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To cite this article: Lisette J. Schmidt, Artem V. Belopolsky & Jan Theeuwes (2015) Attentional capture by signals of threat, *Cognition and Emotion*, 29:4, 687-694, DOI: [10.1080/02699931.2014.924484](https://doi.org/10.1080/02699931.2014.924484)

To link to this article: <https://doi.org/10.1080/02699931.2014.924484>



Published online: 05 Jun 2014.



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BRIEF REPORT

Attentional capture by signals of threat

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Attention can be captured automatically by events that are physically salient. Similarly, emotional stimuli are known to be prioritised by the visual system because of their behavioural significance. The present study investigated whether a neutral stimulus which became associated with fear captured attention in visual search. Using a fear-conditioning procedure, one stimulus was repeatedly combined with an electrical shock (CS+), whereas another stimulus with identical physical features was never combined with a shock (CS–). Following conditioning, participants had to search for a target; while on some trials, either an irrelevant CS+ or CS– stimulus was present. The results show that the presence of an irrelevant distractor that was previously associated with fear slowed a search more than a distractor without fear association. The current results indicate that learned fear associations have the ability to capture our attention even if we try to ignore them.

Keywords: Attention; Emotion; Fear-conditioning.

As perception is limited in its representational capacity, the effective deployment of attention to behaviourally relevant and salient objects has important survival value for any organism. Attention can be employed in a voluntary top-down way in line with the task requirements, or can proceed automatically in a bottom-up way, determined by the physical properties of the environment. The automatic deployment of attention is referred to as attentional capture (see Theeuwes, 2010 for a review).

Salient events have long been known to capture attention in a bottom-up way (Theeuwes, 1992). Similarly, emotional stimuli are also assumed to be

prioritised by the visual system, since quick selection of such stimuli may give an evolutionary advantage and improve chances of survival (LeDoux, 1996). Several studies provided evidence for the view that pictures of threat-related events, such as spiders or angry faces, receive priority in visual selection (e.g., Devue, Belopolsky, & Theeuwes, 2011; Ohman, Flykt, & Esteves, 2001; Schmidt, Belopolsky, & Theeuwes, 2012). However, many studies have provided contradictory results, showing a small or virtually no effect of threatening pictures on attentional selection (e.g., Becker, Anderson, Mortensen, Neufeld, & Neel,

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This research was funded by a grant from the European Research Council [grant number ERC-2012-AdG –323413] to J.T.

2011; Hunt, Cooper, Hungr, & Kingstone, 2007). The question if and how threatening stimuli modulate visual attention is therefore still open.

Inconsistencies in previous studies on automatic attention to threat may be related to the nature of the threatening stimuli. Specifically, most studies used pictorial stimuli, which by themselves do not pose an actual risk for the occurrence of an aversive event. In order to create a more genuine threat-inducing stimulus, previous studies have shown that fear-conditioning is effective in creating fear association. Fear-conditioning is a technique that is widely used to study the influence of emotions on memory and learning (e.g., Pischek-Simpson, Boschen, Neumann, & Waters, 2009; Sevenster, Beckers, & Kindt, 2012). Fear is in this context defined as an anticipatory response to a stimulus that predicts an aversive outcome. The term conditioning refers to the learning of an association between two initially unrelated stimuli (Pavlov, 1927). In a typical fear-conditioning design, an initially neutral stimulus (CS) is associated with an aversive unconditioned stimulus (US) and becomes intrinsically aversive (CS+), while another neutral stimulus remains unpaired (CS-). Previous research investigated the degree to which conditioning alters the deployment of attention. For example, using a dot-probe paradigm, it has been demonstrated that after association with an aversive event, an initially neutral cue caused both facilitated engagement (e.g., Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004) and delayed disengagement of attention (Van Damme, Crombez, & Notebaert, 2008). Even though there was no evidence for attentional capture, Notebaert, Crombez, Van Damme, De Houwer, and Theeuwes (2011) showed that a fear-conditioned stimulus facilitated response times to targets presented at the same location as the fear-conditioned stimulus. However, in both the visual search task and the dot-probe task the location of the conditioned stimulus could coincide with the target location. Thus, participants could have adopted a strategy of actively attending to the threatening stimulus. In the present study, the fear-conditioned

stimuli are always completely irrelevant to the task at hand.

