Anticipation of aversive threat potentiates task-irrelevant attentional capture

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ABSTRACT

Anxiety is believed to have a disruptive effect on attentional control, supported by evidence of increased distractibility among high trait anxious individuals. However, how feelings of current anxious apprehension influence selective attention is less well-understood. The present study examined this by assessing attentional capture by a novel distractor within a visual search task. Participants searched an array of colored objects for a shape-defined target, while attempting to ignore a color singleton distractor presented on half of trials. To induce apprehension, participants completed the task in some blocks with a low probability threat of loud aversive sounds being presented. We found significantly increased distractibility within the threat condition when noise was anticipated but not played, as reflected by a larger distractor presence cost to reaction times. The finding that apprehension potentiates task-irrelevant attentional capture suggests a generalized role of anxious emotion in increasing distractibility.

Keywords: Threat; Anxiety; Stress; Selective attention; top-down control

INTRODUCTION

High levels of anxiety are associated with a number of changes in cognitive function (e.g., Bishop, 2007). In particular, growing evidence suggests a link with alterations in selective attention processes. For example, individuals reporting high levels of dispositional anxiety in their daily life show a tendency for impoverished inhibition, such as in suppressing prepotent responses (Berggren & Derakshan, 2014; Pacheco-Unguetti et al., 2010), or attentional capture by salient distractors (Moran & Moser, 2015). These findings can be accommodated within cognitive models such as the Attentional Control Theory (Eysenck et al., 2007), which posit that anxiety has a deleterious effect on top-down attentional control, primarily evident in tasks that weight on core components of this process such as distractor inhibition.

Given there is much evidence for a link between anxious traits and modulations to attentional control, it is tempting to assume that this could be driven by situational factors such as the mere feeling of anxiety and apprehension as an emotion. For instance, one candidate to explain anxiety-related deficits in inhibition is that high anxiety is associated with active worry, which could impair control through consuming limited-capacity working memory resources shared with executive attention processes (e.g., Eysenck et al., 2007; see Engle, 2002). Alternatively, anxious feelings may promote vigilance to the visual environment to detect potential threats, increasing the likelihood of task-irrelevant distraction (Eysenck, 1992). In either case, any situational experience of anxious emotion would be expected to have similar effects on selective attention as observed in high trait anxiety. Surprisingly, however, investigation of the effect of acute anxiety or apprehension on attention has produced highly inconsistent results.

On the one hand, acute anxiety and apprehension, and more generally acute stress, has been found to reduce performance on a number of tasks assessing executive attention (Schoofs et al., 2009; Starcke et al., 2016), including increased distractibility in selective attention tasks such as the Stroop test (e.g., Choi et al., 2012; Starcke et al., 2016), and larger orienting effects towards task-irrelevant cues (Pacheco-Unguetti et al., 2010). Conversely, a number of studies have reported contrary reduced distractibility, including in similar attention task paradigms (e.g., Stroop task: Booth, in press; Chajut & Algom, 2003; Henderson et al., 2012; Hu et al., 2012), suggesting surprisingly improved attentional control. It is important to note that contradictory findings across studies may relate to the variety of induction methods utilized, as well as the experimental emphasis on examining anxiety to a presence of a direct threat, the apprehension of a forthcoming threat, or more general feelings of stress. For example, anxious apprehension has been induced through low probability threat of electric shock or aversive noise manipulations (Booth, in press; Choi et al., 2012; Henderson et al., 2012; Hu et al., 2012; Starcke et al., 2016), presentation of unpleasant images (Pacheco-Unguetti et al., 2010), or priming moods via movie clips (Finucane, 2011). Meanwhile, general stress has been induced through participants completing unpleasant activities such as immersion of an arm in ice-cold water (Beste et al., 2013), or employing a variety of priming methods simultaneously, such as time pressure, fatigue, and ego threat (Chajut & Algom, 2003). As a consequence, conflicting findings across studies could reflect differences in what is precisely being induced across different methodologies. Nevertheless, the fact a number of studies converge on findings suggesting improved attentional control under high state anxiety or apprehension poses a major problem for any theoretical attempt to draw parallels between short- and long-term anxious experience in influencing selective attention.

