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Was that a threat?

Attentional biases by signals of threat

Daniel Preciado, Jaap Munneke and Jan Theeuwes

Vrije Universiteit Amsterdam

Correspondence:

Daniel Preciado

Cognitive Psychology, Vrije Universiteit Amsterdam

van der Boechorststraat 1

1081 BT Amsterdam

d.f.preciadovanegas@vu.nl

Abstract

The present study rigorously tests whether an arbitrary stimulus that signals threat affects attentional selection and perception. Thirty-four volunteers completed a spatial-emotional cueing paradigm to examine how perceptual sensitivity (d') and response times (RT) were affected by a threatening stimulus. On each side of fixation, two colored circles were presented as cues, followed by two Gabor patches; one of which was tilted and served as target. The color of one of the cues was paired with an electric shock, while others remained neutral. The target could be presented at the location of the threat-associated cue (*Valid*), at the opposite side (*Invalid*), or following neutral cues. Stimulus onset asynchrony (SOA) between cue and target was either 100ms or 1000ms. Results showed increased perceptual sensitivity (d') and faster RTs for targets appearing at the Valid location relative to the Invalidly cued location suggesting that immediately after cue presentation, attention was captured by the threat-associated cue. Crucially, following this initial exogenous capture there was also enhanced perceptual sensitivity at the long SOA, suggesting that attention lingered volitionally at the location that previously contained the threat-associated stimulus. The current results show an effect of threatening stimuli on perceptual sensitivity, providing unequivocal evidence that threatening stimuli modulate the efficacy of sensory processing.

Keywords: Attentional bias, spatial-emotional cueing, threat signals, perceptual sensitivity, reaction time, stimulus history.

Was that a threat?

Attentional biases by signals of threat

Stimuli signaling an imminent threat (the scent of a predator, a flash signaling an electric shock) are highly informative cues indicating the need to adjust behavior so that an individual's survival and well-being is ensured. For any organism, detecting and learning to make use of these information-rich signals is not just advantageous, but essential to cope effectively with immediate threats, and to prepare adequately for future encounters with them. Considering that such threat-informative cues could appear anywhere and anytime in the environment, and are not always readily salient or unambiguous, an individual's continued existence depends on the strategies used to select and prioritize the appropriate environmental stimuli for processing and responding (Mathews & Mackintosh, 1998). This is of particular importance considering the mismatch between the natural processing limitations of the perceptual system, and an overwhelmingly rich, dynamic environment where relevant and irrelevant stimuli coexist in a continuous flux of information (Posner, 1980; Pourtois, Schettino, & Vuilleumier, 2013). To cope with this mismatch, attentional mechanisms have evolved to integrate and respond preferentially to particular sources of information, such as physical salience or subjective relevance, in order to allocate the limited processing resources only to the most relevant, informative, or useful signals available in the environment (Pourtois et al., 2013).

Traditionally, attentional selection mechanisms have been classified either as exogenous (stimulus-driven, bottom-up) or endogenous (goal-driven, top-down) and attentional selection is believed to result from the integration of these two sources of information. However, recent challenges to this dichotomy advocate a model of attentional selection that integrates not only physical stimulus properties and current goals and motivations, but also an individual's prior *stimulus history,* understood as past experiences of the observer relevant for the situation at hand (Awh, Belopolsky, & Theeuwes, 2012). By adding stimulus history to the classic model of attentional selection, the individual's past experiences are acknowledged as a crucial factor in the definition of present attentional priorities. In this context, it has been shown that *attentional biases towards survival-relevant stimuli*, such as threats and rewards, elicit similar patterns of attentional modulation compared to stimuli which are task-relevant or physically salient (Bocanegra & Zeelenberg, 2011b; Munneke, Hoppenbrouwers, & Theeuwes, 2015; Schmidt, Belopolsky, & Theeuwes, 2014).

The present study is concerned with how stimuli that signal threat affect attentional selection. Previous studies have shown attentional biases for processing of pictures signaling threat such as, spiders or emotional faces (for a review see Vuilleumier, 2005). For example, Soares, Esteves, Lundqvist, and Öhman (2009) showed that the time to find a threat-related target presented among neutral distractors is shorter compared to a neutral target. Similarly, search times for a neutral target are longer when they are presented along threat-related distractors, compared to when all distractors are neutral (e.g. Devue, Belopolsky, & Theeuwes, 2011). In spatial cueing, it has been shown that response times are faster when the cue preceding the target is threat-related, relative to neutral (e.g. Mogg & Bradley, 1999). Comparable results have been observed in studies employing conditioning methods to turn an innocuous stimulus into a signal of threat. For instance, Notebaert et al (2011) showed that search times were faster when the target was presented near a stimulus signaling the possibility of an electric shock, relative to a stimulus not signaling any threat. Similarly, Schmidt, Belopolsky, & Theeuwes (2014) used a visual search task in which a colored distractor associated with an electric shock never coincided with the target location, implying that attending to it would always harm performance. In this study the distractor associated with the threat of an electric shock caused impaired performance more than an equally salient object not associated with a shock, providing evidence that a threatening stimulus can capture attention even against the intentions of the observer.

