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Reward alters the perception of time

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ABSTRACT

Recent findings indicate that monetary rewards have a powerful effect on cognitive performance. In order to maximize overall gain, the prospect of earning reward biases visual attention to specific locations or stimulus features improving perceptual sensitivity and processing. The question we addressed in this study is whether the prospect of reward also affects the subjective perception of time. Here, participants performed a prospective timing task using temporal oddballs. The results show that temporal oddballs, displayed for varying durations, presented in a sequence of standard stimuli were perceived to last longer when they signaled a relatively high reward compared to when they signaled no or low reward. When instead of the oddball the standards signaled reward, the perception of the temporal oddball remained unaffected. We argue that by signaling reward, a stimulus becomes subjectively more salient thereby modulating its attentional deployment and distorting how it is perceived in time.

1. Introduction

The perception of time involves processes linked to memory and attention: When we are very busy time seems to fly, while in moments of uttermost significance (e.g. facing a potential threat) time almost seems to stop. Previous studies have linked attentional processes to time perception (Brown, 2010; Coull, Vidal, Nazarian, & Macar, 2004; Glicksohn, 2001; Tse, 2010; Tse, Intriligator, Rivest, & Cavanagh, 2004). For instance, Tse et al. (2004) investigated how infrequently presented stimuli affect duration comparisons. In their experiments, a standard stimulus (e.g. black disk) was repeatedly presented for a fixed duration. Occasionally an infrequent novel stimulus (e.g. red disk), or temporal oddball, was presented for varying durations. Participants had to indicate the duration of the oddball stimulus relative to the standard. The results showed that participants were biased indicating that oddballs appeared to last longer than the standards. This oddball effect was robust across features (e.g. color, size, motion), modalities (visual and auditory) and measurement techniques (method of constant stimuli, magnitude estimation and duration reproduction). Crucially, consistent with the amount of time it takes for attention to be allocated to a stimulus after onset, no oddball effect was observed before 75–120 ms. The authors argued that the oddball drew more attention because it was the unexpected item in the sequence. This increased attentional deployment distorted time perception such that the oddball was perceived to last longer than it actually did. Other studies highlighting attentional deployment as a crucial factor for distortions in time perception support this conclusion (e.g. Kanai & Watanabe, 2006; Mattes & Ulrich, 1998).

Other recent studies have revealed that the deployment of attention is affected by the prospect of earning reward: attention is biased to objects or stimulus features associated with reward. For instance, studies investigating the neural basis of reward processing point to the parallel nature of reward and attention; activity in the lateral intraparietal sulcus – a brain region associated with attentional processing (Bisley & Goldberg, 2010; Gottlieb, Kusunoki, & Goldberg, 1998) – is directly modulated by reward contingencies (Dorris & Glimcher, 2004; Louie, Grattan, & Glimcher, 2011; Sugrue, Corrado, & Newsome, 2004). According to the incentive salience hypothesis by Berridge and Robinson (1998) perceptual responses to stimuli associated with reward are affected by mesencephalic dopamine. The dopamine release triggers not only motivated behavior but also affects the salience of a stimulus. Accordingly, stimuli associated with relatively high reward become subjectively more salient making them more likely to attract attention (Awh, Belopolsky, & Theeuwes, 2012).

Numerous studies now support this notion providing evidence that reward affects attentional selection of visual features such as color (e.g. Anderson, Laurent, & Yantis, 2011; Failing & Theeuwes, 2014) or orientation (e.g. Laurent, Hall, Anderson, & Yantis, 2014). These studies demonstrate that stimuli that are or were previously associated with high reward are attentionally prioritized compared to stimuli associated with low or no reward (e.g. Della

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Libera & Chelazzi, 2009; Kiss, Driver, & Eimer, 2009; Raymond & O'Brien, 2009; for reviews see Anderson, 2013; Chelazzi, Perlato, Santandrea, & Della Libera, 2013; Vuilleumier, 2015). Attentional prioritization for stimuli associated with relatively high reward has been shown to transfer to different task settings (e.g. Failing & Theeuwes, 2015; Lee & Shomstein, 2013), occurs when there is no strategic advantage gained from it (e.g. Failing & Theeuwes, 2014, 2015; Hickey, Chelazzi, & Theeuwes, 2010; Le Pelley, Pearson, Griffiths, & Beesley, 2015; Seitz, Kim, & Watanabe, 2009) and even when it is detrimental for reward payout (e.g. Failing, Nissens, Pearson, Le Pelley, & Theeuwes, 2015; Hickey et al., 2010; Le Pelley et al., 2015). Based on these findings, it has also been argued that reward interacts directly with physical salience facilitating processing of stimuli associated with high reward and making them more likely to involuntarily draw attention (Hickey et al., 2010; Wang, Yu, & Zhou, 2013). Even though many studies have shown an effect of reward on attentional selection, very few, if any, have investigated reward-induced attentional deployment in time perception.

