

The medial prefrontal cortex exhibits money illusion

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Abstract. Human perception of the value of money affects economic decisions and outcomes at all levels. Rationality postulates that individuals should judge the value of money based only on the bundle of goods that it can buy— its real value – and not on the actual amount of currency – its nominal value. 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. Examples include the rigidity of wages and unemployment, housing market bubbles, and the deviation of stock prices from their fundamental values. The existence of money illusion is a highly controversial issue in economics and next to nothing is known about why individuals might engage in this irrational behavior. We used functional magnetic resonance imaging (fMRI) to investigate the properties of neural decision-making mechanisms that might be responsible for this phenomenon. We found that areas of the medial prefrontal cortex (mPFC), which have been previously associated with the processing of anticipatory and experienced rewards, exhibited money illusion. We also found that the amount of money illusion exhibited by the mPFC was correlated with the amount of money illusion exhibited in the evaluation of real economic transactions.

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 discredited the notion of money illusion (3), but recent behavioral evidence has challenged this view (2,4,5,6). For example, when asked to rate the happiness of two otherwise identical persons who either received a wage increase of 2 percent without inflation, or a 5 percent wage increase with four percent 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 only able to indirectly infer 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 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 BOLD activity in response to earned incomes that differed in nominal terms, but which were identical in real terms. In the experiment, 24 subjects earned money in a simple estimation task (Figure 1). At the end of the experiment subjects spent their income purchasing goods displayed in catalogues. There were two conditions: in the high price condition incomes and catalogue prices were 50 percent higher than in the second, low price, condition. Identical goods were sold in both conditions. Thus, real purchasing power was identical in the low and the high price condition, but nominal incomes differed by 50 percent. Conditions alternated every five 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 prior to the fMRI task (see Methods section below for details).

Our main hypothesis was that areas of the brain that are engaged in the experiencing of rewards (8,9,10), such as the medial prefrontal cortex (mPFC), 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 (7) as well as more abstract forms of rewards like monetary incentives (11,12,13).

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

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 mPFC (12/47/0; $p<.001$ unc.; 10 voxel extent-threshold; Fig. 2A; see Methods for details) during the high price trials. Furthermore, as Figure 2B shows, mPFC activation increased with income in both conditions, but was always higher in the high compared to the low price condition for given positive real incomes (joint paired t-test $p<0.05$). This means that reward activation generally increased with income (13), but was significantly higher in situations where nominal incomes and prices were both 50 percent higher, which supports the hypothesis that activity in the mPFC is subject to money illusion.

Additional support for the economic significance of our findings comes from a post-experimental 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 one year later. Similar to our experimental set-up 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 behavioral measure of money illusion based on whether subjects rated the first situation as more advantageous than the second. This measure was highly correlated with the activation difference in the mPFC (Fig 2C; Spearman $r=0.60$, $p<0.01$), suggesting that the amount of money illusion in the mPFC 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 mPFC 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 non-neutrality 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 (14,15). It is also a potential cause of bubbles in important markets, such as the housing market (16) and of deviations of stock prices from their fundamental values (17,18). 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 (19). Finally, the existence of money illusion is important for the understanding of the relation between income, inflation and subjective well-being (20). Importantly, even small amounts of money illusion can have substantial effects: This is nicely demonstrated in a series of laboratory experiments, showing that small deviations from rationality imply big and lasting effects in aggregate outcomes (4,21).

By providing neuroeconomic evidence for the existence of monetary illusion in the brain's reward circuitry, our results advance our understanding of the psychological and neural underpinnings of this phenomenon. Future advances in our understanding of what causes money illusion could aid in the development of strategies that help consumers to act more rationally and efficiently in their daily decision-making.

Methods

Subjects. 24 subjects (SD 3 years, range 21 - 32 years) without any history of neurological or psychiatric disease participated in the study. 2 subjects had to be excluded from the analysis due to scanner dysfunction and 4 due to excessive head movement. All

subjects were right-handed according to the Edinburgh Handedness Scale and gave written informed consent prior to 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 lead to an income of zero and correct ones to a positive income.

The critical idea of the experiment was to create two 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 two catalogues with 120 items including books, CDs, DVDs, sports articles, cosmetics, consumer electronics and outdoor equipment. The catalogues were identical with the exception that all prices were 50% higher in one catalogue (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 catalogue with the lower prices (low price condition) ranged from 5.99 (sun screen) to 89.99 Euro (external hard drive).

To keep real purchasing power constant between the two 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 Euro. 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 condition, respectively. High and low price trials were alternated in blocks of five trials each, which were preceded by a screen specifying the purchase catalogue 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 two catalogues for 10 minutes. Then they were asked to answer several control questions to make sure that they had understood the difference between the two catalogues, e.g., subjects were asked how

much an item with price p in the catalogue with the lower prices would cost in the catalogue with the higher prices.