Most of these studies have used variants of paradigms such as spatial cueing, visual search and dot-probe detection to evaluate the attentional and perceptual effects of stimuli associated with threat. However, showing attentional effects of threat on the basis of changes in response times or perceptual measures alone leaves open alternative interpretations in terms of threat-induced changes in arousal or response activation. Moreover, focusing on either the perceptual or behavioral effects of these signals precludes the possibility to investigate their specific influence on the different stages of the stimulus-response processing cascade.

The current study employed a modified spatial-emotional cueing paradigm to assess the extent to which threat-related stimuli modulate attentional selection and perception. More specifically, we wanted to determine whether a cue associated with threat could selectively enhance visual processing, and to which extent the observed changes in perceptual sensitivity relate to response latency. It is known that response times differences (RT) alone do not necessarily reflect differences in perceptual sensitivity, because RT differences can be attributed to the differences in perceptual, decision-making and behavioral processes (Carrasco & McElree, 2001; Hawkins et al., 1990; Wickelgren, 1977). As argued by McDonald, Teder-Sälejärvi, and Hillyard (2000), “unlike reaction times, signal detection measures allow for a separation of perceptual and decision-level effects of attention” (p. 906). Therefore, in addition of measuring response latency, we employed methods derived from signal detection theory (SDT) to calculate d’ in order to determine whether a cue associated with threat would modulate target detectability and discrimination as well.

Previous studies have established that emotion can affect early attentional processes by showing enhanced visual processing. For example, Phelps, Ling and Carrasco (2006) showed that using a fearful face as a cue resulted in benefits in contrast sensitivity (Exp. 1), an effect that was magnified by transient covert attention (Exp.2). Similarly, Bocanegra and Zeelenberg (2011a) showed that d' benefits in target detection with a cue that consisted of fearful face compared to a neutral face; and Ferneyhough et al., (2013) showed attentional costs of threat signals in high-trait-anxious individuals, evidenced by decreased contrast sensitivity for fearful faces when presented at a non-target location. These studies clearly established that emotional cues, such as fearful faces, can indeed affect early perceptual processing as evidenced by changes in d' and contrast sensitivity. Even though these effects are well established, some aspects of the previous paradigms are less optimal to establish unequivocal evidence for the effects of emotion (i.e. threat) on perception, attention and behavior.

The first aspect relates to the use of emotional and neutral faces as cues to establish attentional guidance. While certain facial expressions are widely regarded as primary, universal signatures of emotion (Ekman & Friesen, 1971), there are inevitable differences in low-level features across faces and expressions. As such, it is more difficult to draw conclusions on whether it was the emotional value of the face as a whole that biased attention, or specific, physical low level features (Whalen, 2004). As a control, most of these previous studies (including Phelps et al., 2006 and Bocanegra & Zeelenberg, 2011a) have used inverted faces and showed that there was no effect on attentional guidance for inverted emotional and neutral faces, suggesting that it is the emotional content what drives the effect, rather than the low-level features of the image. Even though this control condition seems to be reasonable, it should be realized that a face presented upside down disrupts overall processing. For example, in a study by Belopolsky, Devue and Theeuwes, (2011) it was shown that that when making a speeded saccade, an irrelevant *inverted* face presented at fixation resulted in much longer saccade latencies than when that very same face was presented in an upright position. This suggests that even when a face is irrelevant for the task, face processing occurs at a slower speed for an inverted face than for an upright one. Since processing is overall slower for inverted faces than for upright faces, it may not be surprising that there was less evidence for attentional guidance for inverted relative to upright faces in these previous studies. Note however, whether or not slower overall processing of inverted faces was responsible for the absence of an effect in the control condition of these previous studies cannot be derived from the data.

Second, regarding the standard cueing paradigm, we note certain intrinsic design features that may raise concerns about previous studies investigating the perceptual effect of emotional cues. Specifically, studies using this paradigm typically presented a single lateralized cue on the display, thus inducing abrupt onsets, which are well known to cause strong exogenous capture towards the location of the cue (Theeuwes, 1991). Therefore, it is hard to determine the extent to which the emotional expression or the abrupt luminance onset of the cue caused attentional capture. One may argue that this criticism does not hold because these previous studies compared abrupt onset fearful faces with abrupt onset neutral faces. However, with such a design, it is quite feasible that the initial capture was driven by the transient abrupt onset itself, and the emotional expression only had an effect after attention was allocated to the location of the fearful or neutral face.

Moreover, in these studies the single cue was 100% predictive of where the target would appear, making it indisputably task-relevant, and therefore hard to disentangle exogenous (stimulus-driven, bottom-up) from endogenous (goal-driven, top-down) effects. As argued by Yantis and Egeth (1999), one can only speak of (exogenous) attentional capture in a purely stimulus driven fashion when there is no incentive for the observer to attend to it deliberately. In case of a 100% predictive cue, there is every reason for the observer to endogenously attend to it, even if not explicitly instructed to do so.

Finally, unlike previous studies that have particularly focused on performance differences (cue validity effects in emotional versus neutral cueing conditions), we wanted to determine whether there are genuine performance costs and benefits of threat-related cues. Establishing costs and benefits is important as this indicates that performance changes due to threat are related to spatial orienting (see Failing & Theeuwes, 2014).