Why might acute anxious emotion improve attentional control? One classic account put forward by Easterbrook (1959) proposes that emotion reduces “cue utilization”, which can be conceptualized spatially as a narrowing of the breadth of attention or non-spatially as a reduction in the number of objects or basic feature attributes of a stimulus that are simultaneously attended to within the environment. This account encompasses the effect of negative emotionality in general, assuming that additional irrelevant signals are often the first to suffer when cue utilization is reduced, thereby accommodating the basic finding of reduced distractibility. On this account, attentional control is not improved under acute experience of anxious emotion per se, but rather distractor information incidentally suffers by receiving reduced attention, giving the impression of heightened control. While it should be noted that other evidence for Easterbrook’s account has come from visual perception studies (e.g., Bursill, 1958), at the level of selective attention the majority of work highlighting reduced distractibility under anxious or stressful emotion as outlined above has emerged from variations on a single measure: distractibility via response-competition in classic Stroop or flanker tasks. Here, comparison is typically made between participants’ reaction time (RTs) when a response-incongruent distractor attribute is present in a display (e.g., when responding to the color red overlaid on the irrelevant word blue) versus when a distractor attribute is response-congruent (e.g., red overlaid on the word red). The difference between RTs in these two conditions gives a reflection of to what extent a participant failed to ignore an irrelevant distractor’s input, with an increased cost score suggesting heightened distractibility.

A problem with response-competition paradigms, however, is that they can confound multiple facets of attention and cognition. For example, such paradigms also create motor conflict, where an incongruent distractor signal promotes a motor response that differs from a task-relevant signal. In relation to anxiety, there is evidence of influences to motor control, as for example acute apprehension of threat has been implicated in improving the withholding of prepotent responses in motor stopping tasks indicative of harm avoidance (Robinson et al., 2013)[1]. Points such as this raise the possibility that findings of reduced distractibility when acutely experiencing anxiety and apprehension may reflect a phenomenon outside of selective attention per se. Consequently, it is important to examine whether or not such findings of reduced distractibility translate to more direct measures of selective attention that avoid potential issues surrounding response-competition.

Here, we aimed to provide such a test of distractibility within a selective attention task. Participants were asked to search an array of colored shape objects for a target diamond item, responding whether a gray line presented within this shape was horizontally or vertically oriented. On half of trials, all items were presented in the same color (red or green). On the other half of trials, one non-target shape was presented in the opposite color (e.g., red among green items), thereby acting as a task-irrelevant singleton. Studies using this procedure have demonstrated that the inclusion of an additional singleton within search displays elicits task-irrelevant attentional capture, disrupting speeded response to target objects (e.g., Theeuwes,

[1] Note that such an effect in relation to response-competition may be specific to state inducements of anxiety; while there is evidence that chronically anxious individuals also show improvements in motor stopping (Grillon et al., 2017), response-competition as a marker of distractibility is often found to be increased in high trait anxiety (Berggren & Derakshan, 2014; Bishop, 2009; Pacheco-Unguetti et al., 2010).

1992). This paradigm has also been previously utilized to examine the role of trait anxiety in distractibility, which positively correlates with distractor costs (e.g., Moran & Moser, 2015). Importantly, this task does not include any element of response-competition; singleton distractors do not promote a motor response, merely acting to bias spatial attention and requiring suppression in order to efficiently respond to target objects (e.g., Sawaki & Luck, 2010). With regard to anxious emotion, we examined the role of induced apprehension for a forthcoming threat, with participants undergoing two task conditions. Within 'safe' blocks, the task was completed as described above. Within 'threat' blocks, participants completed the task with the added manipulation that loud aversive sound was presented at low probability across trials. Threat of aversive stimuli manipulations are well-established to successfully induce apprehension (threat of loud noise: e.g., Booth, in press; threat of shock: e.g., Choi et al., 2011; Robinson et al., 2013).