Upon leaving the scanner subjects rolled a dice to determine which trial was selected for actual payment. Afterwards they answered a questionnaire and made their selection from the catalogue 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, Erlangen, Germany) 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: Slice thickness: 2 mm; interslice gap 1 mm; matrix size: 128x128; field of view: 230 x 230 mm; echo time (TE): 33 ms; repetition time (TR): 2.5 s. The scanning was performed in two sessions with 100 trials each for ~25 minutes each resulting in an overall scanning time of ~50 minutes and ~1200 scans.

FMRI data preprocessing. FMRI data analysis was performed 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 using a sinc interpolation, normalized to the canonical EPI template used in SPM5 and smoothed with an 8mm Gaussian Kernel. After normalization images were re-sampled to a voxel size of 3x3x3mm.

FMRI model 1. The model was estimated in three steps. First, for every subject we estimated a general linear model with AR(1) and the following regressors:

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=Prediction Error; I = actual income in the given trial; E =expected income for the trial; and δ =learning factor (which was set at 0.3). All monetary variables were measured in real values. All of the regressors were modeled as a box-car function with a duration equal to that event and were convolved with a canonical hemodynamic response prior to estimation of the GLM. We also included a session constant and six motion parameters of no interest.

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

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 subjects were entered into a 2nd level random effects analysis using one-sample t tests on the individual contrast statistics.

The results of these three contrasts are depicted in Table S1. The result of Contrast 1 is also depicted in Figure 2A. Anatomical localizations were then performed by overlaying the *t* maps on an average anatomical image, and with reference to an anatomical atlas.

Figure 2C uses the value of the contrast R2-R6 as the measure of individual neural money illusion.

FMRI model 2. In order to compute the statistics reported in Figure 2B we computed a second GLM model with AR(1) and the following regressors:

- R1) @Work Task (high price)
- R2) @Income & income=0 €(high price)
- R3) @Income & income=60-70 €(high price)
- R4) @Income & income=70-80 €(high price)
- R5) @Income & income=80-90 €(high price)
- R6) @Work Task (low price)
- R7) @Income & income=0 €(low price)
- R8) @Income & income=60-70 €(low price)
- R9) @Income & income=70-80 €(low price)
- R10) @Income & 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 for each subject within the region depicted in Figure 2A. Figure 2B then plots the average beta values across subjects for R2 to R5 and R7 to R10.

Questionnaire Data. Subjects rated the economic advantageousness of a series of eight economic situations on a scale from 1 (not advantageous at all) to 15 (very advantageous) within a time limit of 20s. The exact wording of the question was:

Albert buys a house for 200,000 Euro. A year later he sells the house again. In this year inflation was X % - all prices increased by approximately X%. Albert received Y Euro 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 (1), thus contained information on (nominal) buying and selling prices for a house and the rate of inflation. The buying price was the same for all situations. Selling price and inflation varied to imply four different percentage levels of real change (-2, -1, 2, 5). There was a high inflation and a low inflation version for each level of real change. For example, for a real change of -2% the parameters for the question above in the low inflation condition were X=1, Y=198,000 and Z=-1, and in the high inflation frame they were X=25, Y=154,000 and Z=23.

We constructed a measure of individual money illusion (used in Figure 2C) by taking the individual average of the differences in ratings for a particular level of real change in the high versus low inflation frame.

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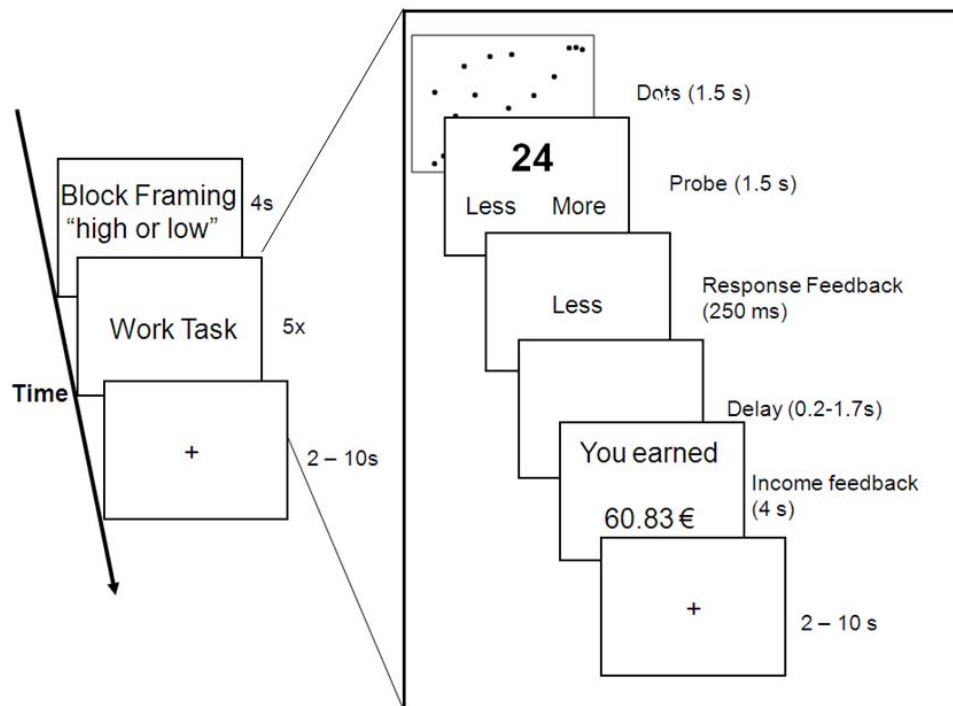


