NeuroImage 137 (2016) 116–123

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

# Reward-associated features capture attention in the absence of awareness: Evidence from object-substitution masking

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ARTICLE INFO

*Article history:*
Received 12 February 2016
Revised 1 April 2016
Accepted 1 May 2016
Available online 3 May 2016

*Keywords:*
Reward
Attention
Awareness
Object-substitution masking
N2pc

ABSTRACT

Reward-associated visual features have been shown to capture visual attention, evidenced in faster and more accurate behavioral performance, as well as in neural responses reflecting lateralized shifts of visual attention to those features. Specifically, the contralateral N2pc event-related-potential (ERP) component that reflects attentional shifting exhibits increased amplitude in response to task-relevant targets containing a reward-associated feature. In the present study, we examined the automaticity of such reward-association effects using object-substitution masking (OSM) in conjunction with MEG measures of visual attentional shifts. In OSM, a visual-search array is presented, with the target item to be detected indicated by a surrounding mask (here, four surrounding squares). Delaying the offset of the target-surrounding four-dot mask relative to the offset of the rest of the target/distracter array disrupts the viewer's awareness of the target (masked condition), whereas simultaneous offsets do not (unmasked condition). Here we manipulated whether the color of the OSM target was or was not of a previously reward-associated color. By tracking reward-associated enhancements of behavior and the N2pc in response to masked targets containing a previously rewarded or unrewarded feature, the automaticity of attentional capture by reward could be probed. We found an enhanced N2pc response to targets containing a previously reward-associated color feature. Moreover, this enhancement of the N2pc by reward did not differ between masking conditions, nor did it differ as a function of the apparent visibility of the target within the masked condition. Overall, these results underscore the automaticity of attentional capture by reward-associated features, and demonstrate the ability of feature-based reward associations to shape attentional capture and allocation outside of perceptual awareness.



## Introduction

In the real world, a multitude of sensory stimuli constantly compete for our attention, and it is therefore essential to select the most relevant ones for more extensive perceptual processing. Due to their behavioral relevance, sensory features associated with rewards tend to capture attention. Within the context of a visual search task, this capture has been observed in behavioral and electrophysiological measures, which show enhanced processing of a stimulus containing a previously rewarded feature. The specific pattern of behavioral results appears to depend upon the elements of the presented search array or scene in which such a feature is embedded, and can either be beneficial or detrimental to the task at hand. For example, when a reward-associated feature is embedded in a task-relevant stimulus, it tends to enhance task behavior, making viewers faster and more accurate in discerning relevant stimulus content (Störmer et al., 2014; Buschschulte et al., 2014; Della Libera and Chelazzi, 2006; Kiss et al., 2009). On the other hand, when a reward-associated feature is embedded in a task-irrelevant stimulus, decrements in behavior in a concurrent primary task are observed, reflecting an effect of distraction from that task (Hickey et al., 2010; Anderson et al., 2011a,b; Chelazzi et al., 2013; Hickey and van Zoest, 2013).

Regardless of its effect on task-relevant behavior, attentional capture by reward is reflected in neural measures of spatial attention allocation. In the context of a visual search task, and whether embedded in a distracter or task-relevant target, the capture of attention by a reward-associated feature is accompanied by modulations of the N2pc, a negative-polarity event-related-potential (ERP) component that reflects the shift or capture of attention to a laterally presented target,

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http://dx.doi.org/10.1016/j.neuroimage.2016.05.010
1053-8119/

and that appears as an enhanced negative evoked potential over contralateral posterior parietal scalp peaking ~200 ms after target onset (Luck and Hillyard, 1994; Woodman and Luck, 1999). Studies using MEG have suggested that this index of spatial attentional shifts arises mainly from ventral extrastriate cortex (Hopf et al., 2000), and intracranial single unit recordings in nonhuman primates have localized an analogous effect to inferotemporal regions (Chelazzi et al., 1998). Modulations of the N2pc activity, such as higher amplitudes or earlier onset latencies, thereby provide a neural index of the enhanced spatial attentional capture by reward-associated features. Such patterns of results have been seen in a number of electrophysiological studies of reward in visual search (Hickey et al., 2010; Kiss et al., 2009; Qi et al., 2013; Donohue et al., 2016).

The automaticity with which reward-associated features can capture visual attention has been probed primarily in terms of stimuli that are visible but are task-irrelevant or ignored (e.g., Qi et al., 2013). Although these findings underscore the potency of reward-associations in driving attentional processes during visual search, the degree to which visual attention can be captured by a reward-associated stimulus or feature of which the viewer does not become aware would provide particularly telling information concerning the automaticity of these influences. One way to probe attentional capture in the absence of awareness is to create conditions in which a physically present target is rendered perceptually unseen by viewers, and to track the hallmark behavioral and neural indices of attentional capture as a function of reward across these conditions of awareness. This method, wherein an implicit or neural measure of a specific perceptual or cognitive process is tracked across varying levels of awareness reflected in an explicit behavioral measure of the same process, is known as the dissociation paradigm (Reingold and Merikle, 1988). Previous studies have employed this approach using a variety of methods and measures, which seem to support the idea that ecologically relevant features or objects can have an influence on visual attention even when presented outside of visual awareness. For example, the affective content of faces has been shown to lead to enhancements of visual processing, regardless of visibility (Jiang et al., 2009; Pegna et al., 2008; Pesciarelli et al., 2011; Smith, 2012). In addition, it has also been shown that ecologically relevant, but otherwise unseen, stimuli can capture attention, as reflected in their tendency to overcome inattentional blindness (Koivisto and Revonsuo, 2007) or facilitate subsequent target discrimination (Wetherill et al., 2014).