If induced apprehension leads to similar effects on selective attention as seen in trait anxious individuals, as according to models such as Attentional Control Theory (Eysenck et al., 2007), increased attentional capture should be found within the threat condition as indexed by increased reaction times when distractor color singleton objects are present. If alternatively findings of reduced response-competition under acute anxiety and apprehension also translate to other measures of distractor processing, as proposed by a reduced cue utilization account (Easterbrook, 1959), an opposing reduction in capture should be observed.

METHOD

Participants

Forty-six participants took part in the study. Of these, four participants' data were excluded as outliers over 2.5 SDs from the sample: one due to raw RT, one due to error rates, and two for extreme distractor capture effects regardless of condition in the task. The final sample was therefore N = 42 (*M* age = 24 years, SD = 6; 17 male; 3 left-handed). Desired sample size was based on power analysis from data in a pilot study, with power of .80 to detect a moderate effect size of *dz* > .45.

Stimuli and Procedures

The experiment was programmed and run using E-Prime 2.0 software (Psychology Software Tools, Inc.). Stimuli were presented on a 19-inch monitor (60Hz; 1280 x 1024 screen resolution), with viewing distance at ~60cm. Responses in the task were recorded via keyboard button presses. All stimuli were presented on a black background, with a grey fixation dot (0.10 x 0.10 degrees of visual angle) presented constantly throughout a block. An example experimental trial sequence is shown in Figure 1. On each trial, a search display was presented containing six colored shapes, a diamond and five circles (1.15 x 1.15°), positioned at six fixed circular points around fixation with an eccentricity of 2.24° as measured from the center of each object to fixation. On each trial, shapes could contain either a horizontal or vertical grey line (0.76 x 0.14°). On half of trials, all objects were the same color, either red (CIE coordinates: .587/.320) or green (.283/.573). On the other half of trials, one circle object appeared as a salient distractor in the opposite color to the rest of the objects. The distractor stimulus was always presented in the opposite lateral hemifield to the diamond target, and was never directly adjacent or vertically/horizontally aligned from the target's position in the circular array. Colors were equated for luminance (35 cd/m^2).

Noise stimuli consisted of 23 possible sound files presented over headphones, all measured using a sound meter to play at 95-100 decibels. One of the sounds was a short burst of white noise, while the remainder were selected from the International Affective Digital Sounds (IADS) database on the basis of high ratings for arousal and unpleasantness[2]. Files were cropped to 600ms duration to reduce context. For example, a sound of a car skidding and crashing was cropped to only the crashing sound, while the sound of a violent altercation was cropped to only the sound of a shriek.

Insert Figure 1 about here

On each trial, a search display was presented for 150ms followed by a 1850ms inter-trial interval that also acted as part of the 2000ms response window. The first trial in each block was preceded by a 1000ms interval. Participants were instructed on each trial to locate the diamond object, responding to the orientation of the line bar within it by pressing '0' for horizontal or '2' for vertical on the numeric keypad with their right index and middle fingers, respectively. Speed

[2] The sound files from the IADS database used were: 105(1), 105(2), 106, 134, 275, 276, 277, 310, 312, 319, 380, 420, 422, 424, 600, 626, 709, 711, 712, 714, 719, 732.

and accuracy were equally emphasized. Participants were also told that, on some displays, one of the non-target objects could appear in a salient color, and that they should ignore this. Finally, participants were instructed that in some blocks the task would be completed as normal (safe condition), but in other blocks there was a low probability of loud noise being presented over headphones during the block (threat condition). This occurred on 12.5% of trials within threat blocks. Before initiating each safe block, participants were encouraged to remove the headphones so that there would be no apprehension of noise.

