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Enhancement from targets and suppression from cues in fast task-irrelevant perceptual learning

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ABSTRACT

Task-irrelevant perceptual learning (TIPL) refers to the phenomenon where the stimulus features of a subject's task are learned when they are consistently presented at times when behaviorally relevant events occur. In this article, we addressed two points concerning TIPL. First, we address the question, are all behaviorally relevant events equal in their impact on encoding processes? Second, we address the hypothesis that TIPL involves mechanisms of the alerting attentional system. Two experiments of fast-TIPL were conducted in which the attentional state of participants was manipulated by using an alerting cue (visual or auditory) that informed participants of the arrival of an upcoming target. Images were presented with task-related stimuli (cues, targets and distractors) and subjects were tested on their memory of those images. Results indicate that memory for target-paired images was enhanced and cue-paired images were suppressed relative to that of distractor-paired images. The alerting cue increased the ability to recall target-paired images presented after this cue, although this result depended on the proportion of cued trials in a session. These results demonstrate a complex interplay between task-elements and the encoding of stimuli paired with them where both enhancement and suppression of task-paired stimuli can be found depending whether those stimuli are paired with task-targets or cues.

1. Introduction

What are the factors that guide learning and memory formation? While it is tempting to believe that learning and memory are primarily guided by conscious processes, there is substantial evidence that implicit factors play key roles in determining what information we encode (DeSchepper & Treisman, 1996; Schacter, Dobbins, & Schnyer, 2004). Recently, a number of studies of task-irrelevant perceptual learning (TIPL) demonstrated that processing the target of a rapid serial detection task can facilitate encoding of information paired with these targets even if this information is not relevant for the serial detection task (Dewald, Sinnett, & Doumas, 2011; Leclercq & Seitz, 2011; Lin, Pype, Murray, & Boynton, 2010; Seitz & Dinse, 2007; Seitz & Watanabe, 2005; Seitz & Watanabe, 2009; Swallow & Jiang, 2010, 2011; Watanabe, Nanez, & Sasaki, 2001). These studies provide a promising paradigm by which to study the encoding process because they allow dissociation between the information being encoded and the task in which the subject is engaged. In this manner the relationships between task-related factors, such as attention and reinforcement, and stimuli to be encoded can be controlled for in a manner not possible with standard approaches.

The phenomenon of TIPL has been studied in most detail in the case of low-level perceptual learning. This research (Seitz & Watanabe, 2009) demonstrates that subjects learn, and become better at detecting or discriminating stimuli, even those that are unnoticed by the subject and that are task-irrelevant, when they are consistently presented at times of reward or behavioral success (Seitz & Watanabe, 2005). These studies suggested that behaviorally relevant events – such as target recognition (Seitz & Watanabe, 2003) or delivery of rewards (Seitz, Kim, & Watanabe, 2009) – lead to a release of diffuse neuromodulatory signals that gate plasticity. However, while initial accounts of TIPL had the goal of establishing that reinforcement in the absence of attention could lead to TIPL (Seitz & Watanabe, 2003, 2005; Watanabe et al., 2001; Watanabe et al., 2002), more recent accounts of TIPL discuss a more complex interplay between attention and reinforcement whereby attentional signals guide learning by suppressing distracting features while permitting the learning of important features (Roelfsema, van Ooyen, & Watanabe, 2010; Seitz & Watanabe, 2009; Tsushima, Sasaki, & Watanabe, 2006; Tsushima, Seitz, & Watanabe, 2008). Indeed TIPL has been observed in some studies but not in other and the role of attention in TIPL can explain this discrepancy in results.

For example, Tsushima et al. (2008) showed that TIPL occurred only for weak, parathreshold, coherent motion stimuli (5% and 15% coherence), but not for strong, suprathreshold, motion stimuli (50% coherence). One hypothesis is that weak task-irrelevant signals fail to be “noticed”, and to be suppressed by the attentional system and

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thus are learned, while stronger stimulus signals are detected, suppressed, and are not learned (Roelfsema et al., 2010; Tsushima et al., 2006). Similar conclusions were drawn by Choi, Seitz and Watanabe (2009) who examined how directed exogenous attention impacted the formation of TIPL.

The interplay between attention and learning has also been shown with studies of TIPL for memory formation. Indeed, recent progress in studies of TIPL has been made by a number of labs with the demonstration of a fast form of TIPL (fast-TIPL) (Dewald et al., 2011; Lin et al., 2010; Swallow & Jiang, 2010, 2011). In this fast-TIPL paradigm, subjects conducted rapid serial visual presentation (RSVP) target detection tasks (looking for a target, letter, color, or word among a series of distractors), while also memorizing other stimuli (images, pictures) that were consistently paired with the stimuli of the RSVP task. Similar to TIPL for low-level perceptual learning, visual memory was enhanced for salient stimuli that were paired with the targets of the RSVP task (Lin et al., 2010; Swallow & Jiang, 2010, 2011). However, such TIPL was not observed if subjects were not informed to memorize the stimuli paired with the RSVP task (Dewald et al., 2011; Swallow & Jiang, 2011). These studies of fast-TIPL drove a number of key advances over the knowledge derived from prior studies of slow-TIPL: 1). That processing of stimuli that are relevant to the subject (although not relevant to the RSVP task), and not only irrelevant stimuli, can be enhanced through TIPL, 2). That TIPL can occur for salient, suprathreshold, stimuli, and 3). That in fast-TIPL, attention to the information presented with the RSVP task increases memorization of this information rather than inhibits it, as found in studies of slow-TIPL (Choi, Seitz, & Watanabe, 2009).

