Bayesian ANOVA testing in JASP (e.g., Wagenmakers, Love, et al., 2018; Wagenmakers, Marsman, et al., 2018). We denoted the Bayes factors as BF_{10} which measures the strength of the evidence in support for the alternative hypothesis compared to the null hypothesis. A BF_{10} of 1 to 0.33

reflects anecdotal evidence, 0.33 to 0.1 moderate evidence, and < 0.1 strong evidence in favor of the null hypothesis.

Results

We conducted a repeated-measures ANOVA analysis with reward as the within-subjects factor (high, low, and no) and the threat condition (threat and no-threat) as the between-subjects factor over accuracy and RT. For accuracy, we found a significant main effect of reward, $F(2,92) = 4.10, p = .020, \eta^2_p = .082$, but no significant effect of threat, $F(1,46) = 0.11, p = .742$, nor an interaction, $F(2,92) = 0.22, p = .802$ (see panel A of Figure 2). To probe the effect of reward in each group, we conducted post hoc pairwise comparisons between each reward condition. In the threat group, there was a significant difference between the high and no reward conditions, $t(23) = 2.13, p = .044, d = 0.360$, but no significant differences between the low and no reward conditions, $t(23) = 0.54, p = .598$, and the high and low reward conditions, $t(23) = 0.93, p = .361$. In the no-threat group, there was again a significant difference between the high and no reward conditions, $t(23) = 2.10, p = .047, d = 0.404$, but no significant differences between the low and no reward conditions, $t(23) = 1.76, p = .091$, and the high and low reward conditions, $t(23) = 1.11, p = .277$.

In the ANOVA over RT, we found a significant main effect of reward, $F(2,92) = 16.46, p < .001, \eta^2_p = .264$, but no significant effect of threat, $F(1,46) = 0.02, p = .891$, nor an interaction, $F(2,92) = 0.26, p = .774$ (see panel B of Figure 2). We again conducted post hoc pairwise

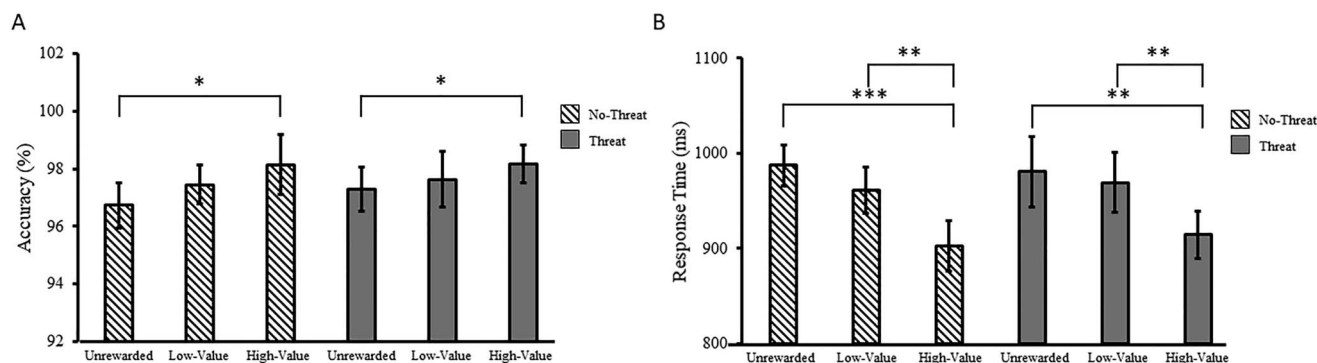


Figure 2. Behavior results. (A) Accuracy and (B) response time broken down by trials based on target-reward contingencies (unrewarded, low-value, and high-value) by subject group (under threat of shock and under no-threat of shock). Error bars depict within-subjects confidence intervals calculated using the Cousineau method (Cousineau, 2005) with a Morey correction (Morey, 2008). * $p < .05$, ** $p < .01$, *** $p < .001$.

comparisons between each reward condition. In the threat group, we identified a significant difference between the high and no reward conditions, $t(23) = 3.05$, $p = .006$, $d = 0.518$, and the high and low conditions, $t(23) = 3.25$, $p = .004$, $d = 0.396$, but no significant differences between the low and no reward conditions, $t(23) = 0.45$, $p = .655$. In the no-threat group, we again identified a significant difference between the high and no reward conditions, $t(23) = 5.10$, $p < .001$, $d = 0.794$, and the high and low conditions, $t(23) = 3.18$, $p = .004$, $d = 0.517$, but no significant differences between the low and no reward conditions, $t(23) = 1.75$, $p = .093$.

