YNIMG-12599; No. of pages: 11; 4C: 3, 5, 6, 7, 8

NeuroImage xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

NeuroImage

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

Neural structures involved in visual search guidance by reward-enhanced contextual cueing of the target location

Stefan Pollmann [a,b,*], Jana Eštočinová [a,c], Susanne Sommer [a], Leonardo Chelazzi [c,d], Wolf Zinke [a,e]

[a] Department of Experimental Psychology, Otto-von-Guericke University, 39106 Magdeburg, Germany
[b] Center for Behavioral Brain Sciences, 39106 Magdeburg, Germany
[c] Department of Neurological and Movement Sciences, University of Verona, 37134 Verona, Italy
[d] National Institute of Neuroscience, Verona, Italy
[e] Department of Psychology, College of Arts and Science, Vanderbilt University, Nashville, TN 37203, USA

A R T I C L E I N F O

Article history:
Received 11 June 2015
Accepted 18 September 2015
Available online xxxx

Keywords:
Reward modulation
Memory-guided search
Contextual cueing
Retrosplenial cortex
Frontomedial cortex

A B S T R A C T

Spatial contextual cueing reflects an incidental form of learning that occurs when spatial distractor configurations are repeated in visual search displays. Recently, it was reported that the efficiency of contextual cueing can be modulated by reward. We replicated this behavioral finding and investigated its neural basis with fMRI. Reward value was associated with repeated displays in a learning session. The effect of reward value on context-guided visual search was assessed in a subsequent fMRI session without reward. Structures known to support explicit reward valuation, such as ventral frontomedial cortex and posterior cingulate cortex, were modulated by incidental reward learning. Contextual cueing, leading to more efficient search, went along with decreased activation in the visual search network. Retrosplenial cortex played a special role in that it showed both a main effect of reward and a reward × configuration interaction and may thereby be a central structure for the reward modulation of context-guided visual search.

1. Introduction

A growing body of evidence shows that learned reward associations can lead to attentional capture by the rewarded item. This has been observed for covert shifts of attention (Anderson et al., 2011) as well as overt eye movements (Camara et al., 2013; Hickey and van Zoest, 2012; Theeuwes and Belopolsky, 2012). Reward can be associated with a feature, but also with a target location, guiding visual search to the rewarded location (Hickey et al., 2014), even when it has become irrelevant due to a target location change (Camara et al., 2013).

However, all these studies have in common that the reward-associated item competes with a salient target for attention, slightly slowing down an otherwise efficient visual search. This was different in a recent study on reward-modulated contextual cueing using an inefficient visual search task (Tseng and Lleras, 2013). Contextual cueing is observed when the same spatial target–distractor configuration is repeatedly shown during an experimental session, leading to reduced search times. This contextual cueing effect occurs incidentally, i.e. in the absence of an intention to learn, and mostly implicitly, without awareness of learning (Chun and Jiang, 1998). This distinguishes the contextual cueing paradigm from explicit memory-guided search, which has been shown to be enhanced at rewarded target locations (Doallo et al., 2013). Visual search in contextual cueing paradigms is typically inefficient, requiring several eye movements before the target is found. Instead of an immediate capture of attention, as in the experiments discussed above, contextual cueing entails a less direct form of search guidance, leading to reduced search times due to more straightforward scan paths (Brockmole and Henderson, 2006; Manginelli and Pollmann, 2009; Peterson and Kramer, 2001; Tseng and Li, 2004). Nevertheless, a recent study showed that contextual cueing could be modulated by assigning different reward values to individual repeated displays (Tseng and Lleras, 2013). After participants had finished searching a display, a reward cue indicated a high or low reduction of the remaining workload in the task. Tseng and Lleras observed a strong contextual cueing effect for displays with high value, whereas contextual cueing for low-value displays developed much more slowly. An explicit recognition test at the end of the experiment yielded no evidence for explicit, intentional learning of repeated displays. Moreover, by presenting the value assignment only after visual search had ended, it was ensured that participants could not voluntarily prepare to attend with greater effort to high value displays (compare Murayama and Kitagami (2014), for a similar post-cueing procedure).