The current study was designed to rigorously determine whether threat-related stimuli modulate attentional selection and perception. Unlike previous studies, we used a fear conditioning procedure to associate threat with an arbitrary chosen stimulus. In addition, by introducing a short and a long interval between the cue and the target we were able to map out threat-induced attentional biases over time. The current design has several advantages over previous studies. First, we used different, isoluminant colored circles as cues, and associated one of the colors (counterbalanced across subjects) with the threat of receiving an electric shock (Figure 1). Clearly, with such a design there are no low-level stimulus differences between the arbitrarily chosen color cues. Due to the fear conditioning procedure, we ensure that any performance difference between the cues could only be due to the acquired threatening nature. Second, on each trial we presented two physically equivalent cues and one target and one non-target Gabor, presented at each side of fixation to ensure there were no asymmetric abrupt onsets (such as luminance differences) that could drive the effect in an exogenous way (Theeuwes, 1995). Third, we introduced a neutral cueing condition consisting of two neutral colored cues which were not associated with threat to serve as baseline to assess performance costs and benefits. Finally, the target was presented at chance level (50%) at the location of the threat-associated cue (*Valid*) or at the opposite side (*Invalid*) to ensure there were no strategic (top-down) reasons to selectively attend the threat-signaling cue.

As earlier noted, to determine whether threat signals had a true effect on perception we used perceptual sensitivity (d') and response times (RT) as our main dependent variables (see also Bocanegra & Zeelenberg, 2011a). By using d', we were able determine the extent to which the threatening cue would modulate the sensory gain of input appearing at the same location where it appeared (Handy, Kingstone, & Mangun, 1996; Theeuwes & Chen, 2005; Theeuwes & Van der Burg, 2007). It is know that response times differences (RT) alone do not necessarily reflect differences in perceptual selectively, because RT differences can be the result of differences in decision processes (Hawkins et al., 1990; McDonald et al., 2000).

Method

Ethical statement

The experimental methods and procedures were reviewed and approved by the Scientific and Ethical review committee of the Faculty of Behavioral and Movement Sciences of the Vrije Universiteit Amsterdam. Participants signed a written informed consent form before taking part in the study. They were informed in advance about its nature, particularly, the use of electric shocks as aversive stimuli.

Participants

34 students from the Vrije Universiteit Amsterdam (19 Females, mean age 24 ± 2.6 years old) volunteered to participate in the study in exchange for a monetary reimbursement (7 Euro) or course credits. All participants reported having normal or corrected-to-normal vision, no color vision impairments, and no other psychiatric, psychological or neurological conditions.

Stimuli and design

Each participant was tested in a dimly lit cubicle, and was instructed to register their responses via key-presses in a standard keyboard. Participants were seated 75cm away from a 21'' computer screen with their head positioned on a chin rest. The experiment was designed and conducted using Matlab (version R2013a) and the Psychophysics Toolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997).

In order to control for the influence of physical properties of the stimuli in our design, we ensured that all stimuli were isoluminant, and all presentation parameters were kept equal across experimental conditions, so that the threatening value of one particular cue remained the only aspect that differentiated the critical threat-associated cue from the neutral ones. Moreover, two SOA conditions were implemented to be able to explore the effects at short (100ms) and long (1000ms) intervals, allowing us to probe the effects of attentional biases at early and late stages of its time-course.

Cue stimuli consisted of solid color discs (isoluminant red, green and blue; 30 cd/m2), whereas target stimuli were Gabor patches (5 cycles/degree spatial frequency, Gaussian envelope), presented either vertically, or tilted 10° to the left or the right (Figure 1). Both cue and target stimulus had a diameter of 2.5° of visual angle, and were presented bilaterally flanking the central fixation point at 6.5° of eccentricity. Counterbalanced over participants, one of these colors would occasionally be paired with an electric shock when presented in the cue display. Participants were informed about this color-shock association both verbally and in written form prior to the start of the experiment, and were indicated that the cue display would feature any color combination at random. Target contrast level was defined in advance for each participant, to ensure that stimulus visibility during the main experimental task would lead to an overall performance of approximately 82% correct responses.

