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Interactions between reward and threat during visual processing

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ABSTRACT

Appetitive stimuli such as monetary incentives often improve performance whereas aversive stimuli such as task-irrelevant negative stimuli frequently impair performance. But our understanding of how appetitive and aversive processes *simultaneously* contribute to brain and behavior is rudimentary. In the current fMRI study, we investigated interactions between reward and threat by investigating the effects of monetary reward on the processing of task-irrelevant threat stimuli during a visual discrimination task. Reward was manipulated by linking fast and accurate responses to foreground stimuli with monetary reward; threat was manipulated by pairing the background context with mild aversive shock. The behavioral results in terms of both accuracy and reaction time revealed that monetary reward eliminated the influence of threat-related stimuli. Paralleling the behavioral results, during trials involving both reward and threat, the imaging data revealed increased engagement of the ventral caudate and anterior mid-cingulate cortex, which were accompanied by increased task-relevant processing in the visual cortex. Overall, our study illustrates how the *simultaneous* processing of appetitive and aversive information shapes both behavior and brain responses.

1. Introduction

Both appetitive and aversive processes impact behavior. For example, positive incentives such as monetary reward improve performance across a diverse set of perceptual and cognitive tasks (Engelmann & Pessoa, 2007; Krebs, Boehler, & Woldorff, 2010; Savine, Beck, Edwards, Chiew, & Braver, 2010; Shen & Chun, 2011). At the same time, task-irrelevant negative stimuli have detrimental effects on performance during related tasks (Dolcos & McCarthy, 2006; Erthal et al., 2005; Hartikainen, Ogawa, & Knight, 2000; Padmala, Bauer, & Pessoa, 2011). Yet, the effects of appetitive and aversive processes on brain and behavior have been investigated largely in an independent fashion (but see Amemori and Graybiel (2012), Choi et al. (in press), Park, Kahnt, Rieskamp, and Heekeren (2011) and Talmi, Dayan, Kiebel, Frith, and Dolan (2009)). Hence, our understanding of how appetitive and aversive processes *simultaneously* contribute to brain and behavior is rudimentary.

Investigating this interaction is important for at least two reasons. First, whereas many brain regions have been traditionally linked to appetitive (Haber & Knutson, 2010; Schultz, Tremblay, & Hollerman, 2000) or aversive (Craig, 2002; LeDoux, 2000) processing, it is increasingly clear that they are engaged during both (Bromberg-Martin, Matsumoto, & Hikosaka, 2010; Mizuhiki, Richmond, & Shidara, 2012; Salamone, 1994; Salzman, Paton, Belova, & Morrison, 2007). Hence, a deeper understanding of the function of these regions necessitates utilizing paradigms that simultaneously manipulate both dimensions. Second, this type of interaction is not hypothetical; in many real-life contexts, rewards and threats may have to be simultaneously considered during behavior. For example, a chimpanzee may be motivated to consume a juicy piece of fruit, but know that doing so may trigger being badly smacked by a higher-ranking male.

In a recent study (Choi et al., in press), we unraveled extensive competitive interactions between appetitive and aversive processing. The interactions were observed during an anticipatory delay "state", namely, in the absence of an explicit stimulus. In the present study, the goal was to investigate interactions between appetitive and aversive processes during perceptual processing, in part to understand potential interactions. We used a factorial design and investigated the effects of monetary reward on the processing of task-irrelevant threat-related stimuli (Fig. 1). Participants performed a visual discrimination task involving a set of stimuli (say, houses) initially associated with reward and a set of stimuli (say, buildings) not associated with reward. Visual stimuli (that is, houses or buildings) were overlaid on task-irrelevant colored backgrounds that were previously linked to "threat" or "safe" contexts, respectively.