Reward modulation of contextual cueing would require an association of the reward value with the complex target–distractor configuration or a subset thereof (contextual cueing is observed when only part of the display is repeated, e.g. Geyer et al., 2010a, 2010b; Jiang and

* Corresponding author at: Otto-von-Guericke-Universität, Institut für Psychologie II, Postfach 4120, D-39016 Magdeburg, Germany. Fax: +49 391 6711947.
E-mail address: stefan.pollmann@ovgu.de (S. Pollmann).

http://dx.doi.org/10.1016/j.neuroimage.2015.09.040
1053-8119/© 2015 Published by Elsevier Inc.

Leung, 2005; Jiang and Wagner, 2004). This would be considerably more complex than the simple association of reward with a specific color or location used in the attentional capture studies mentioned above.

However, there may be an alternative explanation for reward modulation in the contextual cueing paradigm. In repeated displays, not only the distractor configuration is repeated, but also the target is repeatedly presented at the same location, offering the opportunity for target location probability cueing. Probability cueing of the target location (Miller, 1988) was recently investigated in the context of visual search (Jiang et al., 2013). Other than transient inter-trial priming (Kristjánsson and Campana, 2010), probability cueing is a long-term memory phenomenon that can be observed several days after learning (Jiang et al., 2013). In the contextual cueing paradigm, target locations are typically repeated equally often in novel displays and in repeated displays in order to remove probability cueing of the target location as a confound of contextual cueing (e.g. Chun and Jiang, 1998). However, Schlagbauer et al. (2014) pointed out that it was unclear if Tseng and Lleras (2013) had associated reward value consistently with target locations in novel displays in the same way as in repeated displays. In their own experiments, they found evidence for a reward modulation of probability cueing rather than of contextual cueing. Thus, it is currently an open question how these two types of cueing contribute to the reward modulation of visual search in repeated displays.

The present study aimed at investigating the neural architecture underlying reward modulation of contextual cueing in visual search. Specifically, our aim was to investigate the processing of previously learned reward associations with spatial contexts. Therefore, we carried out a training session during which the participants incidentally learned to associate specific target–distractor configurations with differential reward value. In a subsequent fMRI session, they searched the same displays, but in the absence of reward. During training, high and low reward values were associated with specific target locations for novel and repeated displays alike. For the repeated displays, reward value was thus associated both with a specific target location and the associated distractor configuration whereas for novel displays it was only associated with the repeated target location. In this way, reward modulation of contextual cueing could be assessed by the interaction of configuration (repeated, novel) and value (high, low). In addition, reward modulation of target probability cueing could be assessed by the contrast of novel high versus low reward displays.

Contextual cueing was expected to lead to faster search times for repeated displays during the fMRI session. This, in turn, was expected to lead to less activation in the brain areas supporting visual search (Pollmann and von Cramon, 2000), particularly the dorsal attention network supporting overt and covert attention shifts (Corbetta et al., 2008; Wager et al., 2004), in line with a previous study on contextual cueing (Manginelli et al., 2013a).

When a search display became associated with high reward during training, we expected it to elicit increased activation in brain areas known to represent reward value, particularly the ventral frontomedial cortex (Critchley and Rolls, 1996; Elliott et al., 2008; Gläscher et al., 2012; Liu et al., 2011; Tremblay and Schultz, 1999) but also the posterior cingulate cortex (Liu et al., 2011).

If the association of reward value with a particular search display facilitates incidental learning of this display, search times will be shortened for repeated presentations of the same display — the contextual cueing for repeated displays will be enhanced, leading to an interaction of configuration × reward. This interaction was expected to reduce activation in the search network further for repeated high-reward displays.

