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BOLD responses in reward regions to hypothetical and imaginary monetary rewards

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ABSTRACT

Monetary rewards are uniquely human. Because money is easy to quantify and present visually, it is the reward of choice for most fMRI studies, even though it cannot be handed over to participants inside the scanner. A typical fMRI study requires hundreds of trials and thus small amounts of monetary rewards per trial (e.g. 5p) if all trials are to be treated equally. However, small payoffs can have detrimental effects on performance due to their limited buying power. Hypothetical monetary rewards can overcome the limitations of smaller monetary rewards but it is less well known whether predictors of hypothetical rewards activate reward regions. In two experiments, visual stimuli were associated with hypothetical monetary rewards. In Experiment 1, we used stimuli predicting either visually presented or imagined hypothetical monetary rewards, together with non-rewarding control pictures. Activations to reward predictive stimuli occurred in reward regions, namely the medial orbitofrontal cortex and midbrain. In Experiment 2, we parametrically varied the amount of visually presented hypothetical monetary reward keeping constant the amount of actually received reward. Graded activation in midbrain was observed to stimuli predicting increasing hypothetical rewards. The results demonstrate the efficacy of using hypothetical monetary rewards in fMRI studies.

Introduction

Money is a strong motivator. Subjects work harder, more persistently, and more effectively, if they earn more money for better performance (Camerer and Hogarth, 1999). Typical fMRI studies involve hundreds of trials with each trial lasting around 10 s. If one wants to treat each trial equally and incentive-compatible, then monetary rewards paid to the participants per trial need to be small to avoid excessive expenditure for the experimenter. Gneezy and Rustichini (2000) found that while larger amounts of money yielded higher performance (in terms of parents complying with day care rules), smaller amounts yielded poorer performance than no compensation at all. Hence, monetary incentives at low value can have a detrimental effect on performance. Hypothetical payoffs provide one possibility to overcome the limitation of small gambles in experimental situations (Kahneman and Tversky, 1979).

Hypothetical rewards have been investigated in behavioral studies using paradigms such as the Iowa gambling task (Bowman and Turnbull, 2003; Fernie and Tunney, 2006) and temporal discounting tasks (Johnson and Bickel, 2002; Lagorio and Madden, 2005). These previous studies suggest that hypothetical rewards can motivate behavior to a similar degree as actual rewards (but see Holt and Laury, 2002). In a neuroimaging study, Wittmann et al. (2007) investigated temporal discounting using hypothetical rewards in the range of few hundred dollars with delays ranging from 5 days to 10 years. However, hypothetical rewards have also been used for much shorter delays (e.g. in Gregorios-Pippas et al., 2009, where participants received a percentage of displayed reward every trial). Neural findings from these earlier studies using hypothetical rewards were in line with other imaging studies of temporal discounting using potentially real rewards (e.g. McClure et al., 2004, where one of the participant's choices was selected randomly). In agreement with this notion, Bickel et al. (2009) found no difference in behavioral and neural activation when comparing real and hypothetical monetary gains and fictive monetary losses in a temporal discounting task. Thus, at least in situations involving future outcomes, hypothetical monetary rewards seem to be able to influence behavior and neural activity similar to real payoffs.

Monetary rewards are secondary reinforcers that possibly acquired their value by association with more primary rewards. It is therefore conceivable that monetary rewards act through imagination of rewarding objects that can be acquired through them. Indeed in a recent

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reward imagination study by Bray et al. (2010), participants who imagined monetary or other types of secondary rewards activated primary reward regions. However, monetary rewards have become so ubiquitous in our daily life that they can be considered as rewards in their own right. Functional neuroimaging studies using monetary rewards have found the same brain regions as those involved in processing primary rewards also without asking participants to imagine (e.g. Kim et al., 2011; Tobler et al., 2007; Valentin and O'Doherty, 2009). Given that money is easier to present than primary rewards, it is no surprise that monetary rewards have become the choice of most neuroimaging studies of reward processing. We set out to investigate motivational aspects and corresponding neural activity using various different ways of presenting hypothetical monetary rewards.

Human neuroimaging studies using blood-oxygen-level-dependent (BOLD) functional magnetic resonance imaging (fMRI) have identified a set of reward regions in the midbrain, striatum and orbitofrontal cortex, consistent with findings from non-human primates (for review see Haber and Knutson, 2010). Moreover, conditioned stimuli predicting real monetary rewards activate reward regions in humans (e.g. Tobler et al., 2007). Here, we set out to investigate whether also predictors of hypothetical monetary rewards would activate reward regions of the brain. In order to investigate motivational aspects of monetary rewards, we presented participants with hypothetical rewards that displayed a larger value, but told them that they would be able to take home only a specific percentage of the displayed money. Some previous studies (e.g. Dreher et al., 2006; Gregorios-Pippas et al., 2009; Kuhnen and Knutson, 2005) have used a similar strategy but not explicitly studied the effects of hypothetical rewards. Accordingly, we performed two experiments using different scenarios – when the hypothetical rewards are visually presented or imagined (Experiment 1) and when the real pay-off is explicitly displayed (Experiment 2) or invisible (Experiment 1). Furthermore we hypothesized that increasing the hypothetical monetary reward would result in increased activation in reward regions although the real pay-off is kept constant (Experiment 2).