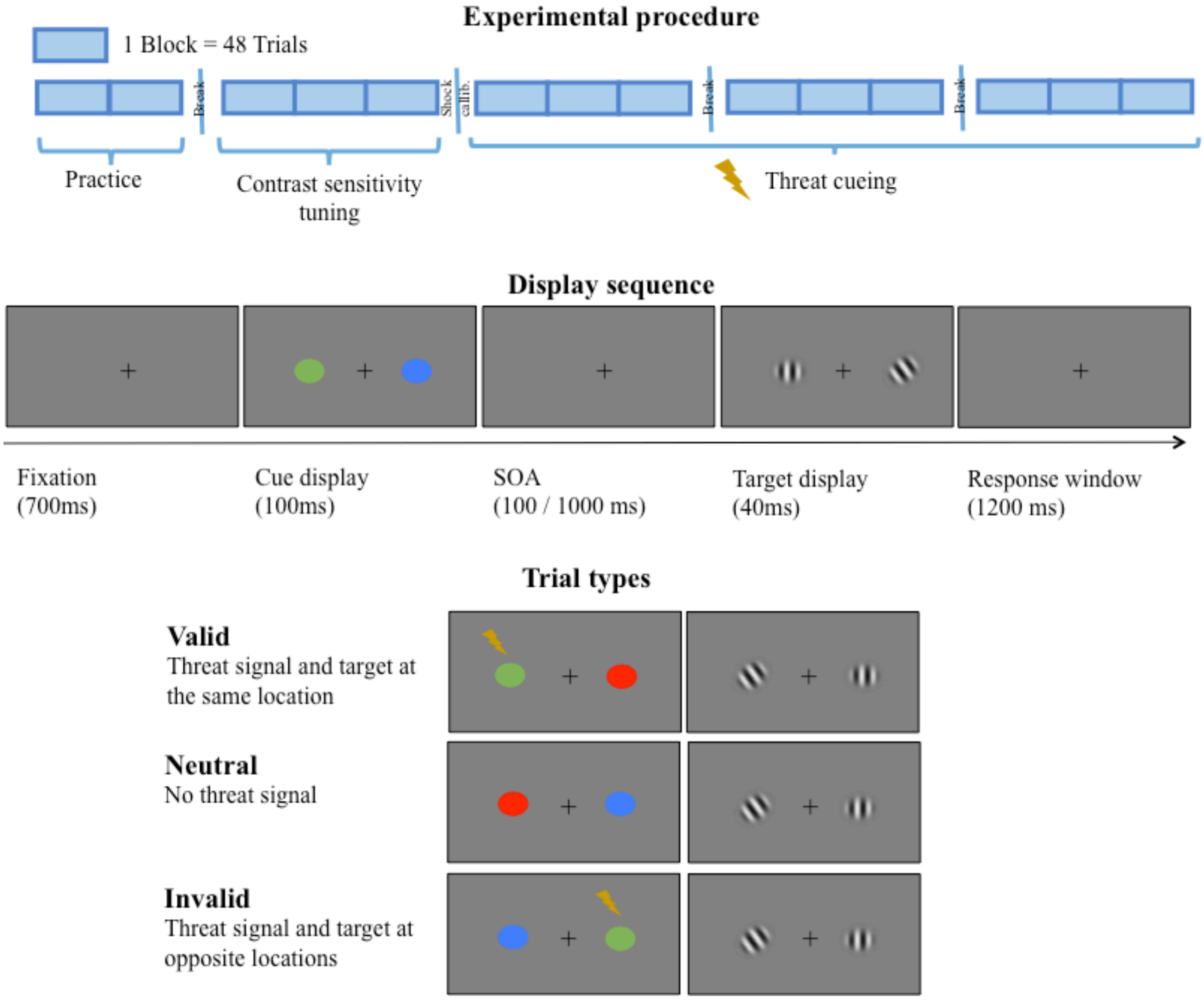

Figure 1. *Experimental procedure, display sequence and trial types in terms of Cue and target location. Note that the critical threat cue could be any one of the 3 colors (counter-balanced across participants), all color combinations were equally likely, and the location of the threat cue was not predictive of the target location.*

The current task evaluated performance in terms of response time (RT) and perceptual sensitivity (d') as a function of two parameters, cue location and SOA. Cue location was used to investigate the attentional effects of threatening or neutral cues on the discrimination of the subsequent target. The cue location condition was determined by the location of the threat cue in reference to the target: *Valid* indicated that both threat cue and target were presented at the same location, *Invalid* that the target was presented at the contralateral location of the threat cue, and *Neutral* referring to trials in which no threat cue was presented (Figure 1). Each of these three cueing conditions was presented equally often (144 trials per condition), rendering the threat cue task-irrelevant, as it was not predictive of the target location or identity. Experimental parameters were counterbalanced across participants where applicable.

Electric stimulation

The required electric shocks were delivered with a constant current stimulator (Digitimer DS7A; Hertfordshire, UK) designed for electrical stimulation in clinical and biomedical research settings. Each shock consisted of a 2ms pulse of 400V, delivered through 2 ECG electrodes placed over the tibial nerve at the medial malleolus of the left ankle.

Calibration procedure.

Shock intensity (in mA) was tailored to the sensitivity of each participant, in order to minimize discomfort and to ensure that no unnecessarily strong pulses were delivered, while preserving the aversive nature of the delivered shock. This procedure consisted of a number of sample shocks, starting at 10 mA and adjusted progressively in steps of 5mA. After each sample shock, participants were asked to rate how annoying or painful the shock was in a 5-point scale (1=Very mild to 5=Painful). Based on participants rating, the intensity was increased or decreased until the sample shocks were rated as “4=Annoying, but not painful”. This procedure was conducted immediately before the experimental phase where the electric shocks were delivered.