During practice, participants were given examples of two of the sounds to ensure the volume was tolerable and that they were happy to proceed. Following this, they completed six experimental blocks of 48 trials each. Safe and threat conditions were alternated each block following an ABABAB format, with this order reversed for half of participants. Each block counterbalanced target location, target color, distractor presence, target line orientation, and, on distractor-absent trials, the exact position of the salient color distractor in the opposite hemifield relative to the target. Line orientations within non-target objects were randomly assigned with the provision that three of each orientation appeared within a single display[3]. Within the threat condition, noise trials were randomly selected independently to the counterbalanced target list, with the specific sound played at each occurrence also chosen randomly. At the end of the experiment, participants were asked to rate the task on the following criteria: how anxious/nervous the threat of noise made them feel during the task,

[3] Note that presenting other horizontal/vertical line objects could create motor conflict between target and non-target items' associated response. As this conflict was constant across the experimental task however, its effect should be independent to that of attentional capture by color singletons. It is possible though that interactions between types of conflict could occur and also in conjunction of the effect of threat anticipation.

how stressed, and how generally unpleasant the noise stimuli were. Participants gave ratings of 1-3, where 1=not at all, 2=moderately so, and 3=very.

RESULTS

Reaction times: As our research question related to anticipation of aversive noise, we excluded trials from analysis where noise was actually presented. Because noise was presented following search displays effectively during the inter-trial interval before the next display, we also excluded trials immediately following noise within the same block to ensure any differences were not due to affecting preparation for the next search episode. Signal-to-noise ratios between conditions were equated, as a matched number of random trials within the safe condition were flagged for exclusion by the experimental software online during data acquisition. Remaining mean RT data from correct-response trials were entered into a 2x2 repeated-measures Analysis of Variance (ANOVA), with the factors Noise Condition (Safe, Threat) and Distractor Presence (Present, Absent). Analysis showed a significant main effect of Distractor Presence ($F(1,41)=16.06$, $p<.001$, $\eta_p^2=.28$), with the presence of a color singleton distractor generally slowing target RTs (M=721 vs. 706ms). There was no significant main effect of Noise Condition ($F(1,41)=1.11$, $p=.30$) but, crucially, a significant two-way interaction ($F(1,41)=9.12$, $p=.004$, $\eta_p^2=.18$). Analyzing Distractor Presence effects separately, this cost was only marginal in the safe condition (*M*=714 vs. 706ms; diff=8ms; $t(41)=1.84$ $p=.07$), but reliably present in the threat condition (*M*=728 vs. 705ms; diff=23ms; $t(41)=4.74$, $p<.001$; see Figure 2)[4].

Insert Figure 2 about here

Error rates: A matching analysis on error rate data showed a trend for a main effect of Distractor Presence ($F(1,41)=1.92$, $p=.17$, $\eta_p^2=.05$) with more errors on distractor-present trials (*M*=8 vs. 7%), but no evidence for an effect of Noise Condition or interaction (*F*'s<1). Error rates were generally low (*M*=7%, SD=6). Assessing the relationship between RT and error rates showed that distractor costs on the basis of RT in the safe and threat conditions, as well as the difference between them, were not related to distractor costs in error rates (*r*'s<.16, *p*'s>.31). General mean RTs in the safe condition were also unrelated to error rates (*r*'s<.16, *p*'s>.30). For the threat condition, there was evidence that longer RTs correlated with more errors under both distractor-present and absent conditions (*r*'s>.337, *p*'s<.03).

Ratings scales: Overall, participants rated that the noise stimuli elicited low to moderate anxious/nervousness and stressfulness (Meds=1.79 & 1.90), while the sounds were generally rated as moderately unpleasant (Med=2.17). Responses for all three ratings positively

[4] As color, specifically red, can hold implicit affective value related to danger (e.g., Friedman & Förster, 2010), we assessed if this may have contributed to observed findings. An additional analysis including Distractor Color as a factor indeed showed an interaction with Distractor Presence ($F(1,41)=6.54$, $p=.01$, $\eta_p^2=.14$), with larger distractor costs for red singletons (*M* diff=23 vs. 8ms). There was no significant two-way (*F*<1) or three-way interaction with Noise Condition ($F(1,41)=1.52$, $p=.22$), suggesting that heightened distractibility by red singletons was unrelated to increased distractibility found in the threat condition. We thank an anonymous reviewer for raising this point.

correlated (r's>.569, N=42, p's<.001). Ratings were then assessed for correlations with distractor costs. There was no evidence that ratings correlated with distractibility within the safe (r's<.10, p's>.48) or threat conditions (r's<.245, p's>.12). Finally, calculating the difference between distractor costs in threat versus safe conditions (i.e., threat cost minus safe cost), there were trends for positive associations with anxiety (r=.264, N=42, p=.09) and unpleasantness ratings (r=.261, N=42, p=.095), but not stress (r=.218, N=42, p=.17). No relationships were evident for error rates (r's<±.227, p's>.15).