Materials and methods

Subjects

A total of 17 right handed participants (mean age 25.5 years, range 21.6–30.5 years) were recruited from among undergraduate and graduate student populations in the Cambridge area of the UK. Ten participants took part in both the experiments (the first experiment was always performed at the end of the session). The data from two participants could not be recovered due to technical reasons. The data from three participants, from each of the two experiments, were excluded from all analyses due to large head movements detected in the realignment process. The final data analysis was performed on 12 participants each in the first (5 female) and second (6 female) experiments. Participants were pre-assessed through self-report to exclude prior histories of neurological or psychiatric illness (including depression and schizophrenia), and drug usage. Participants were asked to refrain from excessive alcohol usage on the night before scanning. All participants gave informed written consent and were paid for participation. The research protocol was approved by the Cambridgeshire Local Research Ethics Committee, U.K.

Stimuli, training and pleasantness ratings

Scanning only took place after participants had learned the meaning of abstract visual stimuli in a training session (see below). Experiment 1 used a 2×2 factorial design in which four abstract stimuli were paired with visually presented or imagined hypothetical monetary reward or a control picture. During the imagination trials, a blank screen was displayed following the offset of the abstract stimulus. Experiment 2 used a 2×3 factorial design in which six abstract stimuli were paired with pictorial or alphanumerical display of parametrically increasing hypothetical monetary rewards with three different magnitudes. The hypothetical monetary rewards were always accompanied by a fixed real-payoff (5 pence) that was invisible (Experiment 1) or explicitly displayed (Experiment 2). The stimulus–reward associations were randomized across subjects for both experiments. The presentation of the stimuli and recording of responses was controlled by Cogent 2000 software on Matlab.

For both experiments 1 and 2, we trained subjects up to a week before the scanning session to learn the correct stimulus–reward contingencies (Fig. 1a). Stimulus pleasantness ratings for the abstract stimuli were collected from the subjects before and after training and scanning sessions (Fig. 1a). The abstract stimuli were rated on a scale of 1 (dislike very much) to 5 (like very much). The value of 3 was marked as indifferent on the pleasantness rating scale. After baseline pleasantness ratings were collected, participants received a customized instruction sheet, showing the exact stimulus–reward contingencies. After reading the instructions, participants returned the instruction sheet to the experimenter. The training session proceeded with identical trial structure (see descriptions below) as the scanning session except that the number of repetitions for each trial type in the training session was half (Experiment 1: 15, Experiment 2: 20) of those in the scanning session.

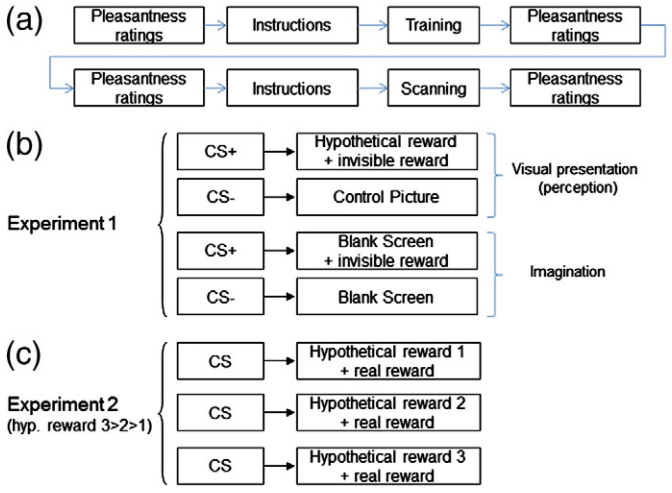

Fig. 1. Experimental design and behavioral results. (a) Training and scanning schedule. Participants were trained up to one week before the scanning session using exactly the same stimulus–reward contingencies. In the first experiment, the instructions to imagine were given in a customized instruction sheet showing the stimulus–reward contingencies for every participant. They reported after every trial what they had seen or imagined using a button press. Participants performed an additional testing task immediately after the training of the second experiment. The training and scanning sessions for the two experiments were identical except that the training sessions had only half the number of trials. Pleasantness ratings for abstract stimuli were collected at the beginning and end of training and scanning sessions. The training and scanning sessions took place on different days separated up to one week. The first experiment was always at the end of the session for those participants who took part in both experiments. (b) Experiment 1. Four conditional stimuli were associated with either rewarding or non-rewarding pictures visually presented on the screen or to be imagined during a blank screen. Participants were instructed before the start of the experiment to imagine the corresponding reward or non-rewarding picture when the blank screen appeared. To ensure minimal demand effects, an invisible actual reward was given for every rewarding trial. The invisible reward was by two orders of magnitude smaller than the hypothetical reward picture and participants were fully informed of this manipulation at the start of the experiment. The contents of visual presentation and imagination were recorded by self-report on every trial. (c) Experiment 2. Three conditional stimuli were associated with three hypothetical rewards that yielded the same actual reward. Two modes of reward presentation were used for hypothetical rewards – alphanumeric and pictorial. The actual reward was not displayed to the participants but added to the total take-home sum that was continuously displayed at the bottom of the screen throughout the experiment.