In a previous study, we showed that motivation is capable of influencing distractor processing by up-regulating attention when reward is at stake (Padmala & Pessoa, 2011). Participants were

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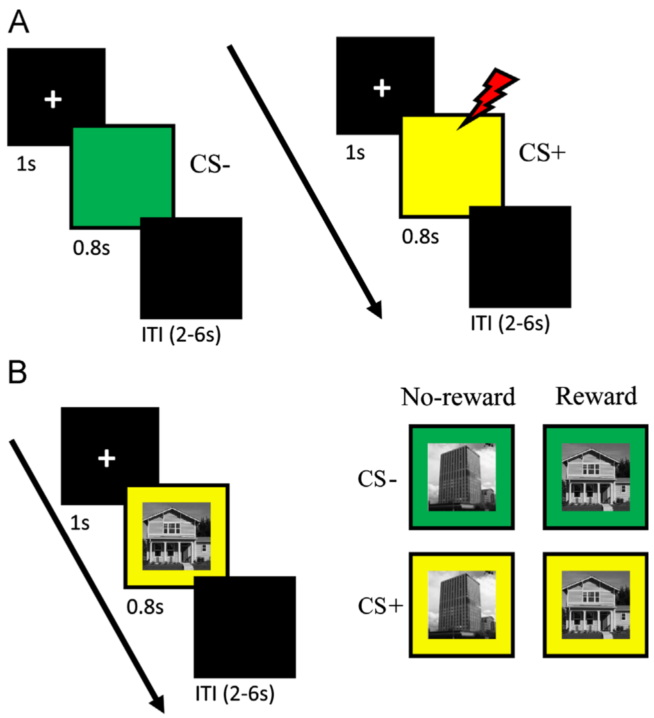

Fig. 1. Task design. (A) Instructed fear conditioning. During this phase, each trial started with an initial fixation display for 1000 ms and was followed by one of the two colored squares for 800 ms. Each trial ended with a 2–6 s blank display. Participants passively viewed the colored square in each trial. They were explicitly informed that there was a chance of receiving a mild aversive shock when one of the colored squares appeared. Shocks (US) occurred in 50% of CS+ trials. (B) Visual discrimination task. During this phase, each trial started with an initial fixation display for 1000 ms and was followed by a picture of a house or building image overlaid on a yellow or green background for 800 ms. Each trial ended with a 2–6 s blank display. Before the start of the experiment, participants were explicitly informed that with one of the image categories they would have the chance of winning extra monetary reward. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

informed of the possibility of reward by a cue stimulus that preceded the target phase during which a Stroop-like interference stimulus was displayed. We proposed that, because reward enhanced attention, the influence of task-irrelevant distractors was reduced leading to decreased conflict during incongruent trials. The goal of the present study was to extend our understanding of the interactions between motivation and attention in two ways. First, we wished to test whether reward would counter the effect of a more powerful task-irrelevant stimuli, such as the one used here that had a history of being linked to aversive electrical stimulation. Second, whereas several neuroimaging studies have investigated how reward cues influence perceptual/cognitive processes, less is known when the impact of reward is *reactive* in nature – especially in the presence of emotional stimuli. Proactive processes that allow one to prepare thoughts and actions in advance based on expectations regarding the upcoming events would be engaged in the case where reward cues are shown in advance, but reactive processes would be engaged when the possibility of reward is not informed in advance of the task at hand (Kiss, Driver, & Eimer, 2009; Krebs, Boehler, Egner, & Woldorff, 2011; Kristjansson, Sigurjonsdottir, & Driver, 2010). This is the case of our visual discrimination task (Fig. 1), during which one of the stimulus categories (house or building) was reward relevant while the other was not. Probing this type of reactive processing (see also Krebs et al. (2011)) is relevant because minimizing the influence of distracting information may benefit from an advance stimulus cue – and possibly the upregulation of *proactive* control processes. In all, our goal was to investigate how the simultaneous presence of appetitive and aversive stimuli affect brain and behavior.

2. Materials and methods

2.1. Participants

Twenty-six volunteers (17 males, mean age = 21 years, range = 18–29 years, all right-handed) with normal or corrected-to-normal vision participated in this study. Based on self-report, all participants were in good health with no past history of neurological or psychiatric disease. The study was approved by the Institutional Review Board of the University of Maryland, College Park, and all participants provided written informed consent before participating in the study.

