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Common and distinct neural substrates of the money illusion in win and loss domains

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ABSTRACT

People often evaluate money based on its face value and overlook its real purchasing power, a phenomenon known as the money illusion. In the present study, using functional magnetic resonance imaging (fMRI) combined with a gambling task, we examined the neural signatures of the money illusion in both win and loss domains. Behavioral results showed that self-reported satisfaction with outcomes was modulated by the face value but not the true value of money in both win and loss domains. At the neural level, activity in the posterior insula was associated with the true value of money in the win domain, but not in the loss domain. Importantly, we found that the ventral striatum, ventromedial prefrontal cortex (vmPFC) and amygdala encoded the money illusion in both domains, indicating a domain-general rather than domain-specific neural signature. Moreover, participants with a larger degree of money illusion at the behavioral level showed stronger functional connectivity between the ventral striatum and ventral anterior cingulate cortex (vACC) in the win domain, but stronger functional connectivity between the ventral striatum and amygdala in the loss domain. Our findings highlight the overlapping and distinct neural substrates underlying the money illusion in the context of wins and losses.

1. Introduction

Money is any token that is generally accepted as payment for goods and services. It contains two elements: the face value (i.e., the denomination of the money) and the real value (i.e., the number of items that can be purchased with the money). Economists have documented that individuals' decisions are frequently affected by the nominal rather than the real value of money, a phenomenon known as the money illusion (Cebula, 1981; Mayer and Rozier, 2000; Reinhardt, 1986; Tyran, 2007; Weber et al., 2009). For example, people generally treat 100 dollars today as they did 10 years ago, although the buying power has changed considerably. People are also usually affected by a wage increase but ignore the effect of inflation. The money illusion, a form of irrational thinking (Fehr and Tyran, 2001; Leontief, 1936; Patinkin, 1965), has been shown to affect human behaviors in a variety of experimental and real-world situations (Fehr and Tyran, 2001; Shafir et al., 1997).

In regard to the psychological causes underlying the money illusion, studies indicate that different representations of the same information can lead to different responses (Shafir et al., 1997; Yellen and Akerlof, 2006). For example, people tend to be risk aversive when the outcome is presented as a gain but become risk-seeking when the same outcome is presented as a loss. This cognitive bias is known as the framing effect (Tversky and Kahneman, 1981). Similar to the framing effect, one explanation for the money illusion is that compared to information about money's real value, the nominal representation of money is simpler, more salient and easier to process in the human brain (Shafir et al., 1997).

Although the money illusion is a common phenomenon, its underlying neural mechanisms have not been fully explored. Recently, several studies have shed light on these mechanisms. Our previous study using the event-related potential (ERP) found that participants' reports of the pleasantness of outcomes was modulated by both the face and true values of money. The feedback-related negativity (FRN) was only influenced by the real value of money, indicating that even when participants demonstrate the money illusion at the behavioral level, the human brain may encode the real value of money rapidly at the early stage of decision-making (Yu and Huang, 2013). Another study using functional magnetic resonance imaging (fMRI) found that a change in face value that had no impact on participants' real buying power activated the ventromedial prefrontal cortex (vmPFC), a brain region that is involved in reward anticipation and processing (Weber et al., 2009). However, because the study only compared conditions in which money was identical in real value but differed in nominal terms, it could not provide information

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about the neural encoding of the true value.

It is unclear whether distinct neural substrates are devoted to encoding face versus true values of money. Importantly, it is unclear whether the money illusion recruits a domain-general value encoding network or whether it is associated with domain-specific neural substrates. Investigations on the neural circuits involved in the processing of rewards and punishment have produced inconsistent results. On the one hand, a large number of studies have suggested that monetary gains and losses activate a similar fronto-subcortical network, and differ only in degree (Dreher, 2007; Gottfried et al., 2003; Nieuwenhuis et al., 2005; Tom et al., 2007). On the other hand, some studies have indicated that reward and punishment outcomes may involve different neural substrates (Frank et al., 2004; Yacubian et al., 2006). For example, Yacubian et al. (2006) found that the ventral striatum only represented the computation of expected value and prediction errors in the gain domain, while loss-related expected value and the associated prediction error were represented in the amygdala. Previous studies have emphasized that the findings obtained from the gain domain are not necessarily generalizable to the loss domain (Guo et al., 2013; Wu et al., 2014; Zhou and Wu, 2011). In addition, it is important to distinguish how the brain regions interact in different domains.

