The medial prefrontal cortex exhibits money illusion

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Behavioral economists have proposed that money illusion, which is a deviation from rationality in which individuals engage in nominal evaluation, can explain a wide range of important economic and social phenomena. This proposition stands in sharp contrast to the standard economic assumption of rationality that requires individuals to judge the value of money only on the basis of the bundle of goods that it can buy—its real value—and not on the basis of the actual amount of currency—its nominal value. We used fMRI to investigate whether the brain's reward circuitry exhibits money illusion. Subjects received prizes in 2 different experimental conditions that were identical in real economic terms, but differed in nominal terms. Thus, in the absence of money illusion there should be no differences in activation in reward-related brain areas. In contrast, we found that areas of the ventromedial prefrontal cortex (vmPFC), which have been previously associated with the processing of anticipatory and experienced rewards, and the valuation of goods, exhibited money illusion. We also found that the amount of money illusion exhibited by the vmPFC was correlated with the amount of money illusion exhibited in the evaluation of economic transactions.

neuroeconomics | ventromedial prefrontal cortex

Intuitively, money illusion implies that an increase in income is valued positively, even when prices go up by the same amount, leaving real purchasing power unchanged (1). In this sense money illusion has been interpreted "as a bias in the assessment of the real value of economic transactions, induced by a nominal evaluation" (2). Economists have traditionally been skeptical about the notion of money illusion (3), but recent behavioral evidence has challenged this view (2, 4–6). For example, when asked to rate the happiness of 2 otherwise identical persons who received either a 2% wage increase without inflation or a 5% wage increase with 4% inflation, the majority of subjects attribute happiness on the basis of greater nominal raises, despite lower real raises (2). A limitation of these studies, however, is that the researchers could not directly observe the cognitive processes that give rise to money illusion and were able to infer only indirectly its presence from its effects on behavior. As a consequence, much of the evidence that has been put forward in favor of money illusion is also consistent with alternative rational explanations (1).

In this study we sidestep this problem by using functional magnetic resonance imaging (fMRI) to test the hypothesis that parts of the brain's reward evaluation circuitry, which are known to play a critical role in decision making and learning, exhibit money illusion. To do so we compared blood oxygen level-dependent (BOLD) activity in response to earned incomes that differed in nominal terms, but that were identical in real terms. In the experiment, 24 subjects earned money in a simple estimation task (Fig. 1). At the end of the experiment subjects spent their income purchasing goods displayed in catalogs. There were 2 conditions: In the high-price condition incomes and catalog prices were 50% higher than in the second, low-price condition. Except for the different prices the catalogs were completely identical in both conditions. Thus, real purchasing power was identical in the low- and the high-price conditions, but nominal incomes differed by 50%. Conditions alternated every

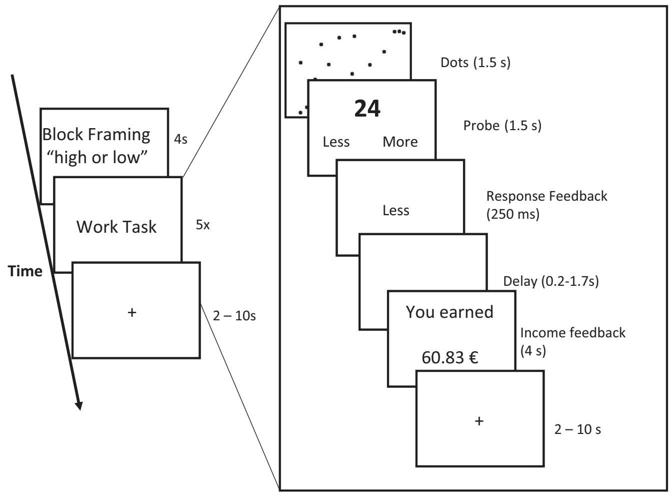

Fig. 1. Diagram of the experimental design. Subjects were informed whether they were in the high- or the low-price condition for the next block of 5 trials. Subjects then saw a number of blue dots for 1.5 s. A number was then presented and subjects had to decide within 1.5 s whether the number of dots on the first screen had been lower or higher. After a response feedback and a short delay, an income screen informed subjects about their monetary reward for the trial.

5 trials and subjects always knew which condition they were in. Furthermore, subjects were extensively familiarized with the prices at which they could purchase goods in both the high- and the low-price conditions before the fMRI task (see *Methods* below for details).

Our main hypothesis was that areas of the brain that are engaged in the experiencing of rewards (7–9), such as the ventromedial prefrontal cortex (vmPFC), would exhibit money illusion in the sense of exhibiting a stronger BOLD response for incomes that were higher in nominal terms, but had an identical real value. Activity in these brain regions has been shown to be modulated by the receipt of both primary rewards such as food delivery (10) and more abstract forms of rewards like monetary incentives (9, 11, 12). Recent neuroimaging studies have also shown that the vmPFC is involved in the valuation of goods at the time of decision making (13–15).

