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Probing the influence of unconscious fear-conditioned visual stimuli on eye movements

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ABSTRACT

Efficient threat detection from the environment is critical for survival. Accordingly, fear-conditioned stimuli receive prioritized processing and capture overt and covert attention. However, it is unknown whether eye movements are influenced by unconscious fear-conditioned stimuli. We performed a classical fear-conditioning procedure and subsequently recorded participants' eye movements while they were exposed to fear-conditioned stimuli that were rendered invisible using interocular suppression. Chance-level performance in a forced-choice-task demonstrated unawareness of the stimuli. Differential skin conductance responses and a change in participants' fearfulness ratings of the stimuli indicated the effectiveness of conditioning. However, eye movements were not biased towards the fear-conditioned stimulus. Preliminary evidence suggests a relation between the strength of conditioning and the saccadic bias to the fear-conditioned stimulus. Our findings provide no strong evidence for a saccadic bias towards unconscious fear-conditioned stimuli but tentative evidence suggests that such an effect may depend on the strength of the conditioned response.

1. Introduction

We are constantly exposed to abundant amounts of sensory information. Due to our brain's limited processing capacity, we need to prioritize information based on its behavioural relevance to be able to take appropriate action. In particular, the efficient detection and evaluation of threatening stimuli, which signal immediate danger in the environment, is critical for survival. There is indeed empirical evidence that threatening stimuli like fearful or angry faces or snakes receive prioritized visual processing and are detected faster than non-threatening stimuli (LoBue, Matthews, Harvey, & Stark, 2014; Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001; Yiend, 2010). Besides such inherent threatening aspects of visual stimuli, stimuli can also acquire a threatening value through classical conditioning, that is, by pairing them with an aversive event. Visual stimuli that have previously been associated with an aversive event (conditioned stimuli, CS+), for instance an aversive noise or an electrical shock, can capture and modulate spatial attention (Armony & Dolan, 2002; Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004) and can be more readily detected (Padmala & Pessoa, 2008) compared to neutral stimuli.

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Emotional and fear-conditioned stimuli also influence the oculomotor system. For instance, fixations increase for CS+ stimuli (Hopkins, Schultz, Hannula, & Helmstetter, 2015) and eye movements are made faster to a peripheral fearful picture than a neutral one (Bannerman, Milders, de Gelder, & Sahraie, 2009). Even for threatening stimuli that are not task-relevant, saccade trajectories and latencies are altered by their occurrence (Mulckhuyse, Crombez, & Van der Stigchel, 2013; Mulckhuyse & Dalmaijer, 2015; Schmidt, Belopolsky, & Theeuwes, 2012, 2015b). Together, these results indicate that fear conditioning has the potency to increase the emotional saliency of a visual stimulus and to consequently enhance its effect on the oculomotor system, drawing eye movements towards conditioned stimuli.

From an evolutionary perspective, it would be biologically advantageous to rapidly detect threat from the environment in order to activate appropriate behavioural responses within a short period of time. In line with this notion, neurocognitive theories propose that threatening visual stimuli can also be processed without awareness through a subcortical visual pathway to the amygdala (Tamietto & de Gelder, 2010; Tamietto, Pullens, de Gelder, Weiskrantz, & Goebel, 2012). Consistent with this theory, recent research showed faster access to awareness of fear-conditioned stimuli (Gayet, Paffen, Belopolsky, Theeuwes, & Van der Stigchel, 2016). While such preferential access to awareness does not unequivocally imply enhanced unconscious processing (Gayet, Van der Stigchel, & Paffen, 2014; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014), there is also evidence for autonomic responses to fear-conditioned stimuli that were permanently suppressed from awareness (Esteves, Dimberg, & öhman, 1994; Parra, Esteves, Flykt, & Öhman, 1997; Raio, Carmel, Carrasco, & Phelps, 2012; Öhman & Soares, 1993). Furthermore, fear-conditioned visual stimuli, conditioned outside of awareness, have also been shown to modulate visuospatial attention in subsequent tasks (Beaver, Mogg, & Bradley, 2005).

Thus, while associations can be formed between aversive unconditioned stimuli (US) and conditioned stimuli (CS) to elicit conditioned responses (CR) outside of awareness, it remains unknown whether fear-conditioned stimuli can modulate overt visual attention and draw eye movements towards them even when presented outside of awareness. Based on results from studies showing physiological responses to fear-conditioned stimuli that were presented outside of awareness (review: Clark, Manns, & Squire, 2002; Critchley, Mathias, & Dolan, 2002) and the oculomotor system's sensitivity to subliminal stimuli (Rothkirch, Madipakkam, Rehn, & Sterzer, 2015; Rothkirch, Stein, Sekutowicz, & Sterzer, 2012; Spering & Carrasco, 2015), we hypothesized that eye movements would be preferentially directed towards fear-conditioned stimuli that the observers are unaware of.

In the current study, we followed a classical fear conditioning procedure (Pavlov, 1927) and manipulated threat by pairing one of two fearful faces (the CS+ stimulus) with an aversive white noise burst (the US stimulus), while never pairing the other face (the CS− stimulus) with the noise. Threat was defined in this context as a state of the world predicting an aversive event and the conditioned response as an anticipatory physiological response to the stimulus that predicts an aversive event as learned from prior experience. We chose fearful faces as stimulus material, since the fear conditioning procedure is well established with emotional face stimuli (Critchley et al., 2002; Esteves et al., 1994; Morris, Öhman, & Dolan, 1998; Öhman & Soares, 1993; review: Öhman & Mineka, 2001), and the effectiveness of fear conditioning likely builds upon the 'preparedness' of the relation between stimuli such that fear conditioning of threat-related stimuli is acquired faster and is more resistant to extinction than non-threatening stimuli (Öhman, 2009; Seligman, 1971). In addition, fearful faces have elicited reliable SCRs even when conditioned under CFS (Raio et al., 2012). To monitor the effectiveness of the conditioning procedure we assessed physiological responses by recording electrodermal activity during the conditioning phase of the experiment. In a subsequent test phase, we used continuous flash suppression (CFS) (Tsuchiya & Koch, 2005) to render the fear conditioned faces invisible. Eye movements were simultaneously recorded during the test phase to assess whether humans have an oculomotor bias towards unconscious fear-conditioned faces.

2. Material and methods

2.1. Participants

Twenty-nine participants took part in the study. The data from two participants were excluded due to poor eye tracking quality. Data from another three participants were excluded due to insufficient suppression of the stimulus (see Section 2.4.2). Thus, the final sample consisted of twenty-four participants (15 female; mean age: 26.41 (±0.99 SEM) years). This sample size was chosen based on a power analysis with the software Gpower V3.1.9.2 (Faul, Erdfelder, Lang, & Buchner, 2007) using an effect size of 0.6 as determined from previous studies that investigated eye movements to stimuli under interocular suppression (Rothkirch et al., 2012, 2015), a power of 0.8 and an alpha level of 0.05. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the study, and were paid for their participation. The study was approved by the local ethics committee and written informed consent was obtained from all participants before the experiment.

2.2. Stimuli

The stimuli in the main experimental session consisted of four fearful female faces taken from the Nimstim dataset (Tottenham et al., 2009). The images were converted to grayscale and cropped into oval shapes comprising a size of $3.5° \times 4.5°$. Two versions of each face were created, which only differed in their luminance contrast. The low-level image