DISCUSSION

The goal of the present study was to examine the effect of induced anxious apprehension on distractibility as measured by attentional capture. Previous investigations on the role of acute anxiety, apprehension, and stress have reported inconsistent findings of increased/decreased distractibility in selective attention tasks, which could be confounded by common measurement of distraction being based on response-competition effects. Here, using a more direct measure of attentional processing, we found that induced apprehension significantly increased distractibility by task-irrelevant singletons during visual search as measured by larger costs to reaction times when distractors were present versus absent. This suggests that apprehension of aversive stimuli has a disruptive effect on selective attention processes, in line with similar observations among trait anxious samples (e.g., Moran & Moser, 2015).

Results contrast with previous studies suggesting that anxiety and negative emotionality allows for improved selectivity (e.g., Booth, in press; Chajut & Algom, 2003; Henderson et al., 2012; Hu et al., 2012; Finucane, 2011). According to Easterbrook's reduced cue utilization account, one would have predicted that participants reduce attention to task-irrelevant color inputs under threat anticipation and instead narrow processing to shape inputs. The fact we observed the opposite result cannot be easily accommodated by this account. Instead, results provide credence to the possibility that a dominant task-measure in previous studies, distractibility based on response-competition, might confound effects of acute anxiety and apprehension, and more generally stress, on selective attention. As outlined in our introduction, such procedures may affect post-perceptual factors such as interacting with motor control over prepotent responses, which may affected by situational anxiety in distinct ways to visual selective attention. Of course, this interpretation remains speculative: here we only examined selective attention when removing any possible role of response-competition. A key avenue for future research is to now investigate what factors might be modulated by acute anxious emotion under response-competition procedures. However, it is worth reiterating that other studies employing such measures have observed evidence of *increased* distractibility when participants are presented with or anticipate aversive stimulation, in line with the current study (Schoofs et al., 2009; Starcke et al., 2016). Thus, it remains unclear why studies using similar methods to examine selective attention have produced strikingly different results.

Another possible factor is the precise induction method used and what emotion is primed in participants. Here, we presented loud aversive sounds at low probability, and focused on selective attention in the absence of a direct threat but rather an apprehension for its forthcoming presentation. While we observed trends particularly between how anxious participants reported they felt within noise blocks, and how unpleasant the noises were perceived in relation to increased distractibility within threat blocks, we cannot conclusively state that the key emotion driving our findings was acute anxiety. Rather, our findings reflect a role of anticipation of aversive threat stimuli on selective attention, and may not generalize, for instance, to situations of anxiety in the direct presence of a threat. This broader point on generalization however applies to previous studies, where induction techniques have variably induced different components of anxious and stressful emotion (e.g., Booth, in press; Choi et al., 2012; Pacheco-Unguetti et al., 2010). Nevertheless, a previous study by Moran and Moser (2015) did in fact measure the role of both trait anxiety and acute apprehension on attentional capture, where apprehension was induced by instructing some participants that they would be asked to deliver an impromptu speech in front of an evaluative audience following the experimental task. While the authors found that trait anxiety predicted increased attentional capture, no effect was seen under acute apprehension. In contrast, the present study induced apprehension transiently within experimental blocks, with potential noise occurring immediately following search displays and therefore temporally linked to the offset of displays. One could therefore argue that a role of apprehension on selective attention is detectable as a transiently-activated effect rather than experienced potently over a prolonged period of time. This could be examined by more precisely measuring the inter-trial variability in reaction times within blocks rather than simply mean RT as in the current study, which fails to fully encapsulate the underlying distribution of responses within and between participants, comparing this with, for instance, objective physiological measures of current apprehension and other measures of attentional capture (e.g., overt eye-movements to distractor objects). However, even if the effects of apprehension on distractibility are transient, this still cannot fully reconcile differences seen in past studies where, for example, similar aversive shock anticipation methods were used by both Choi et al (2012) and Hu et al (2011) within Stroop-like tasks, with the former finding generally increased distraction under threat, and the latter reduced.