Subjects solved the estimation task correctly in 92.94% (SD = 0.06) of the trials in the high-price condition and in 92.33% (SD = 0.06) of the trials in the low-price condition. Performance between both conditions did not differ significantly ($P = 0.682$). Mean incomes earned (in real values) during the high- and low-price conditions were €75.46 (SD = 1.32) and €75.32 (SD = 1.34), respectively ($P = 0.645$).

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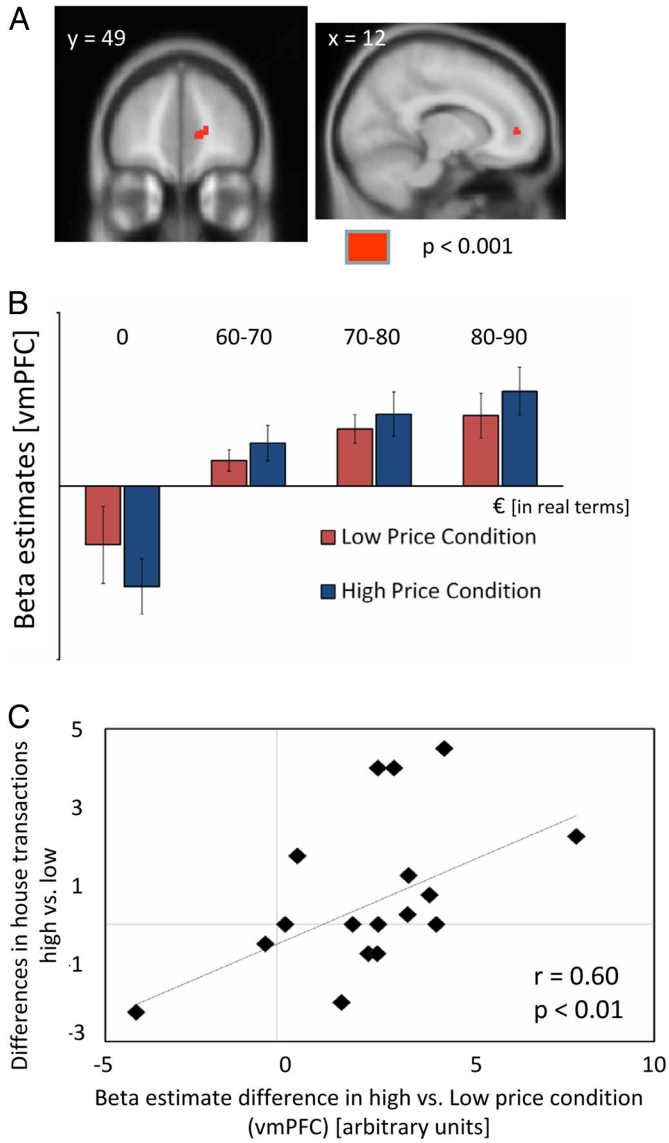

Fig. 2. Results from the fMRI experiment. (*A*) The vmPFC exhibited a stronger BOLD response to income feedback in the high-price than in the low-price condition (12/47/0; $P < 0.001$ uncorrected; 10-voxel-extent threshold). (*B*) Beta estimates for the vmPFC at income feedback for different real income bins during high- and low-price conditions. Joint paired *t* test for real vs. nominal incomes. $P < 0.05$. (*C*) Cross-subject correlation between a neural measure of money illusion (given by the difference in vmPFC activation at income feedback between the high- and the low-price conditions) and a questionnaire measure of money illusion (given by responses to hypothetical economic transactions involving house purchases). $r = 0.60$, $P < 0.01$.

A contrast of BOLD responses between the high- and the low-price conditions at the time of the income feedback showed significantly increased activity within the vmPFC (12/47/0; $P < 0.001$ uncorrected; 10-voxel extent threshold) (Fig. 2*A*; see *Methods* for details) during the high-price trials. Furthermore, as Fig. 2*B* shows, vmPFC activation increased with income in both conditions, but was always higher in the high-price compared to the low-price condition for given positive real incomes (joint paired *t* test, $P < 0.05$). This result means that reward activation generally increased with income (16), but was significantly higher in situations where nominal incomes and prices were both 50% higher, which supports the hypothesis that activity in the vmPFC is subject to money illusion.