Given that we did not find evidence to reject the null hypothesis concerning the modulatory influence of threat (H_0 : threat does not interact with reward) as previously seen in studies measuring involuntary attentional capture (Kim & Anderson, 2020a, 2020c), we evaluated the evidence for the alternative hypothesis (H_A : threat interacts with reward) using a Bayesian ANOVA in JASP over RT. We found the preferred model to include just the effect of reward, $BF_M = 7.941$, corroborating our prior findings from the main effect of value from the repeated-measures ANOVA. Relative to the preferred model, a model with an additional main effect of threat was not likely, $BF_{10} = 0.442$, and there was strong evidence in support of the null hypothesis concerning a model that included an interaction, $BF_{10} = 0.061$.

Discussion

Our findings replicate a prior study demonstrating a significant effect of reward on task-related attentional biases in the auditory domain (Kim et al., 2021b). However, we provide evidence that threat does not modulate reward's influence on the voluntary control of attention through

both null hypothesis testing and Bayesian statistics, which contrasts with prior studies of threat modulating involuntary attentional capture by reward-related stimuli (Kim & Anderson, 2020a, 2020c). These diverging results are consistent with their distinguishable underlying mechanisms, with motivated attention being associated with the ability to selectively process information by allocating neural resources within the frontoparietal attention network and involuntary attention associated with the reflexive orienting to specific stimuli supported by the ventral attention network (e.g., Bowling et al., 2020; Corbetta et al., 2008; Engelmann & Pessoa, 2007; Locke & Braver, 2008; Prinzmetal et al., 2009). The threat of shock and effects of elevated state anxiety have been defined as a sustained physiological response that heightens vigilance (e.g., Davis et al., 2010; Sussman, Jin, et al., 2016; Sussman, Szekely, et al., 2016), and it is unknown whether negative arousal commonly modulates all modes of attentional processing. Our results suggest that the modulatory role of threat on value-based attention may be particular to mechanisms of involuntary attentional capture and, at least in the auditory domain, do not extend as robustly to motivated attentional processes.

In the context of goal-directed attentional control, threat has previously been shown to facilitate search efficiency and improve task performance (Kim et al., 2021a). Furthermore, a state of heightened vigilance has been shown to reduce task-related errors in a Go/No-Go task, again demonstrating that threat facilitates improvements in information processing and benefits task performance (Grillon et al., 2017). In contrast, in the context of the influence of reward on attention, threat has been shown to suppress value-driven attentional biases and reduce attentional capture by previously reward-associated stimuli (Kim & Anderson, 2020a, 2020c). Thus, it is plausible that the null results in the present study are a result of two offsetting attentional control mechanisms in which threat

facilitates motivated attention more broadly while suppressing the more automatic influence of learned value on information processing.

While the robust value-driven effects in the training phase of the VDAC paradigm in the auditory domain provided a useful tool in measuring the influence of threat on voluntary, reward-motivated attentional biases, VDAC is generally less studied in the auditory domain. The extent to which threat modulates attentional processes in the auditory system remains underexplored. Our threat manipulation exactly mirrored that which has consistently both impaired and facilitated the control of attention in the visual domain (Kim & Anderson, 2020a, 2020c; Kim et al., 2021a), and so it is unlikely that the lack of evidence for an interaction with threat in the present study was the result of an ineffective manipulation of threat. The effect of reward on attention in the present study was highly robust, and so there was also ample space for threat to modulate such reward-related priority. An effect of value dependence (low vs. high value) was evident in training phase performance, and it does not appear to be the case that threat and value-based attentional priority directly compete for neural resources (Kim & Anderson, 2020a), so it seems unlikely that the effect of reward was so strong as to preclude threat-based modulation (i.e., ceiling effect). What is clear from the findings of the present study is that the influence of threat with respect to both the value-modulated and goal-directed control of attention is not uniform, either differing across sensory systems or being subject to modulation from competing reward-related and goal-dependent influences. When threatened but motivated by rewards, it does not appear to be the case that threat necessarily results in a deprioritization of reward-related influences, with motivational processes potentially offsetting a tendency toward such deprioritization. Our findings provide an important boundary condition concerning how threat influences attention: Although threat impedes value-based distraction, we see no evidence that threat impairs the ability to voluntarily orient to reward-related stimuli, consistent with an overall highly adaptive mechanism of attentional modulation.