Finally, based on our findings, it is important to consider the attentional mechanisms underpinning distractor capture. Drawing parallels with evidence relating to the role of trait anxiety in attentional control (e.g., Eysenck et al., 2007), one possibility is that acute apprehension reduces top-down suppression of salient color distractors such as via the role of worry in impairing executive attention processes. This is in line with proposals that singleton distractors can elicit an automatic "attend-to-me" signal during visual search, and individual differences in attentional control (e.g., inferred from working memory capacity) predict whether or not distractors elicit capture or instead evidence of active suppression (e.g., Gaspar et al., 2016; Sawaki & Luck, 2010). Models of anxiety such as Attentional Control Theory (Eysenck et al., 2007) posit a similar process, where anxiety disrupts top-down inhibition, resulting in increased bottom-up or saliency-driven attentional capture processes. Alternatively though, it is possible that apprehension primarily only enhances saliency-driven processes, making it more likely for attention to be allocated to salient distractors, while not necessarily disrupting active suppression mechanisms. Gaspar and McDonald (2018) recently delineated these two possibilities in an event-related potential (ERP) study of attentional capture in high trait anxious individuals. They examined two ERP components, the N2pc and P_D, which are believed to reflect the allocation of attention to objects in visual space and the suppression of attentional allocation, respectively. They found that while both low and high anxious individuals showed a reliable P_D component in response to irrelevant color singletons, only high anxious individuals showed a preceding significant N2pc component to such objects. This could suggest that increased distractibility observed in high anxious individuals may primarily reflect enhanced saliency-driven capture, while having little effect on top-down suppression (though see Gaspar & McDonald, 2018, who note an alternative possible role of impaired proactive control in top-down filtering). Future research dissociating these two factors with regards to the role of induced apprehension would allow assessment of whether similar mechanisms as observed in trait anxiety underlie the increased distractibility found in the present study. Moreover, how acute experience of apprehension may interact with trait levels of anxiety, or one's general attentional control ability, is also of interest to discern whether situational factors may interact with one's disposition to modulate selective attention.

In summary, the present study suggests that acute apprehension of aversive stimuli increases an observer's propensity to task-irrelevant attentional capture. Considering complementary findings reported among high trait anxious individuals, our results indicate a generalized role of anxiety-related emotion in increasing task-irrelevant distraction.

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Figure captions

Figure 1: Example experimental trial display within the threat condition (not to scale). On each search display, participants saw six colored shapes, a diamond acting as the target and five non-target circles. Participants responded whether the line inside the diamond on each display was horizontally or vertically oriented. On half of trials, all shapes appeared in the same color, either red or green (distractor-absent). On other trials, one of the circle objects appeared in the opposite color to its neighbors (distractor-present). Participants were instructed to ignore any odd color item and respond to the diamond object as quickly and as accurately as possible. Within the threat condition, at the offset of search displays, there was a 12.5% probability that a loud aversive sound would be presented over headphones for 600ms. Such trials were discarded from analysis – only trials where noise was anticipated were examined. Within the safe condition, the task was completed without any possible noise being presented.

Figure 2: (Left panel) Mean reaction times within safe and threat conditions, shown separately for distractor-present (dark gray) and distractor-absent trials (light gray). Error bars denote +/- 1 SE. (Right panel) Distractor presence costs, calculated as distractor-present minus absent RT, within the two conditions.