Additional support for the economic significance of our findings comes from a postexperimental questionnaire based on Shafir et al. (2). We asked subjects to rate the economic advantageousness of a series of economic situations in which a person bought a house and sold it 1 year later. Similar to our experimental setup there was a high-price and a low-price version for each level of real change. For example, the house could be sold for 23% above buying price when inflation was 25% (high) or for 1% below when inflation was 1% (low), both implying a real loss of 2%. We constructed a measure of money illusion on the basis of whether subjects rated the first situation as more advantageous than the second. This measure was highly correlated with the activation difference in the vmPFC (Spearman's $r = 0.60$, $P < 0.01$) [Fig. 2*C*; for further results concerning the potential interaction between money illusion and loss aversion see supporting information (SI) Table S1], suggesting that the amount of money illusion in the vmPFC might affect economic evaluations in a systematic way.

The findings in this paper suggest that money illusion is real in the sense that the level of reward-related brain activity in the vmPFC in response to monetary prizes increases with nominal changes that have no consequence for subjects' real purchasing power. The importance of this finding derives from the fact that the answer to many classic economic problems depends on whether money illusion exists. For example, money illusion has been put forward as an explanation for the nonneutrality of money, which implies that central banks can affect production, investment, and consumption through changes in monetary policy that have an impact on the inflation rate. Likewise it offers an explanation for the important phenomenon that wages and prices are often downwardly rigid, a leading explanation for involuntary unemployment (17, 18). It is also a potential cause of bubbles in important markets, such as the housing market (19), and of deviations of stock prices from their fundamental values (20, 21). At the firm level, money illusion is important to determine optimal wage policies, which depend much on whether workers care about nominal or real wages (22). Finally, the existence of money illusion is important for the understanding of the relation between income, inflation, and subjective well-being (23). Importantly, even small amounts of money illusion can have substantial effects: This impact is nicely demonstrated in a series of laboratory experiments, showing that small deviations from rationality imply big and lasting effects in aggregate outcomes (4, 24). The results of the current experiment are complementary to these behavioral studies. Although the latter show that pure nominal changes can lead to behavioral responses, they had to assume that money illusion was indeed induced by the experimental manipulation. In contrast, the current experiment does not lead to behavioral changes, but instead provides a more direct neurophysiological account for the existence of money illusion. The combination of findings from both approaches provides a strong case for the importance of money illusion.

Methods

Subjects. Twenty-four subjects (SD = 3 years, range 21–32 years) without any history of neurological or psychiatric disease participated in the study. Two subjects had to be excluded from the analysis because of scanner dysfunction and 4 because of excessive head movement. All subjects were right-handed according to the Edinburgh Handedness Scale and gave written informed consent before the study.

Task. Subjects performed 200 trials of a simple work task described in Fig. 1. The task involved estimating the number of dots on a screen. At the end of each trial, subjects received feedback about their performance and income for the trial. Incorrect guesses always led to an income of zero and correct ones to a positive income.

The critical idea of the experiment was to create 2 conditions, which were identical in real income terms, but that differed in their nominal representations. To this end subjects did not earn their income in cash but had to spend it on a large but fixed menu of items. We created 2 catalogs with 120 items including books, CDs, DVDs, sports articles, cosmetics, consumer electronics, and outdoor equipment. The catalogs were identical with the exception that all prices were 50% higher in one catalog (high-price condition). The broad range of goods ensured that our mode of paying subjects did not differ too much from paying them in cash. Prices in the catalog with the lower prices (low-price condition) ranged from €5.99 (sun screen) to €89.99 (external hard drive).

To keep real purchasing power constant between the 2 conditions incomes were generated in the following way. First, we randomly generated a potential real income (obtained by the subjects conditional on solving the task correctly) for each trial in the low-price condition in the interval between €60 and €90. For each income in the low-price condition we constructed a high-price trial in which income was exactly 50% higher. Note that in the trials for which prices were 50% higher, incomes were also 50% higher; i.e., real purchasing power was identical in the low- and high-price conditions, respectively. High- and low-price trials were alternated in blocks of 5 trials each, which were preceded by a screen specifying the purchase catalog that applied to those trials.

Before subjects entered the scanner they read the instructions for the experiment and were given the opportunity to familiarize themselves with the 2 catalogs for 10 min. Then they were asked to answer several control questions to make sure that they had understood the difference between the 2 catalogs; e.g., subjects were asked how much an item with price *p* in the catalog with the lower prices would cost in the catalog with the higher prices.

On leaving the scanner, subjects rolled a dice to determine which trial was selected for actual payment. Afterward they answered a questionnaire and made their selection from the catalog with the low or high prices (depending on which trial had been selected). The chosen items were mailed directly to the subjects. All shipping costs were borne by the experimenters.

fMRI Data Acquisition. Scanning was performed on a 3-Tesla (T) Trio Scanner (Siemens), by using a standard 8-channel head coil. Slices were in axial orientation and covered all of the brain including the midbrain but not the entire cerebellum. Scan parameters were as follows: slice thickness, 2 mm; interslice gap, 1 mm; matrix size, 128 × 128; field of view, 230 × 230 mm; echo time (TE), 33 ms; repetition time (TR), 2.5 s. The scanning was performed in 2 sessions with 100 trials each for ≈25 min each, resulting in an overall scanning time of ≈50 min and ≈1,200 scans.