Experimental procedure

The current experimental design is an adaptation of the standard spatial-emotional cueing paradigm (e.g., Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008). Figure 1 depicts the experimental details of the session, trial display sequence and cueing conditions. A trial began with a fixation cross presented for 700ms, followed by color cues presented at both sides of the fixation point, visible for 100ms. On each trial, two different colored cues were used on either side of fixation. Following the cue display and after an SOA of 100ms or 1000ms, Gabor patches were presented left and right of fixation for 40ms, after which they were removed. One Gabor patch was always presented with a vertical orientation (non-target), whereas the other Gabor patch was tilted at a 10° orientation to the left or the right (randomly assigned). Participants were instructed to respond as fast and accurately as possible to the orientation of the target Gabor by making a key press on a standard keyboard (z for left, m for right). Because we wanted to investigate the effect of threat on both speed (RT) and accuracy (d'), we stressed both performance indexes equally. The next trial began 500ms after a response was given or after the maximum response window (1200ms) had expired. Colored cues and target Gabor patches appeared on either side of the display with equal probability. Participants were instructed to maintain their gaze fixated in the middle of the display throughout the experiment. Each session was divided in 3 phases: Practice, Staircase and Threat cueing.

Practice phase.

Consisted of 2 blocks of 48 trials each. The objective of this phase was to give participants a chance to get familiar with the task before manipulating the contrast of the target display or introducing the electric shocks. During this phase, the contrast level of the target Gabor patches was fixed to 80% and no shocks were administered.

Staircase phase.

During this phase, participants completed 3 blocks of 48 trials each. The objective of the phase was to establish the individual contrast level at which performance was approximately 82% correct. Starting from 0.5, contrast was adjusted step-wise based on the participants' responses, following a QUEST staircase procedure (Watson & Pelli, 1983).

Threat-cueing phase.

The task in this phase was exactly the same as on the previous phases, except for the introduction of electric shocks in association with a color, and the use of the contrast level defined in staircase phase. The threat cueing phase consisted of 9 blocks of 48 trials each, with a maximum of 2 shocks delivered on each block (maximum number of shocks was set to 18). The electric shocks were delivered semi-randomly. Specifically, a shock was delivered only on trials where the predefined threat cue was present. This threat cue was presented in roughly 67% of the trials (288/432 trials), and was accompanied with the shock in only 4% of those trials (18/432 trials). Shocks were delivered at the onset of the cue display.

Critically, participants were explicitly informed that the cues were not relevant to the experimental task, but only to indicate the probability of a shock. Breaks were given during the threat cueing phase every 3 blocks, and participants were encouraged to fully take advantage of them and rest their eyes to avoid exhaustion (Minimum break duration was 10 seconds, after that participants could indicate they were ready to continue at will). No feedback was provided regarding their overall or trial-by-trial performance, on the basis of available evidence indicating that feedback on performance may act as a rewarding or aversive signal (Rothermund, 2003; Tricomi, Delgado, McCandliss, McClelland, & Fiez, 2006; Yeung, Holroyd, & Cohen, 2005), a potential confound to be avoided in order to ensure that findings could only be attributed to the threatening nature of the conditioned cue.

Results

Data from four participants who basically did not perform above chance level (overall accuracy between 51-54% correct) was excluded from the analysis. The remaining participants performed well above 75% correct. For d' analyses; we excluded trials in which a shock was delivered (4%), and those in which participants reacted too slow (> 2.5 SD), or faster than 200ms (5%). For RT analyses incorrect trials were also excluded, which resulted in an average trial loss of 20%.

All dependent variables were normally distributed (as assessed by Shapiro-Wilk's normality test), indicating that parametric tests could be used. Data analysis is based on 2x3 repeated measures ANOVA conducted on RT and d' as dependent variables with SOA (100ms, 1000ms) and cue location (Valid, Invalid, Neutral) as independent factors. Greenhouse-Geisser corrected results are presented whenever Mauchly's test indicated that the dependent variables failed to fulfill the sphericity assumption.

Sensitivity (d')

For each participant and each experimental condition, d' was calculated following the methods described by Macmillan & Creelman (2004). Calculation of d' was performed on the normalized (z-converted) hit and false alarm rates. Furthermore, a correction factor for cases with no false alarms was used, namely setting the false alarm rate in these cases to 0.5 before conversion to z-scores (Macmillan & Creelman, 2004).

Mauchly's tests for d' data indicated that the sphericity assumption was met, thus d' results are presented without correction. The SOA x cue location repeated measure ANOVA conducted on d' data (Figure 2) revealed no interaction between SOA and cue location ($F(2, 58) = 1.006$, $p=0.37$, $\eta_p^2 = 0.03$).

Crucially however, there was a main effect of cue location ($F(2, 58) = 3.938$, $p=0.025$, $\eta_p^2 = 0.12$), indicating that the threat-associated cue indeed modulated perceptual sensitivity. To further investigate this effect, planned comparisons were evaluated with paired t-tests conducted independently for three contrasts within the cue location condition (Valid Vs. Invalid, Valid Vs. Neutral, Invalid Vs. Neutral). Results showed that that the observed effect is driven primarily by a difference between the Valid and Invalid conditions (mean d' difference = 0.204, $t(29)= 2.581$, $p=0.008$, 1-sided), indicative of a specific threat-driven modulation of spatial attention. The comparison between Invalid and neutral conditions was also significant (mean d' difference = 0.173, $t(29)= 2.173$, $p=0.019$, 1-sided), suggesting that that the allocation of spatial attention to the Invalid location results in a reduced perceptual sensitivity at the location of the target (i.e., performance costs).

