Vision Research 107 (2015) 22–29

Contents lists available at ScienceDirect

Vision Research

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

Reward associations impact both iconic and visual working memory

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ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form 21 October 2014
Available online 3 December 2014

Keywords:
Reward
Iconic memory
Visual working memory
Interference
Value

ABSTRACT

Reward plays a fundamental role in human behavior. A growing number of studies have shown that stimuli associated with reward become salient and attract attention. The aim of the present study was to extend these results into the investigation of iconic memory and visual working memory. In two experiments we asked participants to perform a visual-search task where different colors of the target stimuli were paired with high or low reward. We then tested whether the pre-established feature-reward association affected performance on a subsequent visual memory task, in which no reward was provided. In this test phase participants viewed arrays of 8 objects, one of which had unique color that could match the color associated with reward during the previous visual-search task. A probe appeared at varying intervals after stimulus offset to identify the to-be-reported item. Our results suggest that reward biases the encoding of visual information such that items characterized by a reward-associated feature interfere with mnemonic representations of other items in the test display. These results extend current knowledge regarding the influence of reward on early cognitive processes, suggesting that feature-reward associations automatically interact with the encoding and storage of visual information, both in iconic memory and visual working memory.

1. Introduction

Rewards play a fundamental role in human cognition. The ability to learn reward contingencies in the environment is crucial to anticipate positive or negative outcomes and optimize value-oriented behavior. Rewards can accordingly act as motivational incentives, guiding the deployment of cognitive resources in order to effectively orient attention and prioritize processing of task relevant information (Engelmann et al., 2009; Pessoa, 2009; Pessoa & Engelmann, 2010; Watanabe, 2007).

A growing number of studies have shown that learned stimuli-reward associations can modulate the allocation of attention when rewards are no longer provided (for a review see Chelazzi et al., 2013). Reward associations appear to automatically bias selective attention in favor of the associated object or feature even when individuals are not aware of the established feature-reward associations. Importantly, the processing of reward associated stimuli is prioritized when this confers no strategic advantage, and perhaps even when it creates a performance cost (Anderson, Laurent, & Yantis, 2011a, 2011b; Della Libera & Chelazzi, 2006, 2009; Krebs, Boehler, & Woldorff, 2010). Initially neutral visual features that have been linked to reward through experience seem to subsequently become salient, acquiring the ability to draw attention in space (Anderson, Laurent, & Yantis, 2011a, 2011b; Della Libera & Chelazzi, 2006, 2009; Hickey, Chelazzi, & Theeuwes, 2010a, 2010b, 2011) and time (Raymond & O'Brien, 2009), and to drive oculomotor capture (Anderson, Laurent, & Yantis, 2012; Hickey & van Zoest, 2012, 2013; Theeuwes & Belopolsky, 2012). These results have led to the proposal that reward may act on attention through a mechanism that is independent of the traditional dichotomy of bottom-up and top-down processes (Awh, Belopolsky, & Theeuwes, 2012).

While increasing effort has been made in the last years to study the influence of learned value associations on attentional and visual search tasks, fewer studies have been dedicated to the relation between reward and other cognitive processes. With the present study, we aim to expand the existing literature addressing the non-strategic influence of reward-value associations on the encoding and storage of information in visual memory.

Memory is the "neurocognitive capacity to encode, store, and retrieve information" (Tulving, 2000). In the visual domain, the early stages of visual memory have been classically distinguished in iconic memory (IM) and visual working memory (VWM). IM is a high capacity, fast decaying storage system where visual representations are encoded and stored only for a few hundreds of milliseconds after the offset of briefly presented stimuli (Coltheart, 1980; Neisser,

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http://dx.doi.org/10.1016/j.visres.2014.11.008
0042-6989/

1967). Only a limited subset of the information retained in IM is then selected and transferred into the limited-capacity system of VMW, where it can be actively maintained for several seconds (Cowan, 2001). VWM is a system with limited resources where capacity is limited in terms of number of items that can be remembered and accuracy of the encoded representations (Alvarez & Cavanagh, 2004; Bays, Catalao, & Husain, 2009; Bays & Husain, 2008; Zhang & Luck, 2008). Whether information is selected and transferred from IM to VWM depends on its relevance for subject's goals as well as perceptual properties of the visual input (Belopolsky, Kramer, & Godijn, 2008; Schmidt et al., 2002).

Recent studies have demonstrated that incentives can improve performance in a visual memory task, increasing VWM capacity (Kawasaki & Yamaguchi, 2013) and speeding response times for the most valuable stimuli (Krawczyk, Gazzaley, & D'Esposito, 2007). Interestingly, learned feature-reward associations have been shown to influence VWM also in the absence of direct incentive motivation, when rewards are no longer provided. Learned item-reward associations lead to enhanced VWM capacity for stimuli associate to high compared to low reward (Gong & Li, 2014).