fMRI Data Preprocessing. fMRI data analysis was performed by using Statistical Parametric Mapping 5 (SPM5, www.fil.ion.ucl.ac.uk/spm/). For preprocessing, functional images were realigned to the first image of the first session of each time series and again realigned to the mean image after first realignment. Images were then slice-timed by using a sync interpolation, normalized to the canonical EPI template used in SPM5, and smoothed with an 8-mm Gaussian kernel. After normalization images were resampled to a voxel size of 3 × 3 × 3 mm.

fMRI Model 1. The model was estimated in 3 steps. First, for every subject we estimated a general linear model with autoregressive order 1 [AR(1)] and the following regressors (R):

(R1) @ work task during high-price condition.

(R2) @ income screen during high-price condition.

(R3) @ income screen during high-price condition modulated by binned real income (bin values were 0, 6, 7, and 8, indicating, respectively, incomes of €0, €60–€70, €70–€80, and €80–€90).

(R4) @ income screen during high-price condition modulated by prediction error for the trial.

(R5) @ work task during low-price condition.

(R6) @ income screen during low-price condition.

(R7) @ income screen during low-price condition modulated by binned real income.

(R8) @ income screen during low-price condition modulated by prediction error for the trial.

The prediction error in any trial equals the real income for that trial minus a weighted sum of the real payoffs received in all previous trials,

$$PE_t = I_t - E_t$$

$$E_{t+1} = E_t + \delta * PE_t$$

where *PE* is prediction error, *I* is actual income in the given trial, *E* is expected income for the trial, and δ is the learning factor (which was set at 0.3). All monetary variables were measured in real values. All of the regressors were modeled as a boxcar function with a duration equal to that event and were convolved with a canonical hemodynamic response before estimation of the general linear model (GLM). We also included a session constant and 6 motion parameters of no interest.

Second, for each subject we calculated the following first-level contrasts (C):

(C1) @ income screen during the high-price condition minus at income screen during the low-price condition (R2–R6).

(C2) @ income screen modulated by binned real income in high- minus low-price trials.

(C3) @ income screen modulated by prediction error in high- minus low-price trials.

Finally, the estimates on the individual level for each subject were entered into a second-level random-effects analysis, by using one-sample *t* tests on the individual contrast statistics.

The results of these 3 contrasts are depicted in Table S2. The result of contrast 1 is also depicted in Fig. 2*A*. Anatomical localizations were then performed by overlaying the *t* maps on an average anatomical image and with reference to an anatomical atlas.

Fig. 2*C* uses the value of the contrast R2–R6 as the measure of individual neural money illusion.

fMRI Model 2. To compute the statistics reported in Fig. 2*B* we computed a second GLM with AR(1) and the following regressors:

(R1) @ work task (high price).

(R2) @ income and income = €0 (high price).

(R3) @ income and income = €60–€70 (high price).

(R4) @ income and income = €70–€80 (high price).

(R5) @ income and income = €80–€90 (high price).

(R6) @ work task (low price).

(R7) @ income and income = €0 (low price).

(R8) @ income and income = €60–€70 (low price).

(R9) @ income and income = €70–€80 (low price).

(R10) @ income and income = €80–€90 (low price).

Omitted details for this second analysis were identical to those for the first model.

The results of this model were used to extract individual beta estimates for the different income bins at the voxels of peak activation (contrast 1, model 1) for each subject within the region depicted in Fig. 2*A*. Fig. 2*B* then plots the average beta values across subjects for R2–R5 and R7–R10.

Questionnaire Data. Subjects rated the economic advantageousness of a series of 8 economic scenarios on a scale from 1 (not advantageous at all) to 15 (very advantageous) within a time limit of 20 s. The exact wording of the question was as follows: ''Albert buys a house for €200,000. A year later he sells the house again. In this year inflation was X%—all prices increased by ≈X%. Albert received Y euros for the house (Z% more than he paid for it). How advantageous do you think this transaction was? (1, not advantageous at all; 15, very advantageous).'' The question, taken from ref. 1, contained information on (nominal) buying and selling prices for a house and the rate of inflation. The buying price was the same for all scenarios. Selling price and inflation varied to imply 4 different percentage levels of real change (−2, −1, 2, 5). There was a high-inflation and a low-inflation representation for each level of real change. For example, for a real change of −2%, the parameters for the question above in the low-inflation representation were $X = 1$, $Y = 198{,}000$, and $Z = -1$, and in the high-inflation representation they were $X = 25$, $Y = 154{,}000$, and $Z = 23$.

We constructed a measure of individual money illusion (used in Fig. 2*C*) by taking the individual average of the differences in ratings for a particular level of real change in the high- vs. low-inflation representation.

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