2.2. Stimuli and behavioral paradigm

The experiment consisted of two phases: instructed fear conditioning phase (6 runs) and the discrimination task phase (6 runs). Participants completed instructed fear and discrimination task runs in alternating fashion starting with the instructed fear conditioning run.

During an instructed fear conditioning run, each trial started with a fixation display for 1000 ms and was followed by a colored (yellow or green) square for 800 ms (Fig. 1A). Participants were required to passively view these colored squares (no response was required). Each trial ended with a 2–6 s (mean: 3 s) blank display. Before the start of the experiment, participants were explicitly informed that there was a chance of receiving a mild aversive shock when one of the colored squares appeared (for example: yellow [CS+] and green [CS−]; counterbalanced across participants). Shocks (US) occurred in 50% of CS+ trials, but the probability was not informed to participants. The US was 500 ms in duration and was delivered after 300 ms from the onset of the CS+ stimulus and hence co-terminated with it. At the beginning of the first instructed fear conditioning run, to calibrate the intensity of the electric shock, each participant was asked to choose his/her own stimulation level, such that the stimulus would be "highly unpleasant but not painful". At the start of subsequent instructed fear conditioning runs, participants were asked about the unpleasantness of the US and were asked to, if needed, re-calibrate it so that the shock would be still "highly unpleasant but not painful". Shocks were administered with an electrical stimulator (Coulbourn Instruments, PA, USA) on the fourth ("ring") and fifth ("pinky") fingers of the non-dominant left hand. The first instructed fear conditioning run included 40 trials (CS−: 20; CS+: 10; CS+ with US: 10) and the subsequent instructed fear conditioning runs included 20 trials per run (CS−: 10; CS+: 5; CS+ with US: 5). Each instructed fear conditioning run started and ended with a 20 s blank display to provide adequate baseline signal for the fMRI analysis. Participants were told to relax during these blank displays at the start and end of each run.

During a discrimination task run, each trial started with an initial fixation display for 1000 ms and was followed by a picture of a house or building image overlaid on a yellow or green background for 800 ms (Fig. 1B). These images were chosen because they strongly recruit portions of visual cortex, specifically parahippocampal gyrus (PHG). To make the house/building images more discriminable, we made sure that all building images contained a clear vertical elongation whereas house images lacked this type of asymmetry (example images shown in Fig. 1B). Finally, each trial ended with a 2–6 s (mean: 3 s) blank display. Before the start of the experiment, participants were explicitly informed that with one of the image categories (for example: house [reward] or building [no-reward]; counterbalanced across participants) they would have the chance of winning extra monetary reward (100% contingency, which was informed to participants) based on fast and accurate performance. Hence, there were four trial types in this phase (Fig. 1B), allowing us to investigate the interactions between *Reward* and *Threat*. Participants were asked to indicate "house" or "building" by pressing the index or middle finger button (counterbalanced across participants). The RT threshold to determine "fast" responses was set at 650 ms based on behavioral pilot data. On each reward trial, participants won $0.25 if they were both accurate and fast. They won $0.00 during error or slow trials. During no-reward trials, participants won $0.00 irrespective of their performance. A visual reward feedback display (2 s duration always followed by 8-s blank display) with cumulative earnings was provided after every 8 trials. Each discrimination task run consisted of 24 trials (6 per trial type), thus providing 36 trials per condition for the entire experiment. Importantly, no shocks were delivered during discrimination task runs and participants were explicitly informed about this. Each discrimination task run also started and ended with a 20 s blank display to provide adequate baseline signal for the fMRI analysis. As before, participants were told to relax during these blank displays at the start and end of each run.

During the initial anatomical scan (see below) participants performed a short reward "familiarization block" so as to experience the reward structure. During this block, participants performed the same discrimination task as described above, except that house/building images were overlaid on a black background;