The extent to which the observed prioritization of high-value targets relies on attentional processes *per se* is unclear. As in implementations of the VDAC paradigm in the visual domain (e.g., Anderson et al., 2011; Anderson & Halpern, 2017), auditory targets competed for representation with nontarget distractors although, in this case, it was a single distractor (but see Kim & Anderson, 2019, for an implementation of the VDAC paradigm in the visual domain with one distractor). The resolution of such competition generally requires selective attention (Desimone & Duncan, 1995). It remains possible, however, that value modulated perceptual learning, with high-

value stimuli being prioritized independently of selective attention, although both perceptual learning in general and the modulatory effect of reward on perceptual learning more specifically typically require more protracted training (e.g., Seitz et al., 2009; Serences & Saproo, 2010).

The present study is not without methodological limitations. Although we have replicated the anxiety-inducing effect of threat of shock in both within-subjects and between-subjects designs (e.g., Kim & Anderson, 2020a, 2020b, 2021c), we cannot rule out the possibility that group differences (e.g., personality and state-anxiety) could have interfered with our threat manipulation in this current dataset (essentially, a failure of random assignment). We *a priori* chose to complete a between-subjects design due to the relatively stronger behavioral differences reported compared to a within-subjects design (Kim & Anderson, 2020c). Furthermore, although we have verified that our threat of shock protocol induces a negative arousal effect using pupil size analyses (Kim & Anderson, 2020a) and self-report questionnaires (e.g., Kim & Anderson, 2020a, 2021c), this current dataset lacks a manipulation check that confirms a significant change in arousal within the threat group.

In conclusion, our findings support for two distinct mechanisms of the influence of threat on the value-dependent control of attention, with threat distinctly blunting the automatic but not the voluntary and motivational influences of reward. However, future research is needed to understand the scope of this potential distinction. It remains unclear whether threat of unpredictable electric shock modulates value-based attentional processes differently across vision and audition and whether this influence varies with the type of threat and the sensory system implicated. A threat in the auditory dimension (e.g., unpredictable aversive loud noise) might be more effective at modulating value-based attentional priority in the auditory domain. As a teaching signal, however, electric shock and aversive white noise have shown to have comparable effects on visual attention (e.g., Anderson & Britton, 2020; Mikhael et al., in press). Our findings are at odds with the idea that threat has a broadly uniform influence on the value-based control of attention, inviting further investigation into the specific factors that determine whether and how threat and reward interact to determine how stimuli are processed. While the neural mechanisms of threat and involuntary attentional capture by reward cues have previously been investigated in the visual domain (Kim & Anderson, 2020a), no such studies have been conducted in the auditory domain and with voluntary attentional biases. Our study provides a framework for future investigations into how processing of attention, threat, and reward interact across sensory modalities.