Taken together, these studies show that learned fear value of a stimulus can modulate attention. Other studies have demonstrated that this effect is not only limited to threat, but also applies for other behaviourally relevant stimuli. For example, Anderson, Laurent, and Yantis (2011) showed that stimuli associated with reward are able to capture attention automatically. In a training procedure, they associated one colour with high reward and another colour with low reward. In a subsequent visual search experiment in which no rewards were delivered, the colour associated with high reward caused more interference than the colour associated with low reward, suggesting that learned reward value magnifies attentional capture. This suggests that reward-induced changes in attentional control might be automatic in nature beyond control of the observer.

The present study was designed to test whether a neutral stimulus which became associated with fear would capture attention in visual search. To test attentional capture we used a variation of the additional singleton paradigm of Theeuwes (1992) and associated the colour of one of the distractors with an aversive electrocutaneous stimulus, while the other distractor colour was never paired with an electrocutaneous stimulus. We investigated whether a stimulus associated with threat would magnify attentional capture and cause more interference than a stimulus that is not associated with threat.

The use of a fear-conditioning paradigm has two major advantages compared to previous research on emotion and attention using pictorial stimuli. First, instead of the symbolic representation of threat that pictures impose, fear-conditioned stimuli are signals of imminent threat. In other words, the stimuli pose a direct threat that is likely to be appraised as aversive. Fear-conditioned stimuli will therefore presumably cause a more robust modulation of attentional effects. Second, because neutral stimuli such as geometrical shapes become associated with fear, it is ensured that it is the association of fear that drives a possible effect on attention and not low-level feature differences between fear and non-

fear inducing stimuli such as differences in luminance, complexity and appearance.

By associating a neutral stimulus with an aversive electrical shock, we predict that the increased salience of that stimulus would interact with the ability to shift attention to a target at another location. Importantly, both the fear-conditioned and the neutral distractor are physically salient items, and are expected to slow responses to targets to a similar degree. However, similar to what Anderson et al. (2011) predicted for learned reward value, we predict that learned fear value magnifies attentional capture such that a distractor associated with fear slows a search more than a distractor not associated with fear.

METHOD

Ethics statement

Written consent was obtained from each participant prior to the experiments. The experiments were approved by the ethics committee of the VU University.

Participants

Twenty-four naïve students from VU University Amsterdam (19 females, mean age 21 ± 3) participated in return for course credits or cash. All participants reported having normal or corrected-to-normal vision.

Procedure

US calibration

Conditioning started with calibration of the US. The US consisted of a 400 V electric stimulus with duration of 2 ms, delivered to the right ankle. Two electrocardiogram electrodes were placed over the tibial nerve at the medial malleolus of the right ankle of the participants. Electrodes were connected to a Digitimer DS7A constant current stimulator (Hertfordshire, UK), which is devised for percutaneous electrical stimulation of subjects in clinical and biomedical research settings. The

intensity of the current was calibrated to an “unpleasant but painless” level for each participant individually. Starting at 16 mA, the current was increased stepwise with 2 mA, each time checking with the participant whether the “unpleasant, but painless” level had been reached. When the participant indicated that the stimulus was painful, the current was regulated down. The maximum amperage was 45 mA and calibration ended when this maximum was reached.

After the calibration procedure, participants completed two practice blocks of the experimental session (see the “Experimental session” section). Each practice block consisted of 36 trials. Afterwards, the fear-conditioning procedure started.

Fear-conditioning

During fear-conditioning, two diamonds of different colours served as the CSs. For half of the participants, the CS+ consisted of an orange diamond, whereas the CS− consisted of a blue diamond, both with sides of 1.74° and matched for luminance. For the other half of participants, the assignment of CS+ and CS− was reversed.

The conditioning procedure consisted of a habituation phase and an acquisition phase. Habituation consisted of 2 CS+ and 2 CS− presentations in a random order. The stimuli were presented for 4000 ms and no shocks were delivered. Acquisition consisted of 7 trials with paired presentations of CS+ and US, 3 presentations of CS+ without US and 10 trials of CS− alone, in a random order.

A trial started with the presentation of a fixation dot for 2000 ms. Afterwards, a fixation cross was present for 4000 ms, to keep attention constant and fixated on the CS. Afterwards, a CS was presented at the centre of the screen for 4000 ms. The US terminated together with the CS+. Participants were passively viewing the stimuli.