In the present study, we used fMRI combined with a simple gambling task to investigate the neural signature and functional connectivity of the money illusion in both win and loss domains. We created different face values and true values of money by manipulating magnitudes and price conditions: For the same magnitude of money in the cheap condition and expensive condition, the face value was identical but real purchasing power differed; for small magnitude in the cheap condition and large magnitude in expensive condition, the true value was identical, but the face value differed (Fig. 1A). We hypothesized that the brain areas that are engaged in computing and experiencing rewards, such as the ventral striatum and vmPFC, would encode the true value and the face value of money. Moreover, besides analytic processes, more intuitive or emotional responses could also play an important role in guiding outcome evaluation. When evaluating monetary winning and losing in complex contexts (i.e., in different price conditions), individuals may rely on heuristics or emotional responses. Thus, we hypothesized that brain regions that are involved in emotional processing, such as the amygdala, might also activate in processing the money illusion.

2. Materials and methods

2.1. Participants

Twenty-five healthy, right-handed participants (11 male; mean age ± SE, 20.36 ± 0.32 years) participated in return for payment. All participants were right-handed and had normal or corrected-to-normal vision. They all reported no history of neurological or psychiatric disorders. The study was approved by the Academic Committee of the School of Psychology at South China Normal University. All participants gave written, informed consent and were informed of their right to discontinue participation at any time. They received a base payment of 60 yuan (about 10 US dollars).

2.2. Experimental paradigm

The experimental paradigm was similar to that in our previous study (Yu and Huang, 2013). Before beginning the task, participants were given the opportunity to familiarize themselves with two shopping catalogs. Each catalog contained 14 items of stationery including a notebook, ruler, pen, etc. All the items in the two catalogs were identical with the exception their price. Prices in the catalog with "cheap prices" ranged from ¥1.4 to ¥2.6 (mean of ¥2), whereas prices in the catalog with "expensive prices" ranged from ¥9.4 to ¥10.6 (mean of ¥10). Participants were then asked to answer several control questions to make sure that they understood the difference between the two catalogs. Participants were told that at the end of the experiment, the money they earned in the following gambling task would not be paid in cash but could be spent on

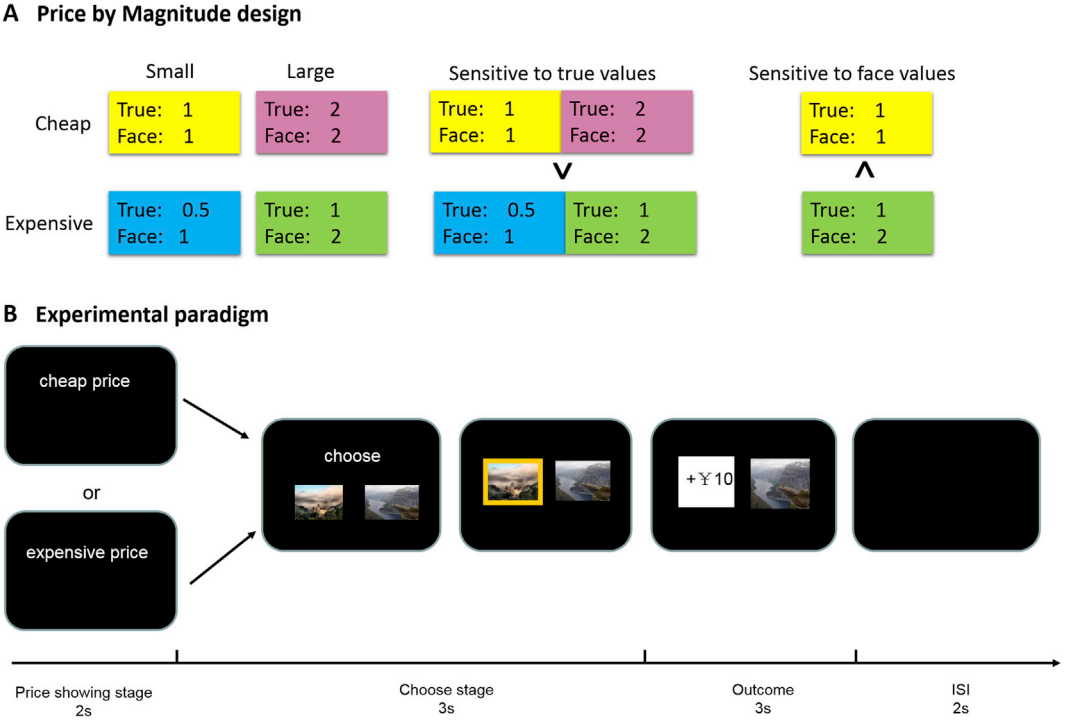

Fig. 1. (A) Study design: price by magnitude of money won (lost). For the same magnitude in the cheap condition and expensive condition, the face value was identical but real purchasing power differed. For small magnitude in the cheap condition and large magnitude in the expensive condition, the true value was identical, but the face value differed. (B) Experimental paradigm. At the beginning of each trial, the cheap price or the expensive price context information was shown. Then participants performed a simple gambling game in which they won (lost) a large or a small magnitude of money based on unpredictable outcomes.