References

- Anderson, B. A. (2016a). The attention habit: How reward learning shapes attentional selection. *Annals of the New York Academy of Sciences*, 1369(1), 24–39. <https://doi.org/10.1111/nyas.12957>
- Anderson, B. A. (2016b). Value-driven attentional capture in the auditory domain. *Attention, Perception, & Psychophysics*, 78(1), 242–250. <https://doi.org/10.3758/s13414-015-1001-7>
- Anderson, B. A. (2019). Neurobiology of value-driven attention. *Current Opinion in Psychology*, 29, 27–33. <https://doi.org/10.1016/j.copsyc.2018.11.004>
- Anderson, B. A., & Britton, M. K. (2020). On the automaticity of attentional orienting to threatening stimuli. *Emotion*, 20(6), 1109–1112. <https://doi.org/10.1037/emo0000596>
- Anderson, B. A., & Halpern, M. (2017). On the value-dependence of value-driven attentional capture. *Attention, Perception, & Psychophysics*, 79(4), 1001–1011. <https://doi.org/10.3758/s13414-017-1289-6>
- Anderson, B. A., & Kim, H. (2019a). On the relationship between value-driven and stimulus-driven attentional capture. *Attention, Perception, & Psychophysics*, 81(3), 607–613. <https://doi.org/10.3758/s13414-019-01670-2>
- Anderson, B. A., & Kim, H. (2019b). Test–retest reliability of value-driven attentional capture. *Behavior Research Methods*, 51(2), 720–726. <https://doi.org/10.3758/s13428-018-1079-7>
- Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences*, 108(25), 10367–10371. <https://doi.org/10.1073/pnas.1104047108>
- Anderson, B. A., & Yantis, S. (2012). Value-driven attentional and oculomotor capture during goal-directed, unconstrained viewing. *Attention, Perception, and Psychophysics*, 74(8), 1644–1653. <https://doi.org/10.3758/s13414-012-0348-2>
- Anderson, B. A., & Yantis, S. (2013). Persistence of value-driven attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, 39(1), 6–9. <https://doi.org/10.1037/a0030860>
- Asutay, E., & Västfjäll, D. (2016). Auditory attentional selection is biased by reward cues. *Scientific Reports*, 6, 36989. <https://doi.org/10.1038/srep36989>
- Asutay, E., & Västfjäll, D. (2016). Auditory attentional selection is biased by reward cues. *Scientific Reports*, 6(1), 36989. <https://doi.org/10.1038/srep36989>
- Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: A meta-analytic study. *Psychological Bulletin*, 133(1), 1–24. <https://doi.org/10.1037/0033-2909.133.1.1>
- Bowling, J. T., Friston, K. J., & Hopfinger, J. B. (2020). Top-down versus bottom-up attention differentially modulate frontal–parietal connectivity. *Human Brain Mapping*, 41(4), 928–942. <https://doi.org/10.1002/hbm.24850>
- Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, 10(4), 433–436. <https://doi.org/10.1163/156856897x00357>
- Corbetta, M., Patel, G., & Shulman, G. L. (2008). The reorienting system of the human brain: From environment to theory of mind. *Neuron*, 58(3), 306–324. <https://doi.org/10.1016/j.neuron.2008.04.017>
- Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology*, 1(1), 42–45. <https://doi.org/10.20982/tqmp.01.1.p042>
- Davis, M., Walker, D. L., Miles, L., & Grillon, C. (2010). Phasic vs sustained fear in rats and humans: Role of the extended amygdala in fear vs anxiety. *Neuropsychopharmacology*, 35(1), 105–135. <https://doi.org/10.1038/npp.2009.109>
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18(1), 193–222. <https://doi.org/10.1146/annurev.ne.18.030195.001205>
- Engelmann, J. B., & Pessoa, L. (2007). Motivation sharpens exogenous spatial attention. *Emotion*, 7(3), 668–674. <https://doi.org/10.1037/1528-3542.7.3.668>