Experimental session

The task was a variant of the additional singleton task of Theeuwes (1992). Participants were seated 75 cm from a computer screen with their head resting on a chinrest. Stimuli were presented

against a grey background on a 21-inch monitor. The stimulus display consisted of nine elements placed around fixation on an imaginary circle with a radius of 6° . The target stimulus was a green outline circle with a diameter of 1.74° . The non-target stimuli were green outline diamonds with sides of 1.74° . The distractors were the exact same stimuli that were used in the conditioning procedure (i.e., a blue or an orange diamond). The target stimulus contained a black line (0.87°) with a horizontal or vertical orientation. The non-target and distractor stimuli contained a black line (0.87°) with a randomly chosen orientation (22.5° , 45° or 67.5° of arc, to either side of the vertical plane).

The experimental session consisted of 5 blocks of 36 trials. A trial started with the presentation of a central fixation cross ($0.35^\circ \times 0.35^\circ$) for 1200 ms. Afterwards, a fixation dot ($0.3^\circ \times 0.3^\circ$) was presented. After 600 ms, the stimulus display was shown. In 50% of the trials, the display contained a distractor stimulus, which could be orange or blue with an equal probability. In the practice blocks, no distractors were present. The target stimulus could appear at any of the nine locations with an equal probability (see Figure 1).

Participants were instructed to respond as fast as possible to the orientation of the line within the target stimulus, by pressing the “z” key if the line was horizontal and the “/” key if the line was vertical. It was emphasised that the participant should fixate the central dot and not move his/her eyes during the course of any trial. Participants were informed that all distractors were irrelevant to the task. Feedback on average speed and accuracy was provided after each block. A warning beep informed participants when they made an error.

At the end of the experimental session, contingency of the CS and US was assessed by asking participants whether the blue or orange diamond was followed by a shock or not in the conditioning phase.

RESULTS

Experimental session

Trials with incorrect responses, response times higher than 1000 ms and response times higher or lower than 2.5 standard deviations from the participants’ average were excluded from the analyses. This led to an average loss of 7.6% of the trials. Two participants reported to be unaware of CS-US contingency. The data of these participants were included in the analyses.

A Greenhouse-Geisser corrected ($\epsilon = .778$) repeated measurements ANOVA on reaction time (RT) with condition (no-distractor, CS–distractor and CS+ distractor) as independent variable revealed a significant effect ($F(1.556, 35.789) = 27.305$, $p < .001$, $\eta_p^2 = .54$; see Figure 2). The results showed a significant difference between the CS+ and CS– distractor conditions ($t(23) = 2.69$, $p < .05$, $d = .55$). Cohen’s effect size value suggested a moderate to high practical significance. Response times to targets in the presence of a CS+ distractor (632 ms) were slower compared to a CS– distractor (615 ms). Thus, the presence of a fear-conditioned distractor interfered with allocating attention to a target at another location. Response times on trials without distractor (587 ms) were faster compared to trials with a CS+ distractor ($t(23) = 6.12$, $p < .001$, $d = 1.25$), and faster than trials with a CS– distractor ($t(23) = 6.36$, $p < .001$, $d = 1.30$).¹

An ANOVA on error percentage revealed a significant effect of condition ($F(2, 46) = 5.346$, $p < .01$, $\eta_p^2 = .19$). A t test revealed that participants made more errors (8.5%) in the CS– condition than in the no distractor condition (5.8%; $p < .01$). Participants also made more errors in the CS+ condition (8.5%) than in the no distractor condition ($p < .05$). There was no difference in an error rate between the CS– and CS+ condition. This pattern of results indicates

¹These data replicated a pilot experiment involving 10 participants in which we used a different proportion of distractor trials (.66 instead of .50). In this experiment, we also found a difference between RTs on CS+ and CS– trials (639 vs. 617 ms, $t(9) = 4.04$, $p < .01$, $d = 1.28$). However, the no distractor condition did not differ from the distractor conditions.