The most salient finding of studies of TIPL is that encoding of information is enhanced at times when behaviorally relevant events occur. However, are all behaviorally relevant events equal in their impact on encoding processes? For example, most studies of TIPL have paired stimuli with the targets of the participants' tasks. To date, it is unclear how other behaviorally relevant stimuli, such as a cue, which provides important information to the participant but does not resolve their task, would impact encoding of stimuli paired with it. This outlying issue is directly addressed in the present study where we test, using fast-TIPL, how memorization of images is impacted by images paired with a cue.

The use of a cue also allows us to experimentally address, for the first time, the hypothesis that TIPL is partially resultant from mechanisms of the alerting attentional system (Posner & Petersen, 1990; Seitz & Watanabe, 2005, 2009). Posner and Petersen (1990) described three distinct attentional networks, each of which having a different effect on stimulus processing: *Alerting* is defined as achieving and maintaining an alert state, *Orienting* is the selection of information from sensory input, and, *Executive control* is defined as resolving conflict among response. Most interestingly, each of these attentional factors has been linked to different neuromodulatory systems in the brain (Fan, Wu, Fossella, & Posner, 2001) that have also been proposed to have a role in learning (Seitz & Watanabe, 2005; Wise, 2004). The alerting system has been link to the norepinephrine system (Coull, Frith, Frackowiak, & Grasby, 1996; Marrocco, Witte, & Davidson, 1994; Witte & Marrocco, 1997) that has an important role in learning, notably by synaptic plasticity (Dalley et al., 2001; Tully & Bolshakov, 2010). Orienting of attention has been linked with the acetylcholine neuromodulatory system (Davidson & Marrocco, 2000), which has been shown to modulate perceptual learning (Rokem & Silver, 2010; Wilson, Fletcher, & Sullivan, 2004) and cortical plasticity (Bear & Singer, 1986; Kilgard & Merzenich, 1998, 2002). The executive control network has been linked with the dopamine system (Fossella et al., 2002), and also plays important roles in learning and plasticity (Bao, Chan, & Merznich, 2001; Wise, 2004). These studies indicate that attention and reinforcement may share some underlying mechanisms and suggest a behavioral route by which to make distinctions among these systems. Seitz and Watanabe (2005) hypothesized that TIPL is most consistent with a featurally non-specific, but temporally precise, learning signal and suggested that the alerting/norepinephrine system had properties most consistent with this.

The objectives of the present study were to test whether TIPL occurs for stimuli paired with a cue and to address the role of the alerting system in fast-TIPL. To do so, we conducted four experiments of fast-TIPL in which the attentional state of participants was manipulated by using an alerting cue. More specifically, in some trials, the target of the RSVP task was preceded by a cue and images (pictures of natural and urban scenes) were paired with the cue, the task-target, and the task-distractors. Given that the alerting cue is a behaviorally relevant event, then one might expect enhanced performance for images that are paired with the cue. However, research of TIPL has found that successful target processing can be required to enhance encoding of target-paired stimuli (Seitz, Lefebvre, Watanabe, & Jolicoeur, 2005) and in this framework, TIPL may not occur for the cue alone. However, the alerting effect takes some time to build (Fernandez-Duque & Posner, 1997; Nebes & Brady, 1993), and then it is probable that benefits of the alerting signal on TIPL will be observable on the performance of images presented after the cue (at the time of the target). Consequently, if the alerting system plays a role in TIPL, then performance for images paired with task-targets should be enhanced when the target is preceded by a cue compared to when the target is not preceded by a cue. In Experiments 1 and 3A we employed a visual cue and in Experiments 2 and 3B we employed an auditory cue.

2. Experiment 1

In our first experiment, we set out to test how a visual cue presented before the target can impact fast-TIPL. We used the fast-TIPL paradigm (Leclercq & Seitz, 2012) where subjects perform an RSVP task in which they make an immediate response to a target — a white square — that can be preceded by a cue — a green square (to which subjects are instructed not to respond). An image was presented with each stimuli of the RSVP task (target, distractor and cue). Because the cue is a task-relevant stimulus we expected that memorization should be enhanced for cue-paired images compared to distractor-paired images. Moreover, we hypothesized that this alerting cue would result in enhanced memorization for target-paired images preceded by a cue, compared to target-paired images that were not preceded by a cue.

2.1. Methods

2.1.1. Participants

Twenty-two participants gave informed consent to participate in this experiment, which was approved by the Human Subjects Review Board of University of California, Riverside. As our objective was to study the role of the cue, we included only participants who successfully withheld responses to the cue. Thus, subjects with more than 35% of responses to the cue (more than 35% of RTs < 150 ms) in all the experiments were excluded. This criterion did not exclude any subjects in Experiment 1. Thus, 22 participants were included in this experiment (20 y.o. ± 15 months; 13 females, 9 males). All participants reported normal or corrected-to-normal visual acuity and received course credit and financial compensation for the one-hour session. Prior to testing, participants were familiarized with the 192 images that were to be used in the experiment by viewing each image for 2 s presented once before to run the experiment. After this, participants performed a practice block of 12 trials. Each participant was then tested for a total of 264 trials, in 11 blocks of 24 trials. Blocks were separated by brief breaks.

2.1.2. Apparatus and stimuli

An Apple Mac Mini running Matlab (Mathworks, Natick, MA) and Psychtoolbox Version 3 (Brainard, 1997; Pelli, 1997) was used for