There is evidence, however, that reward influences time estimation in the range of seconds to minutes (for a review see Balcı, 2014). For instance in studies using the peak interval (PI) procedure, animals are trained on a discrete fixed interval (e.g. 40 s). The first response after this fixed interval is reinforced with food pellets while responses during the interval are not rewarded. The resulting response curve is usually characterized by a bell-shaped form (Balcı, 2014). During probe trials that last much longer and in which reward is omitted for any response, several studies found evidence for a modulation of the response curve by the expected reward. In experimental blocks in which a relatively high reward was expected, animals responded earlier thereby effectively shifting the peak of the response curve to the left. This suggests that the reward manipulations affected the threshold of response initiation for these animals (e.g. Galtress & Kirkpatrick, 2009; Ludvig, Conover, & Shizgal, 2007; but see Galtress & Kirkpatrick, 2010). At least one study using an adaptation of the PI procedure has provided similar findings in humans (Balcı, Wiener, Çavdaroğlu, & Coslett, 2013). Similarly, the authors of this study argued that expected reward modulates the decision threshold for the initiation of timed responding in the context of the PI procedure (Balcı, 2014; Balcı et al., 2013). Converging evidence for the above findings comes from other studies demonstrating that a modulation of dopamine levels (e.g. by administering dopamine agonists and antagonists) affects the response curve of animals in an analogous fashion as manipulating the expected reward (Drew, Fairhurst, Malapani, Horvitz, & Balsam, 2003; Meck, 1983).

Unlike these previous studies that investigated the estimation of relatively long time intervals using response curve shifts as their dependent measure here we investigated the effect of reward-induced modulations in attentional deployment on time perception using the temporal oddball task. We hypothesized that associating a particular stimulus feature with relatively high reward makes it subjectively more salient and accordingly increases attentional deployment to it. Consequently, if attentional deployment affects time perception, this increase should affect the temporal perception of that stimulus such that stimuli associated with a relatively high reward are perceived to last longer.

2. Experiment 1

In Experiment 1, a sequence of seven disks was presented in the center of the display. Six of the disks were black with each disk presented for a fixed duration ("standard"). Among those black disks, one colored disk was presented for a variable duration ("oddball"). Participants indicated whether the oddball was presented shorter or longer than the standards. Crucially, the color of the oddball indicated whether a reward could be earned on that particular trial. One color (e.g. red) signaled that a reward could be earned for a correct response while another color (e.g. blue) signaled that no reward was available on that particular trial. We predicted that if associating reward with a particular stimulus feature (color) makes the stimulus subjectively more salient and accordingly more likely to draw attention, this stimulus would be perceived to last longer.

2.1. Materials and Methods

2.1.1. Participants

Twenty individuals (sixteen female, mean age ± 23) with reported normal or corrected-to-normal vision gave written informed consent for participation. Participants were provided monetary compensation of between €8 and €14 (M = €8.90 ± SD = 0.79) based on performance. In order to assure that participants were able to do the task properly irrespective of our manipulations, we aimed to only include participants who scored on average above 65% of the trials correctly. Based on this a priori criterion, data of two participants were removed from analyses due to overall accuracy at near chance-level (51.8% ± 1.4).

2.1.2. Apparatus and stimuli

Experiments were run in a dimly lit and sound-attenuated cubicle. Participants were seated at a distance of 70 cm to the computer monitor with their head on a chin rest. All stimuli were created in OpenSesame 2.8 (Mathôt, Schreij, & Theeuwes, 2012) and presented on a Samsung SyncMaster 2233RZ monitor (1680 × 1050 resolution, 120 Hz). Each task display consisted of a disk (1.5° diameter) centered on the screen and presented on a uniform, gray background (CIE: x = 0.433, y = 0.327, 21.43 cd/m^2). The standard was a black disk, while the oddball was a colored disk (red, CIE: x = 0.575, y = 0.403, 13.12 cd/m^2, green, CIE: x = 0.241, y = 0.689, 11.79 cd/m^2, or blue, CIE: x = 0.174, y = 0.115, 10.88 cd/m^2).

2.1.3. Procedure and design

The trial design is illustrated in Fig. 1a. Each trial started with a randomly jittered fixation period of 300–500 ms. Subsequently six standards and one oddball were successively presented. The oddball could either be the fifth, sixth or seventh stimulus in the sequence. During the presentation of the stimuli, participants were instructed to maintain fixation on the center of the screen as no fixation dot appeared in between the appearance of successive stimuli (Tse et al., 2004). After the offset of the last stimulus, the fixation dot reappeared and participants were asked to indicate whether the oddball was presented shorter or longer than the standards by pressing one of two keys on a standard keyboard ('X' for shorter, 'M' for longer). The response was unspeeded and the experiment proceeded only when participants pressed one of the two response buttons. After a response, a feedback display appeared for 1000 ms indicating how many points were earned for that trial. Earned reward was denoted with a "+", lost reward with a "−". We informed participants prior to the experiment that the points they would earn for correct responses corresponded with up to €14 paid out to them at the end of the experiment. No information was given about how many points corresponded to how much reward.

Two design features were crucial to the experiment: First, each standard was always presented for 500 ms with an ISI of 300 ms, while the presentation duration of the oddball varied. The oddball was either presented for 350, 400, 450, 475, 525, 550, 600 or 650 ms. Note that in order to most accurately estimate the point of subjective equality (PSE; see analysis and psychometric function), oddball durations closer to the standard duration were tested