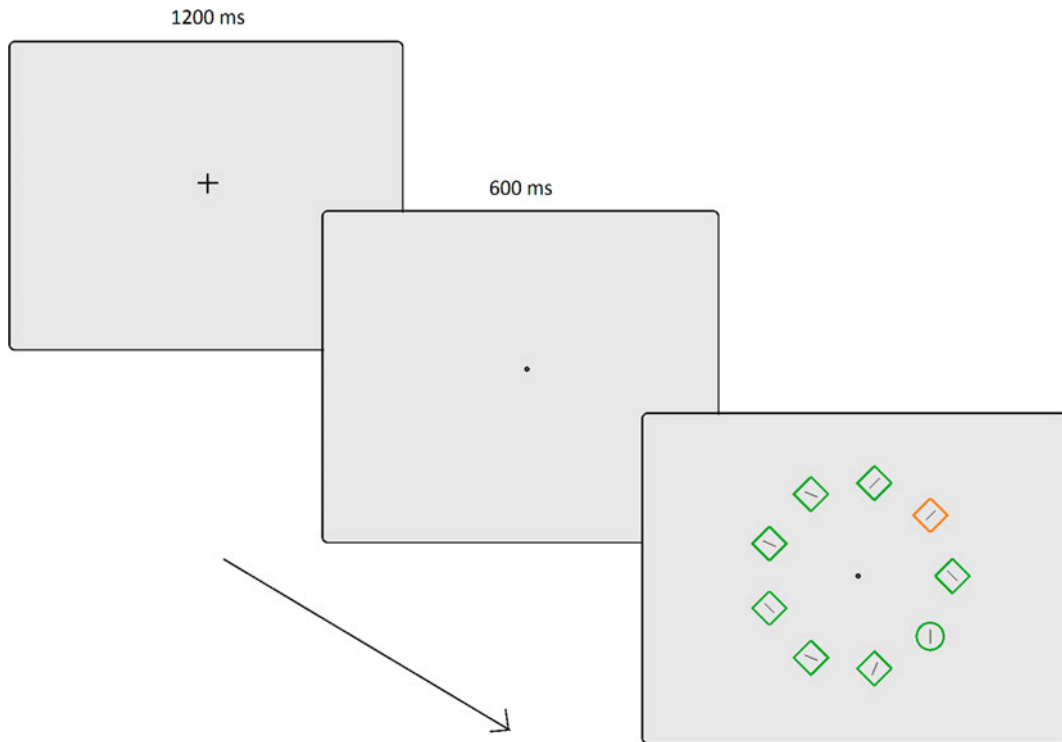


Figure 1. Example of a trial in the experimental session. A green target circle with a horizontal or vertical line was presented at one of the nine locations. Simultaneously, a previously conditioned or neutral distractor was presented at another random location. Participants had to respond as fast as possible to the orientation of the line inside the circle.

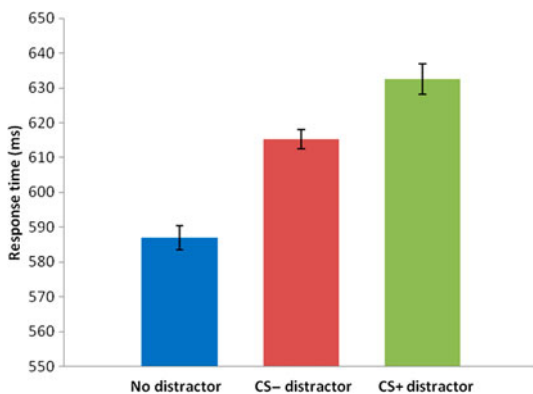


Figure 2. Mean response times to targets in no distractor, CS- distractor and CS+ distractor condition. Response times in the CS+ distractor condition were slower than response times in the CS- distractor condition, and slower than responses times in the no distractor condition. Error bars show within-subjects normalised standard errors (Loftus & Masson, 1994).

that the observed differences in RTs cannot be attributed to a speed-accuracy trade-off.

DISCUSSION

The present study demonstrates that a neutral stimulus that becomes associated with threat captures attention above and beyond its physical salience. Even though the threatening stimulus was completely irrelevant for the task at hand, it captured attention (for a different definition of task relevance, see Lichtenstein-Vidne, Henik, & Safadi, 2012). The neutral distractor slowed search times to targets because of its physical salience, but the conditioned distractor, which had an identical physical salience, slowed search times even more, suggesting a magnification of capture. Whereas

previous studies showed some evidence of attentional prioritisation of fear-conditioned stimuli (Koster et al., 2004; Notebaert et al., 2011), our study shows that fear-conditioned stimuli grab attention in an automatic fashion and disrupt ongoing task performance. Our results are in line with a recent study by Mulckhuyse, Crombez, and Van der Stigchel (2013), who showed that a fear-conditioned distractor had an effect on saccadic eye movements as the presence of an irrelevant fear-conditioned distractor altered the eye movement trajectory. Importantly, unlike previous studies using fear-conditioning approach, in our study no shocks were delivered during the testing session. We clearly demonstrate that a conditioned distractor grabs attention even when the actual threat is no longer present.

