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Where is the chocolate? Rapid spatial orienting toward stimuli associated with primary rewards ☆

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ABSTRACT

Some stimuli can orient attentional resources and access awareness even if they appear outside the focus of voluntary attention. Stimuli with low-level perceptual salience and stimuli with an emotional content can modulate attention independently of voluntary processes. In Experiment 1, we used a spatial cuing task to investigate whether stimuli that are controlled for their perceptual salience can modulate the rapid orienting of attention based exclusively on their affective relevance. Affective relevance was manipulated through a Pavlovian conditioning paradigm in which an arbitrary and affectively neutral perceptual stimulus was associated with a primary reward (i.e., a chocolate odor). Results revealed that, after conditioning, attentional resources were rapidly oriented toward the stimulus that was previously associated with the reward. In Experiment 2, we used the very same conditioning procedure, but we devaluated the reward after conditioning for half of the participants through a sensory-specific satiation procedure. Strikingly, when the reward was devaluated, attention was no longer oriented toward reward-associated stimuli. Our findings therefore suggest that reward associations rapidly modulate visual processing independently of both voluntary processing and the perceptual salience of the stimulus. This supports the notion that stimuli associated with primary rewards modulate rapid attention orienting on the basis of the affective relevance of the stimulus.

1. Introduction

When we concentrate on a task, we are still able to process information appearing outside our voluntary attentional focus. For instance, when we read a book in a noisy cafeteria, we do not process all the chatter of the people sitting around us; however, if a baby starts crying, we stop reading and reallocate our attentional resources toward the baby's location. This kind of stimuli can involuntary orient our attentional resources because (a) they have low-level perceptual properties that are salient (e.g., Theeuwes, 1991) and (b) they have emotional content (e.g., Vuilleumier, 2005).

Despite a large amount of evidence (see, e.g., Yiend, 2009, for a review) consistently demonstrating that attention is involuntarily orientated toward emotional stimuli, to date there has been little agreement on which properties allow emotional stimuli to have this privileged attentional status (Brosch, Pourtois, & Sander, 2010). Some authors claim that emotional stimuli can orient attentional resources if they have intrinsic properties that represent a threat to the organism survival (Flykt, 2006). Appraisal theories propose an alternative explanation. According to these theories, it is not the intrinsic property of the stimulus itself that matters, but rather the interaction between

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the stimulus and the concerns of the individual perceiving it (e.g., Sander, Grandjean, & Scherer, 2005). If a stimulus is appraised as relevant to an important current concern of the individual, the individual's attention is rapidly and involuntarily oriented toward it (Brosch, Sander, Pourtois, & Scherer, 2008). Therefore, according to appraisal theories, not only should threatening stimuli orient attention, but also positive stimuli because they are affectively relevant.

Consistent with this proposal, several experiments have demonstrated that attentional resources are rapidly orientated toward positive emotional stimuli as well as negative stimuli (e.g., Brosch et al., 2008; Öhman, Flykt, & Esteves, 2001). However, these experiments typically used emotional stimuli that are perceptually salient (e.g., pictures of spiders, pictures of baby faces), thereby rendering it virtually impossible to dissociate influences caused by affective relevance from those caused by low-level perceptual characteristics. One way to behaviorally dissociate these two types of influences is to demonstrate that (a) initially neutral stimuli that do not influence the involuntary orienting of attention may become modulators of attention once they acquire affective relevance, and (b) that they would lose their capacity to orient attention once they lost their affective relevance. Neutral, perceptually common, stimuli that are systematically associated with a reward can acquire positive affective relevance. Theories in the neuroscience of motivation have proposed that attention is automatically oriented toward reward-associated stimuli (e.g., Bromberg-Martin, Matsumoto, & Hikosaka, 2010). According to the incentive salience hypothesis (Berridge & Robinson, 1998), the organism attributes incentive salience to stimuli associated with the reward through learning. During this process, previously neutral stimuli may acquire the ability to modulate attention independently of voluntary attention, even if they do not have any particular low-level perceptual salience.