In addition, there was a significant main effect of SOA ($F(1, 29) = 17.531$, $p<0.001$, $\eta_p^2= 0.38$), consistent with a global, non-spatial effect of the cue predicting the imminent occurrence of a target. A t-test comparing SOA conditions resulted in a robust difference (mean d' difference = 0.35, $t(29)= 4.182$, $p<0.001$, 2-sided), indicating that performance was significantly better at the 100ms SOA condition.

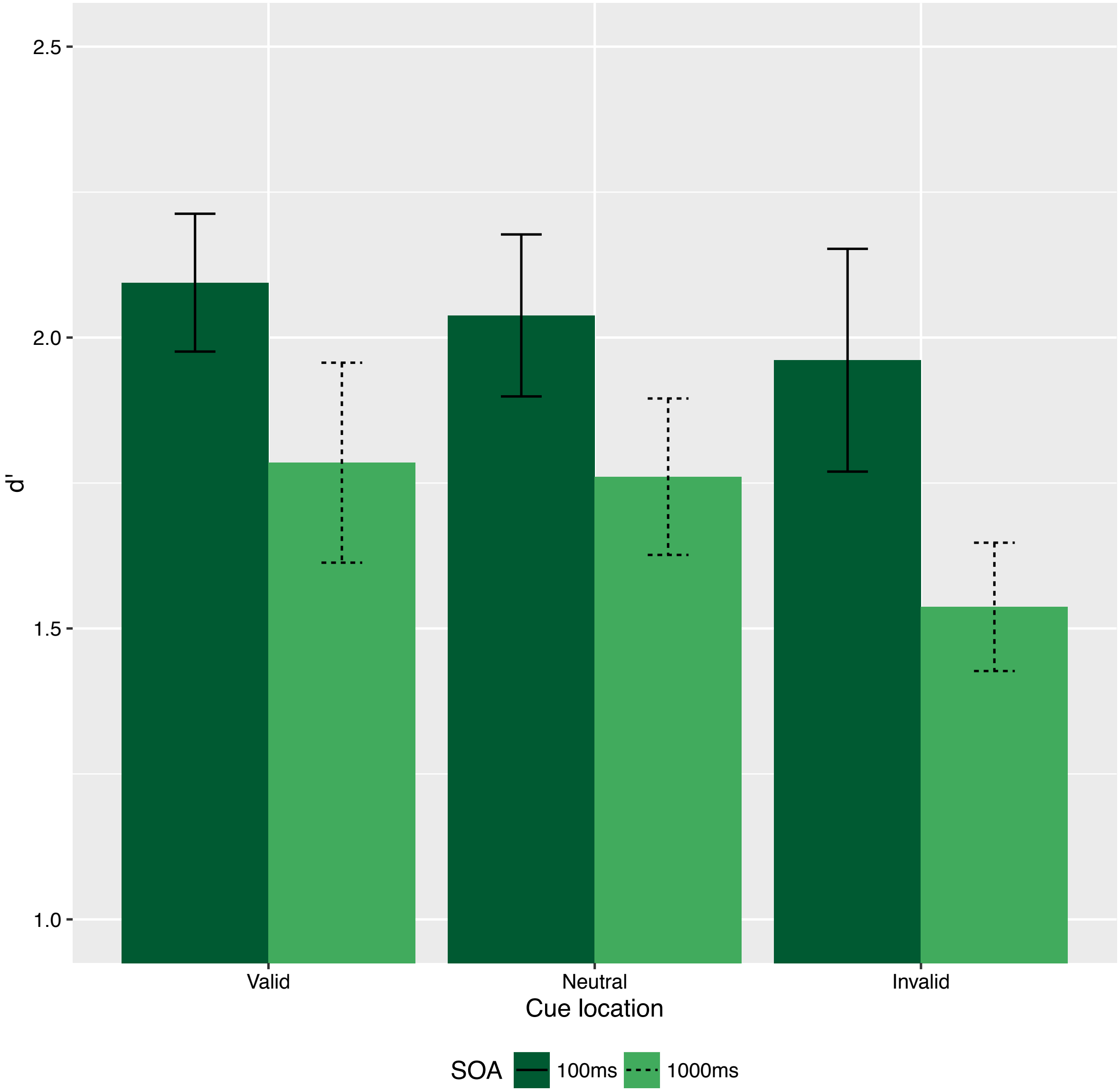

Figure 2. *d' by Cue location and SOA. Error bars represent within-subjects confidence intervals, calculated according to Morey (2008).*

Response time (RT)

RT was calculated from the onset of the target display until response. For the analysis, the mean RT was calculated for each participant and condition. RT measures by cueing condition failed to fulfill the sphericity assumption, thus Greenhouse-Geisser corrected results will be discussed. The repeated-measures 2x3 ANOVA analysis conducted on RT with SOA and cue location as factors revealed only a significant effect of Cue location (Greenhouse-Geisser corrected $F(1.98, 57.45) = 4.533$, $p=0.015$, $\eta p^2= 0.14$), but no main effect of SOA (uncorrected $F(1, 29) = 0.367$, $p=0.549$, $\eta p^2= 0.01$) nor interaction between SOA and Cue location (uncorrected $F(2, 58) = 0.556$, $p=0.576$, $\eta p^2< 0.01$). The results are depicted in Figure 3.