Of particular relevance in examining the deployment of visual attention to unseen visual targets is a study by Woodman and Luck (2003), which successfully dissociated the focusing of attention reflected in the N2pc from the construct of visual awareness. Specifically, these authors showed that the N2pc was present for targets that were masked by object substitution (described below), whether they were ultimately seen or unseen by the viewer, whereas those targets masked by a more traditional form of backward pattern masking did not elicit an N2pc when unseen. Whether or not the enhancement of the N2pc by reward-associated features would also be present under such circumstances would speak not only to the automaticity of reward processing, but also whether its ability to modulate attentional allocation can operate outside the purview of awareness. This issue is the main focus of the present study.

To create conditions of reduced visual awareness, masking by object substitution can serve as a particularly useful method. In object-substitution masking (OSM), an array of stimulus items (i.e., a single target item among an array of distracters) is briefly presented (~17–50 ms duration). The target item, which occurs in an unpredictable location in the array, is denoted as the target by a surrounding four-dot mask (Enns and Di Lollo, 2000; Giesbrecht and Di Lollo, 1998). On half of the trials, all elements of the briefly presented array (distracters, target, and mask) disappear simultaneously, which tends to leave the target visibility intact. On the other half of the trials, the four-dot mask remains on the screen for a short period of time (typically several hundred milliseconds) following the offset of the rest of the target/distracter array. In these instances, the visibility of the target is greatly reduced. The most favored account of the mechanism of OSM cites the convolution of a feedforward signal comprised of the offset-lagging mask with the reentrant signal containing the initial mask-plus-target information. This integration process is proposed to result in the representation of the mask (i.e., the only consistent element between the two signals) being substituted for the initial target-plus-mask as an input signal to later visual processing stages, and ultimately to perceptual awareness (Boehler et al., 2008; Di Lollo et al., 2000; Harris et al., 2013). Consequently, any process shown to occur despite the perceptually disruptive effects of OSM can be interpreted as occurring independently from this reentrant signaling mechanism.

Based on what is known about masking via object substitution, as well as previous findings regarding the capture of attention by rewarded visual features, the introduction of a feature-based reward association to masked targets can lead to one of several possible patterns of results. At the behavioral level, the rapid capture of attention by a reward-associated feature may make OSM less effective at reducing the visibility of such targets. An enhanced N2pc response in the case of reward-associated vs. reward-unassociated targets in the masked condition would likely accompany this behavioral result. Such an overall pattern of results would be consistent with previous findings pointing to the central role of attentional deployment in determining the efficacy of masking by object-substitution, wherein correctly discriminated masked targets were accompanied by an enhanced N2pc to the target location relative to those not consciously perceived (Harris et al., 2013; Prime et al., 2011).

On the other hand, it is possible that the behavioral changes associated with reward processing (e.g., increased accuracy) rely on the visual process that is disrupted by OSM. If so, no behavioral difference due to reward would be expected in the masked condition. The neural results would therefore be of central interest, with two main patterns of electrophysiological results being possible. One possibility would be that the N2pc enhancement in response to reward-associated features, like the corresponding behavioral effects, depends upon the process disrupted by OSM, thus resulting in no reward-related enhancement under conditions of reduced target visibility. Another intriguing possibility would be that an enhanced N2pc to reward-associated targets would still be elicited, even in the absence of awareness of that target and any behavioral effect of the reward association. This would indicate that reward-associated feature detection, and subsequent enhanced capture of visual attention, are part of a process that is independent from the low-level reentrant signaling that gives rise to awareness (Chelazzi et al., 2013; Woodman and Luck, 2003). That is, given the putative low-level reentrant mechanism by which OSM disrupts awareness, this would show that a feedforward signal from a stimulus containing a reward-associated feature is sufficient to capture attention automatically, even when that stimulus fails to reach awareness.

## Methods

### *Subjects*

Thirty-seven subjects participated in the experiment, of which two were ultimately excluded due to an insufficient number of trials following artifact rejection for eye movements and blinks. This yielded a total of 35 subjects in the grand average (all right-handed, 14 female) with a mean age of 26.4 $\pm$ 2.9 years. Participants were compensated for their time and performance, and informed consent was obtained for all subjects in accordance with protocol approved by the Institutional Review Board of the Otto-von-Guericke University in Magdeburg, Germany.

### *Stimuli and task*

#### *General*

The stimuli and tasks were created using the Presentation software package (Neurobehavioral Systems, Inc., Albany, California) and were