- Folyi, T., Liesefeld, H. R., & Wentura, D. (2016). Attentional enhancement for positive and negative tones at an early stage of auditory processing. *Biological Psychology*, 114, 23–32. <https://doi.org/10.1016/j.biopsycho.2015.12.001>
- Folyi, T., & Wentura, D. (2019). Involuntary sensory enhancement of gain- and loss-associated tones: A general relevance principle. *International Journal of Psychophysiology*, 138, 11–26. <https://doi.org/10.1016/j.ijpsycho.2019.01.007>
- Geng, J. J., & Behrmann, M. (2002). Probability cuing of target location facilitates visual search implicitly in normal participants and patients with hemispatial neglect. *Psychological Science*, 13(6), 520–525. <https://doi.org/10.1111/1467-9280.00491>
- Grillon, C., Baas, J. P., Lissek, S., Smith, K., & Milstein, J. (2004). Anxious responses to predictable and unpredictable aversive events. *Behavioral Neuroscience*, 118(5), 916–924. <https://doi.org/10.1037/0735-7044.118.5.916>
- Grillon, C., Robinson, O. J., Krinsky, M., O'Connell, K., Alvarez, G., & Ernst, M. (2017). Anxiety-mediated facilitation of behavioral inhibition: Threat processing and defensive reactivity during a go/no-go task. *Emotion*, 17(2), 259–266. <https://doi.org/10.1037/emo0000214>
- Hardman, C. A., Rogers, P. J., Etchells, K. A., Houston, K. V. E., & Munafò, M. R. (2013). The effects of food-related attentional bias training on appetite and food intake. *Appetite*, 71, 295–300. <https://doi.org/10.1016/j.appet.2013.08.021>
- Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience*, 2(3), 194–203. <https://doi.org/10.1038/35058500>
- Jiang, Y. V., & Swallow, K. M. (2013). Spatial reference frame of incidentally learned attention. *Cognition*, 126(3), 378–390. <https://doi.org/10.1016/j.cognition.2012.10.011>
- Kim, H., & Anderson, B. A. (2019). Dissociable components of experience-driven attention. *Current Biology*, 29(5), 841–845. <https://doi.org/10.1016/j.cub.2019.01.030>
- Kim, A. J., & Anderson, B. A. (2020a). Arousal-biased competition explains reduced distraction by reward cues under threat. *eNeuro*, 7(4), ENEURO.0099-20.2020. <https://doi.org/10.1523/ENEURO.0099-20.2020>
- Kim, A. J., & Anderson, B. A. (2020b). Neural correlates of attentional capture by stimuli previously associated with social reward. *Cognitive Neuroscience*, 11(1–2), 5–15. <https://doi.org/10.1080/17588928.2019.1585338>
- Kim, A. J., & Anderson, B. A. (2020c). Threat reduces value-driven but not salience-driven attentional capture. *Emotion*, 20(5), 874–889. <https://doi.org/10.1037/emo0000599>
- Kim, A. J., & Anderson, B. A. (2021). Raw data for “How does threat modulate the motivational effects of reward on attention?”. <https://doi.org/osf.io/852fm/>
- Kim, A. J., Lee, D. S., & Anderson, B. A. (2021a). The influence of threat on the efficiency of goal-directed attentional control. *Psychological Research*, 85(3), 980–986. <https://doi.org/10.1007/s00426-020-01321-4>
- Kim, A. J., Lee, D. S., & Anderson, B. A. (2021b). Previously reward-associated sounds interfere with goal-directed auditory processing. *Quarterly Journal of Experimental Psychology*, 74(7), 1257–1263. <https://doi.org/10.1177/1747021821990033>
- Kristjánsson, Á., Wang, D., & Nakayama, K. (2002). The role of priming in conjunctive visual search. *Cognition*, 85(1), 37–52. [https://doi.org/10.1016/s0010-0277\(02\)00074-4](https://doi.org/10.1016/s0010-0277(02)00074-4)