The current results provide clear evidence that threatening stimuli influence attention as a result of associations that develop during fear-conditioning. Fear-conditioning is a widely known and successful method to link an initially neutral stimulus with a stimulus that is intrinsically aversive. Consequently, CS+ presentation typically elicits a variety of physiological reactions indicative of fear. Our results show that the learned fear value of a stimulus is strong enough to elicit prioritisation in visual selection and to compete with ongoing tasks goals. Such attentional priority to threat-related stimuli can be considered as evolutionary adaptive, since efficient detection and processing of threat-related stimuli may improve chances of survival (LeDoux, 1996). At a neural level it has been suggested that the amygdala, a subcortical structure specialised in detection of potentially dangerous events, might be involved in the prioritised processing of threat-related information. Fear-conditioned stimuli have been shown to be associated with enhanced amygdala activation (e.g., Davis & Whalen, 2001) and enhanced processing in visual cortex (e.g., Lim, Padmala, & Pessoa, 2009). It has been argued that stimuli with a learned fear value may be enhanced directly because of the reciprocal connection between the amygdala and earlier visual areas (Alpers, Ruhleder, Walz, Mühlberger, & Pauli, 2005). Still, the existence of such a

connection in the human brain is under debate (de Gelder, van Honk, & Tamietto, 2011; Pessoa & Adolphs, 2010), and further research is necessary to clarify the underlying neural mechanisms in visual processing of emotional stimuli.

Our results robustly show that fear-conditioned distractors are involuntary attended. However, our task does not allow to distinguish between capture and holding of attention. An emotion-driven increase in attentional priority could either be the result of a faster detection of the fear-conditioned stimuli or an increase in attentional dwell time following salience-driven capture (e.g., Belopolsky, Devue, & Theeuwes, 2011). However, the present study clearly shows that fear-related stimuli interfered with execution of a simple task goal.

Although the relevance of attentional prioritisation of threatening stimuli is evident because of its evolutionary importance, automatic modulation of attention is not specific to threat. Recently, several studies have shown that reward-associated stimuli also cause attentional capture (Anderson et al., 2011). The behavioural impact of prioritising a rewarding event may be just as high, since selecting rewarding events may be equally important for an organism's survival chances. Indeed, it has been suggested that the amygdala's role is more general than previously assumed, and it may act as a detector of behaviourally relevant stimuli, such as stimuli that are novel, surprising or sad (Ousdal et al., 2008). Importantly, the similarity between the effects of reward and punishment on the brain was implied by a functional magnetic resonance imaging (fMRI) study by Kim, Shimojo, and O'Doherty (2006), who showed that avoiding aversive outcomes and receiving a reward provoked a similar response in the medial orbitofrontal cortex. However, the behavioural significance of threat and reward originates from different motivational systems. It is likely that after being quickly detected, a stimulus with a learned fear value potentiates avoidance responses, but in the case of the option of reward, approach behaviour occurs. Thus, whereas reward-related elements may increase the motivation to obtain them, fear-related objects may increase the motivation to avoid them (e.g., Ford et al., 2010). Indeed, it has been

suggested that early vigilance to fear-evoking stimuli is followed by later avoidance (e.g., Mogg, Bradley, de Bono, & Painter, 1997). Dissimilarities between behaviourally relevant stimuli and their influence on attention may be revealed in future experiments that distinguish between approach and avoidance, i.e., in tasks including behavioural responses of approach or escape.

In sum, the present study shows that the presence of irrelevant threatening stimuli interferes with the completion of explicit task requirements. Even though all stimuli were initially completely neutral and did not differ in their physical salience, the presence of an irrelevant distractor with a learned fear association slowed response times more than a distractor without a fear association. The current results clearly indicate that learned fear associations have the ability to grab our attention even if we try to ignore them.

Manuscript received 9 January 2014
Revised manuscript received 6 May 2014
Manuscript accepted 11 May 2014
First published online 4 June 2014

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