The current study was designed to further characterize the influence of reward on the early stages of visual memory. On the one hand, we aimed to describe the influence of learned feature-reward associations on visual memory over time, from the earliest sensory storage of IM gradually moving to VWM. On the other, we wanted to investigate how the presence of a previously reward-associated item in the memory array influences the capacity to encode and store the identity of other neutral items in the display.

To address these issues, we combined a value-learning procedure with a visual memory task. During value-learning participants performed a visual search task loosely based on that employed by Anderson, Laurent, and Yantis (2011a, 2011b). Two magnitudes of reward outcome were associated to two colors that characterized the target object. Participants conducted a visual memory task immediately after this training. In this test phase they were presented with a number of items arranged in a circle, where a probe identified a single item in the array and participants reported the orientation of a line element within this item. Importantly, one of these items could have the color associated with reward during training, rendering it a *color singleton*. This item was no more likely to act as memory target than any of the other elements in the array.

Our test task was modeled on the partial report technique introduced by Sperling (1960). By presenting the probe at short or long delays after stimulus offset, Sperling used this task to investigate the content of IM independent of the limitations of working memory. As compared to full report paradigms, where observers are able to report around 3–5 items from the memory array, partial report studies suggest the presence and availability of much more information at short probe delays (i.e. partial report superiority).

We approached our results with interest not only in raw accuracy, but also in the interference created when a singleton stimulus was present in the display and participants were probed to report a non-singleton item. We quantified this interference effect as the accuracy difference between conditions where the response associated with the line inside the singleton was congruent to that of the line inside the probed target (same response, *congruent trials*) vs. when it was incongruent (different response, *incongruent trials*; see Theeuwes & Burger, 1998). This measure was examined for modulation as a function of the color-reward association established during the training phase.

Our hypothesis was that learned reward associations could act on visual memory at different levels, influencing IM, VWM, or both. To foreshadow, we did not find direct evidence of enhancement of visual memory performance for a reward associated item, but we did observe a stronger interference effect on performance when an irrelevant singleton had its color associated to high-magnitude reward. This interference effect was insensitive to the timing of the probe, suggesting that the entrained reward association impacted both IM and VWM.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Thirty students of the University of Trento (26 female) participated in the experiment. Mean age was 22 (ranging from 19 to 37). All had normal or corrected-to-normal vision, normal color vision, and were naïve to the purpose of the experiment. Participants were reimbursed for their participation, with compensation varying between 7.50€ and 9€ based on performance. Written informed consent was obtained from all participants and the experiment was carried out in accordance with the Declaration of Helsinki and was approved by the local Ethics Committee.

2.1.2. Apparatus

Stimuli were presented on a gamma-calibrated ViewSonic Graphic Series G90fB 19″ CRT monitor (1024 × 768) at a refresh rate of 100 Hz. Participants were seated in a dimly illuminated room approximately 60 cm from the display with their head supported by a chinrest. Stimuli were created using a custom Matlab script (Mathworks Inc., Massachusetts, USA) and the Psychophysics Toolbox 3.8 (Brainard, 1997; Pelli, 1997).

2.1.3. Stimuli

All stimuli appeared on a uniform gray background (2.58 cd/m^2) and were regularly displaced along an imaginary circle at a radius of 5° of visual angle from the fixation point (0.12° in diameter). Stimuli were light gray lines (36.1 cd/m^2; 1.5° × 0.12°) oriented vertically or horizontally, presented inside a circle of 2° diameter (width 0.12°). We selected 7 colors to assign to the circles and these colors were adjusted to be physically equiluminant (~24 cd/m^2).

2.1.4. Procedure

The experiment lasted for about an hour and was structured in two parts.

2.1.4.1. Visual search training. In the training phase participants completed a visual search task where the target was defined by one of two colors, one associated to high reward and one associated to low reward (Fig. 1A). The training began with 40 practice trials which were followed by 480 experimental trials divided in 8 blocks. Each trial began with a fixation display; after a variable delay of 400, 500, or 600 ms a visual search display was presented for 100 ms. The search display consisted of 6 gray lines each surrounded by a uniquely colored circle. Targets were defined as circles of one of two possible colors and only one of them could be presented in each trial. Participants were instructed to report as fast and as accurately as possible the orientation of the line inside the target circle, pressing "m" for vertical or "z" for horizontal on a standard computer keyboard. Feedback was provided for 1500 ms beginning immediately after response. The feedback display was identical to the memory display except that light gray text indicating the number of earned points was overlaid at the center of the screen subtending about 1° of visual angle. Participants received either "+01" points or "+10" points for correct responses (10 points corresponded to €0.032). No points, indicated with three dashes "—", were assigned for incorrect responses or trials where participants