- Locke, H. S., & Braver, T. S. (2008). Motivational influences on cognitive control: Behavior, brain activation, and individual differences. *Cognitive, Affective, & Behavioral Neuroscience*, 8(1), 99–112. <https://doi.org/10.3758/cabn.8.1.99>
- McDonald, J. J., Teder-Sälejärvi, W. A., & Hillyard, S. A. (2000). Involuntary orienting to sound improves visual perception. *Nature*, 407(6806), 906–908. <https://doi.org/10.1038/35038085>
- Mikhael, S., Watson, P., Anderson, B. A., & Le Pelley, M. E. (in press). You do it to yourself: Attentional capture by threat-signaling stimuli persists even when entirely counterproductive. *Emotion*.
- Mogg, K., Bradley, B. P., Hyare, H., & Lee, S. (1998). Selective attention to food-related stimuli in hunger: Are attentional biases specific to emotional and psychopathological states, or are they also found in normal drive states? *Behaviour Research and Therapy*, 36(2), 227–237. [https://doi.org/10.1016/s0005-7967\(97\)00062-4](https://doi.org/10.1016/s0005-7967(97)00062-4)
- Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorials in Quantitative Methods for Psychology*, 4(2), 61–64. <https://doi.org/10.20982/tqmp.04.2.p061>
- Parmentier, F. B. R. (2014). The cognitive determinants of behavioral distraction by deviant auditory stimuli: A review. *Psychological Research*, 78(3), 321–338. <https://doi.org/10.1007/s00426-013-0534-4>
- Placanica, J. L., Faunce, G. J., & Soames Job, R. F. (2002). The effect of fasting on attentional biases for food and body shape/weight words in high and low Eating Disorder Inventory scorers. *International Journal of Eating Disorders*, 32(1), 79–90. <https://doi.org/10.1002/eat.10066>
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, 32(1), 3–25. <https://doi.org/10.1080/00335558008248231>
- Prinzmetal, W., Zvinyatskovskiy, A., Gutierrez, P., & Dilem, L. (2009). Voluntary and involuntary attention have different consequences: The effect of perceptual difficulty. *Quarterly Journal of Experimental Psychology*, 62(2), 352–369. <https://doi.org/10.1080/17470210801954892>
- Quigley, L., Nelson, A. L., Carriere, J., Smilek, D., & Purdon, C. (2012). The effects of trait and state anxiety on attention to emotional images: An eye-tracking study. *Cognition & Emotion*, 26(8), 1390–1411. <https://doi.org/10.1080/02699931.2012.662892>
- Sanz, L. R. D., Vuilleumier, P., & Bourgeois, A. (2018). Cross-modal integration during value-driven attentional capture. *Neuropsychologia*, 120, 105–112. <https://doi.org/10.1016/j.neuropsychologia.2018.10.014>
- Schmidt, L. J., Belopolsky, A. V., & Theeuwes, J. (2015). Attentional capture by signals of threat. *Cognition and Emotion*, 29(4), 687–694. <https://doi.org/10.1080/02699931.2014.924484>
- Seitz, A. R., Kim, D., & Watanabe, T. (2009). Rewards evoke learning of unconsciously processed visual stimuli in adult humans. *Neuron*, 61(5), 700–707. <https://doi.org/10.1016/j.neuron.2009.01.016>
- Serences, J. T., & Saproo, S. (2010). Population response profiles in early visual cortex are biased in favor of more valuable stimuli. *Journal of Neurophysiology*, 104(1), 76–87. <https://doi.org/10.1152/jn.01090.2009>
- Störmer, V. S., McDonald, J. J., & Hillyard, S. A. (2009). Cross-modal cueing of attention alters appearance and early cortical processing of visual stimuli. *Proceedings of the National Academy of Sciences*, 106(52), 22456–22461. <https://doi.org/10.1073/pnas.0907573106>
- Sussman, T. J., Jin, J., & Mohanty, A. (2016). Top-down and bottom-up factors in threat-related perception and attention in anxiety. *Biological Psychology*, 121(pt B), 160–172. <https://doi.org/10.1016/j.biopsycho.2016.08.006>
- Sussman, T. J., Szekely, A., Hajcak, G., & Mohanty, A. (2016). It's all in the anticipation: How perception of threat is enhanced in anxiety. *Emotion*, 16(3), 320–327. <https://doi.org/10.1037/emo0000098>
- Theeuwes, J. (1991). Categorization and identification of simultaneous targets. *Acta Psychologica*, 76(1), 73–86. [https://doi.org/10.1016/0001-6918\(91\)90054-4](https://doi.org/10.1016/0001-6918(91)90054-4)
- Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics*, 51(6), 599–606. <https://doi.org/10.3758/bf03211656>
- Wagenmakers, E.-J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E.-J., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., . . . Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*, 25(1), 58–76. <https://doi.org/10.3758/s13423-017-1323-7>
- Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychon Bull Rev*, 25(1), 35–57. <https://doi.org/10.3758/s13423-017-1343-3>
- Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance*, 15(3), 419–433. <https://doi.org/10.1037//0096-1523.15.3.419>

History

Received May 6, 2021

Revision received August 4, 2021

Accepted August 5, 2021

Published online October 29, 2021

Conflicts of Interest

The authors declare no conflicts of interest.

Publication Ethics

Written informed consent was obtained for each participant, and all study procedures were conducted in accordance with the principles expressed in the Declaration of Helsinki.

Authorship

The corresponding author has transitioned to a new position at the University of Southern California.

Open Data

Full raw data for the participants in the threat condition and participants in the no-threat condition are available at <https://osf.io/852fm/> (Kim & Anderson, 2021).

My article contains no experiment with a completely executed preregistration.

Funding

This study was supported by grants from the National Institutes of Health (R01-DA046410) to Brian A. Anderson.

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