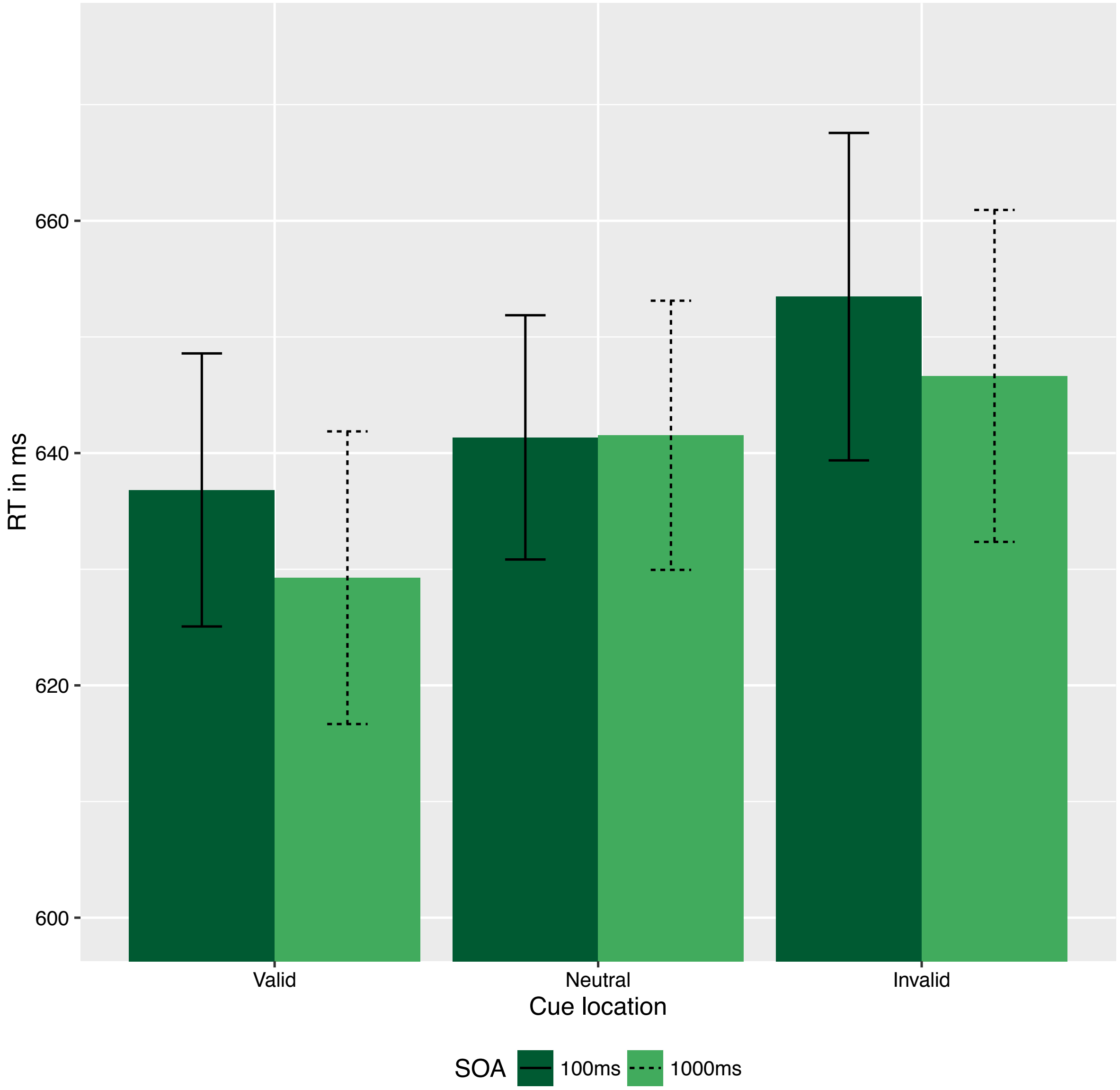

Figure 3. *RT by Cue location and SOA. Error bars represent within-subjects confidence intervals, calculated according to Morey (2008).*

Planned pairwise comparisons on RT revealed a reliable difference between valid and invalidly cued conditions (RT Valid = 632.5; Invalid = 649.2; $t(29)= 2.402$, $p=0.011$, 1-sided). Crucially, there were also differences between the valid and neutral cue condition (RT Valid = 632.5; Neutral = 640.8, $t(29)= 1.886$, $p=0.035$ 1-sided) and the invalid and neutral condition (RT Invalid = 649.2; Neutral = 640.8, $t(29)= 1.753$, $p=0.045$, 1-sided) indicating that threat resulted in both RT costs and benefits which is generally taken as evidence for spatial attentional orienting (Posner, 1980). Overall, these findings resemble the results we observed for perceptual sensitivity, and further strengthen the notion of signals of threat driving specific attentional benefits (indicated by reduced RT in the Valid condition) and costs (indicated by the increased RT in the Invalid condition).

Discussion

The present study shows that an arbitrary stimulus that signals threat (the possibility of receiving an electric shock) had a strong influence on attentional selection as evidenced by changes in both perceptual sensitivity (d') and response times (RT).