This hypothesis has recently been tested in humans (Anderson, Laurent, & Yantis, 2011a, 2011b; Hickey, Chelazzi, & Theeuwes, 2010a, 2010b, 2011). In Anderson et al. (2011a), (2011b), a simple visual stimulus (i.e., a one-color shape) was associated with a secondary reward (i.e., a visual monetary symbol). Subsequently, the same shape was used as a distractor in trials of a visual search paradigm: if the reward-associated shape was present between the distractors, then voluntary target detection was delayed. This task interference shows that attention is oriented toward reward-associated stimuli even when participants are asked to orient their attention toward a different target. Hickey et al., 2010a, 2010b, 2011 demonstrated that attention is oriented toward a feature associated with secondary reward even when it is counterproductive for the current participants performance, therefore providing empirical evidence suggesting that attention is orientated toward reward-associated stimuli independently of voluntary controlled processes. If this is the case, then attentional modulation of the reward-associated stimuli should rapidly occur at early stages of information processing. Electrophysiological results reported by Hickey et al. (2010a) suggest that this is indeed the case. They showed that reward-associated features lead to enhanced brain activity during early stages of visual processing. However, the rapidity of this attentional modulation remains underinvestigated. To the best of our knowledge, all experiments testing the attentional modulation of reward-associated stimuli in humans used paradigms with a relatively long exposure time (i.e., more than 600 ms), thus preventing to know whether the early modulation of the brain activity is translated in a likewise rapid modulation of involuntary attentional orienting which would influence behavior.

Here we directly investigated this question by testing whether reward-associated stimuli influence involuntary orienting of covert attention after 100 ms. In this context, involuntary modulation of spatial attention orienting can be driven by two mechanisms: (a) initial orienting toward the emotional stimulus, or (b) difficulty in disengaging attention from the emotional stimulus and reallocating it toward another target (e.g., Posner, Inhoff, Friedrich, & Cohen, 1987). Research conducted in animals supports the hypothesis of initial orienting by showing an attentional bias generated by faster eye movements toward reward-associated stimuli (Matsumoto & Hikosaka, 2009). Recent studies showed similar results in humans, by demonstrating that reward associated stimuli were more likely to draw initial gaze than neutral stimuli (Anderson and Yantis, 2012a; Hickey & van Zoest, 2012; Theeuwes & Belopolsky, 2012), but the gaze is not maintained at that location for a longer period (Theeuwes & Belopolsky, 2012). In the present study, we further investigated the role of initial orienting and disengagement in attentional orienting toward reward-associated stimuli, by using an attentional paradigm that has been specifically designed to investigate this issue (i.e., spatial cuing task; Posner & Cohen, 1984).

Moreover, in the present study neutral stimuli were associated with a primary reward, in this case a chocolate odor. This is different from all previous studies investigating human attention toward reward-associated stimuli, because other studies only used a secondary reward, namely, a visual symbol representing monetary gain. The typical distinction between primary and secondary rewards is that whereas secondary rewards like money or power acquire value or significance only through experiences and associative learning, primary rewards like food and odors have an innate value and biological significance (Gottfried, 2011). Although several studies revealed that primary rewards modify human's perceptual processes (e.g., Seitz, Kim, & Watanabe, 2009) they have never been used, to the best of our knowledge, to investigate attention toward reward-associated stimuli. There are two main advantages in using a primary reward in this particular context. First, it is possible to test whether results found with secondary rewards can be replicated by using primary rewards. Second, and more importantly, the rewarding properties of primary reward such as odor can easily be manipulated. It has been shown that the reward value of a food odor decreases when related food has been eaten to satiety, an effect termed sensory-specific satiation (O'Doherty et al., 2000; Rolls & Rolls, 1997). Moreover, it has also been demonstrated that sensory-specific satiation does not only influence the processing of the rewarding