Figure 1

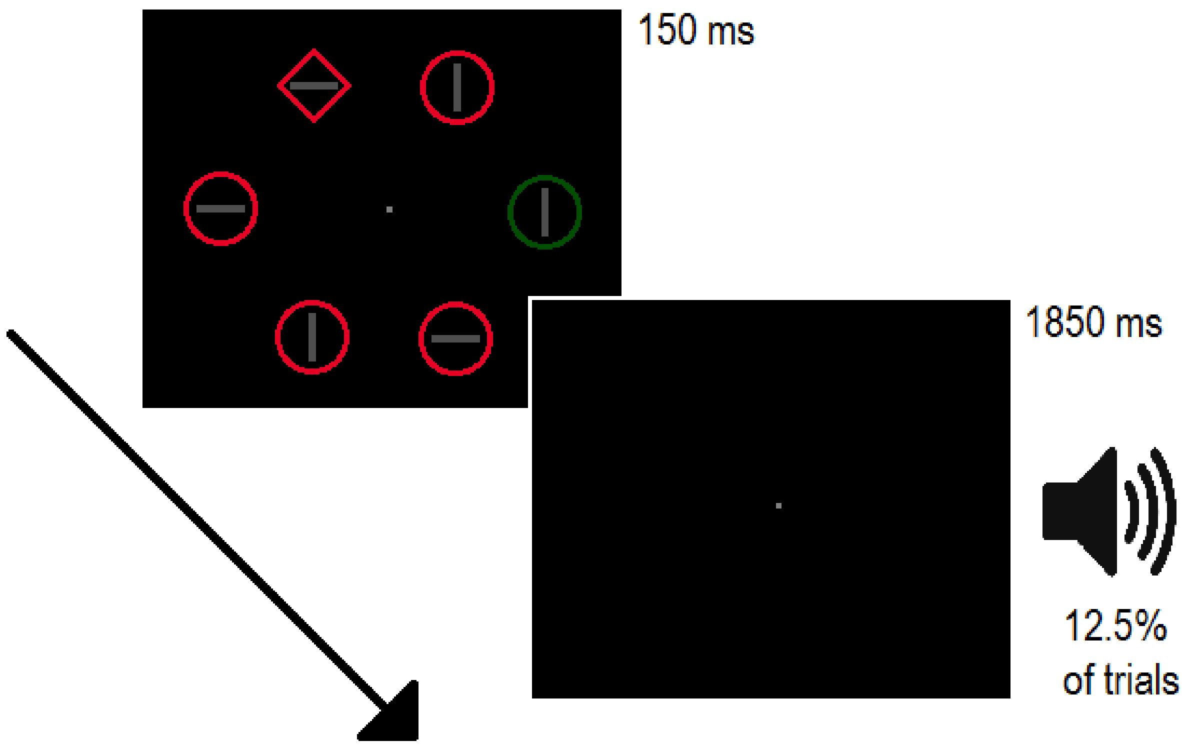
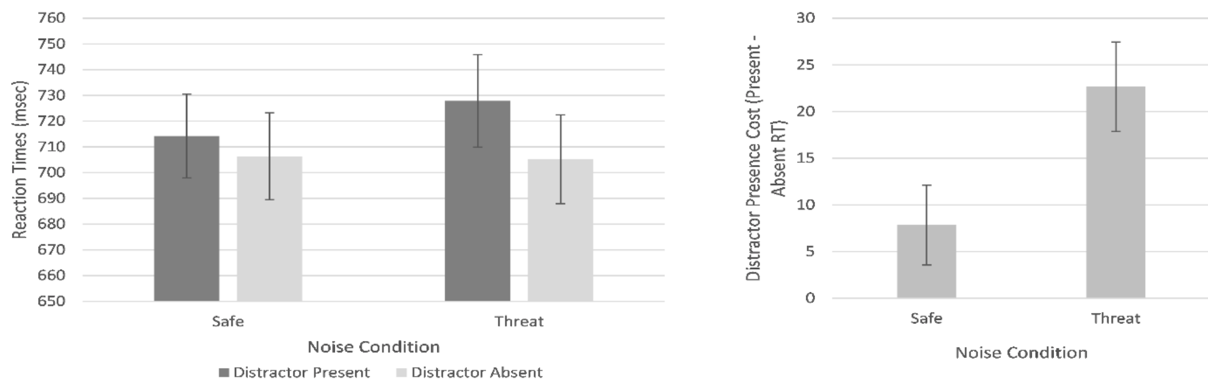


Figure 2



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