With respect to RT, our findings indicate that the cue associated with the threat captured attention: Relative to a neutral baseline, there were RT benefits when the target appeared at the same location as the threat signaling stimulus (validly cued trials), and RT costs when the target appeared at the location no associated with the shock (invalid trials; see Figure 3). Finding both RT costs and benefits indicates that attention was oriented to the location that contained the stimulus that signaled threat. Alternative explanations such as interference by the threat signaling stimulus not due to shifts of attention (also known as filtering costs, see Kahneman, Treisman, & Burkell, 1983) are highly unlikely when both performance costs and benefits are found (see Failing & Theeuwes, 2014).

Our study also shows that attention lingers at the location of the cue signaling threat, as there are also RT benefits and costs for the long SOA. Even though the cue is no longer present during the 1000ms interval, spatial attention remains at the location that previously contained a cue that was associated with a threat. This result is important as it suggests that threatening cues not only capture attention but also can hold it over a relatively longer time interval, even in the absence of the threatening cue (Fox, Russo, Bowles, & Dutton, 2001). Similar results have been reported by Schmidt, Belopolsky and Theeuwes (2016) using eye tracking. They showed that people are faster to make a saccade to a location that previously contained a stimulus signaling threat than to a control location not signaling a threat even when they had to postpone making the saccade for 1000ms.

In the current study, the results of d' basically mimic those obtained with RT. Even though previously reported effects on RT may represent influences of threat on late decision-making processes (such as response facilitation or biases), the current study, using a conditioning procedure, provides unequivocal evidence that threatening cues facilitate early perceptual processes that code input from the visual field (e.g., Theeuwes & Van der Burg, 2007). The current findings are in line with other studies that reported similar effects using fearful faces as cues (Bocanegra & Zeelenberg, 2011a; Ferneyhough et al., 2013; Phelps et al., 2006).

The present study is also unique in that two different SOAs were used which allowed us to study the time course of the attentional bias to threat. Typically in exogenous cueing, after attention is initially captured by the cue (resulting the transient effects which can be seen at an SOA of 100ms), it wanes from that location, sometimes resulting in suppression of the location (referred to as Inhibition of Return - IOR, Klein, 2000). In the current study, there is no evidence for IOR or for any waning of attention at that location. Rather, at an SOA of 1000ms the cueing benefits and costs are similar to those observed at an SOA of 100ms. To explain this result we have to assume that some form of endogenous allocation of attention to that location follows initial, purely exogenous capture. Even though such a pattern of results is typically not seen with exogenous capture involving abrupt onsets (Posner, 1980), such effects have been reported before in studies using gazing cueing. Typically, in this type of studies, a representation of a face gazing to either the left or right side of fixation is presented in center of the display. As in the current study, the cue (in this case the direction of gaze) was not predictive for where the target will appear. The usual result is faster detection, localization, or identification of targets presented at the validly cued location, compared to invalidly cued ones (e.g., Friesen & Kingstone, 1998). Just as in the current study, cueing effects were observed at short SOA and persisted at longer intervals. As Friesen & Kingstone (1998) observed cueing effects that persisted well beyond the time course associated with exogenous (reflexive) orienting effects (~300ms), they also argued for a combination exogenous and volitional influences, where facilitation observed at short SOAs is driven by reflexive mechanisms, while cueing effects at the long SOA are mediated by voluntary (i.e. endogenous) forces (see also Langton & Bruce, 1999).

The observed enduring cueing effects at the long SOA are also consistent with the notion that more attentional resources are allocated to locations where threat has occurred. Indeed, there is evidence that it is difficult to disengage attention from sources the signal threat (Sheppes, Luria, Fukuda, & Gross, 2013; Van Damme, Crombez, & Notebaert, 2008). For example, Belopolsky, Devue and Theeuwes (2011) showed delayed disengagement from faces with an angry expression, relative to neutral faces. Furthermore, similar results demonstrating difficulty to disengage attention have been reported with paradigms such as dot-probe detection (Koster, Crombez, Verschuere, & De Houwer, 2004) and emotional exogenous cueing (Fox et al., 2001). From this perspective, it can be argued that the observed cueing effects at the longer SOA reflect an attentional strategy in which it is beneficial to maintain attention at those locations associated potential threat.

In sum, the current study shows that attention is biased towards a stimulus that signals threat as evidence by changes in both perceptual sensitivity (d') and response times (RT). We show that attention is initially captured by the stimulus signaling threat and remains biased towards this location even after the stimulus signaling the threat is no longer present. We suggest that the observed pattern of results is combination of early exogenous attentional effects, which are followed by some form of volitional control responsible for attention lingering at the location that used to contain the threat-signaling stimulus.

Author's affiliations

Daniel Preciado:

Cognitive Psychology, Vrije Universiteit Amsterdam, the Netherlands

Jan Theeuwes:

Cognitive Psychology, Vrije Universiteit Amsterdam, the Netherlands

Jaap Munneke:

First affiliation: National Magnetic Resonance Research Center (UMRAM), Bilkent University, Ankara, Turkey

Second affiliation: Cognitive Psychology, Vrije Universiteit Amsterdam, the Netherlands

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