Contextual cueing depends on medial temporal structures (Geyer et al., 2012; Kasper et al., 2015; Manns and Squire, 2001; Preston and Gabrieli, 2008). More generally, the posterior parahippocampal gyrus has been shown to be particularly important for context memory (for a recent review, see Ranganath and Richey, 2012). The posterior parahippocampal gyrus is connected with the retrosplenial cortex/posterior cingulate and angular gyrus, areas that support spatial memory, scene perception and navigation (Baumann et al., 2010; Bohbot et al., 2000; Ekstrom et al., 2011; Janzen and van Turennout, 2004; Schinazi and Epstein, 2010; Sommer et al., 2005; Uncapher et al., 2006). Perhaps most closely related to the current task, Summerfield et al. (2006) have shown right retrosplenial cortex, left parahippocampal gyrus and right angular gyrus to be preferentially involved in memory retrieval for scenes. If contextual cueing is modulated by reward, this may lead to differential activation for repeated high versus low reward configurations in these areas.

2. Methods Q5

2.1. Participants

Nineteen right-handed volunteers without any history of neurological impairment took part in the experiment (7 males; mean age: 24.6 ± 4.7 years, range: 20–38 years). All had normal or corrected-to-normal vision and were naive as to the purpose of the present research. All the participants provided written informed consent for taking part in this study. The study was subdivided into two experimental phases, a training session in a psychophysical lab and an fMRI session conducted a few days later (1–6 days, mean: 2.28 days). The participants received a reimbursement for their participation. This reimbursement was variable for the training session, depended on the number of errors. Because only few errors were made, the variability of the earned reward was low (mean: €19.38, range: €18–21). For the fMRI session it was fixed (€15). The experiments were approved by the Ethics Committee of the University of Magdeburg. Three participants were excluded from the analysis due to technical problems during the fMRI data acquisition.

2.2. Training session

2.2.1. Stimuli

All experiments were carried out with version 3 of the Psychophysics Toolbox (Brainard, 1997) running in Matlab (MathWorks, Sherborn, MA) on an MS-Windows computer. In the training session, the participants viewed stimuli on a 24-inch screen monitor (resolution: 1920 × 1200 pixels; refresh rate: 60 Hz). The viewing distance of 60 cm was ensured by using a chin rest.

The experimental design was a variant of a contextual cueing paradigm (Chun and Jiang, 1998; Exp. 1). The display consisted of an array of twelve black items that were presented on a gray background (Fig. 1). These items were a T-shaped target that was rotated 90° clockwise or counterclockwise (balanced across trials) and eleven L-shaped distractors rotated by 0°, 90°, 180°, or 270°. The line junction of the L-shapes had an offset of 4 pixels to make them more similar to the T-shape, in this way increasing the task difficulty (Jiang and Chun, 2001). The size of the items was 1.25° × 1.25°. The positions of the items were chosen on four imaginary concentric circles with radii of 2.03°, 4.74°, 7.43°, and 10.15°. These circles comprised 4, 12, 20, and 28 equidistant possible item locations, respectively. Twenty-four target locations were chosen on the two outer circles. Target and distractor positions were balanced across all displays to ensure that each visual quadrant contained six target locations and that each display contained three items in each quadrant.

2.2.2. Procedure

Trials started with the presentation of a fixation cross for 1 s followed by a search display (Fig. 1). Participants were instructed to report the orientation of the target as fast and accurately as possible by pressing the left or right arrow key on a standard keyboard. The search display was presented until a manual response occurred. Correct responses were followed, after a blank interval of 0.2 s, by the picture of a coin (size: 9.1° × 9.1°) that informed the participant about the received

Please cite this article as: Pollmann, S., et al., Neural structures involved in visual search guidance by reward-enhanced contextual cueing of the target location, NeuroImage (2015), http://dx.doi.org/10.1016/j.neuroimage.2015.09.040