Fig.1 Diagram of the experimental design. Subjects were informed whether they were in the high or low price condition for the next block of five trials. They then saw a number of blue dots for 1.5 s. A number was then presented and subjects had to decide within 1.5s whether the number of dots on the 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.

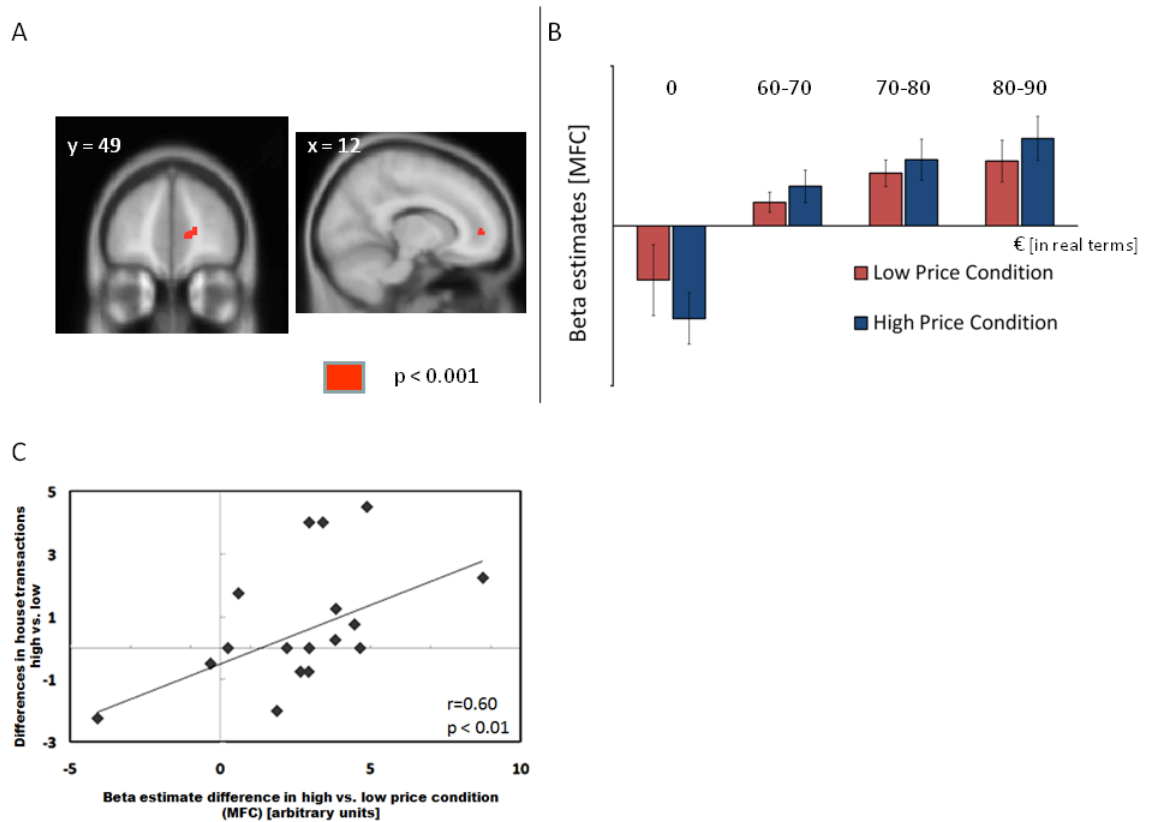


Fig. 2 (A) The mPFC exhibited a stronger BOLD response to income feedback in the high than in the low condition (12/47/0; $p < .001$ unc; 10 voxel extent-threshold). (B) Beta estimates for the mPFC at income feedback for different real income bins during high and low conditions. Joint paired t-test for real versus nominal incomes $p < 0.05$. (C) Cross-subject correlations between a neural measure of money illusion (given by the difference in mPFC activation at income feedback between the high and low conditions) and a behavioral measure of money illusion (given by responses to hypothetical economic transactions involving house purchases). $r = 0.60$, $p < 0.01$.