

Orbitofrontal cortex encodes willingness-to-pay in everyday economic transactions

SUPPLEMENTARY MATERIALS

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These supplementary materials report the details of several contrasts briefly mentioned in the main text. An Appendix with the experimental instructions is also included.

A. Free bid trials vs. forced bid trials while exposed to item (Regressors R1 vs R3)

Using a whole brain analysis we identified areas that showed more activation while exposed to food pictures in free trials than in forced bid trials. Supplementary Table 1.A lists the results of this contrast and Supplementary Figures 1.A and 1.B provide images of some of the areas of interest. Supplementary Figures 1.C and 1.D compare the hemodynamic response to item presentation in free and forced trials for the voxels with maximal response in the lateral and medial OFC.

Since it is the case that subjects need to compute their WTP in free bid trials, but not in forced bid trials, some of the areas identified by this contrast are likely to be involved in the computation of economic values. However, since it may be the case that the brain pays more attention to the stimuli in free bid trials than in forced bid trials, some of these areas might be related to attention and not to the computation of WTP per se. Our experiment cannot disentangle these two possible interpretations.

Supplementary Table 1.B lists the areas that showed more activation in forced bid trials than in free bid trials while exposed to the item.

B. Free bid trials vs. forced bid trials at response (Regressors R2 vs. R4)

Using a whole brain analysis we identified areas that showed more activation at response in free trials than in forced bid trials. See Supplementary Table 2.A and Supplementary Figure 2 for the results. It is natural to speculate that some of these areas *might be*

involved in the execution of voluntary actions as opposed to actions that involve following external commands.

Supplementary Table 2.B lists the areas that showed more activation in forced bid trials than in free bid trials at response.

C. Modulation by surplus₊ and surplus₋ during free and forced bid trials when exposed to items (Regressors M2, M6 and M7)

No areas showed modulation by surplus₊ or surplus₋ in either free or forced bid while exposed to the item at a level of $p < 0.001$ uncorrected and an extent threshold of 10 voxels.

We conjecture that the reason no significant effects were found in the surplus contrast is that whereas following the optimal strategy is straightforward, the computation of surplus in the BDM auction is complicated. As a result, subjects might not have computed the surplus correctly. In particular, during the instruction period we emphasized that the best strategy in the auction was to bid the amount closest to their true value. Debriefing data during piloting showed 100% compliance with the optimal strategy. This might have led some subjects to follow an incorrect heuristic for the computation of surplus in which they believed that, since they were bidding their entire true value, their surplus from the transaction must be zero. This heuristic would explain the lack of observed activation.

To appreciate the complexity of the correct surplus computation, consider, for example, the case of a free bid trial in which the subject's WTP for the item is \$3, and he bids \$3. The surplus is given by

$$0.25 * (3 - 0) + 0.25 * (3 - 1) + 0.25 * (3 - 2) + 0 = 1.5,$$

where the first term equals the net value of the transaction if the random number is zero and thus the subject gets the item at a price of zero, the second term equals the net value of the transaction if the random number is 1, etc.

D. Modulation by WTP during free trials at the time of response (Regressor M3)

No areas showed modulation by WTP in the free bid trials at the time of bidding at a level of $p < 0.001$ uncorrected and an extent threshold of 10 voxels.

**E. Modulation by WTP during forced bid trials at the time of response
(Regressor M8)**

No areas showed modulation by WTP in the forced bid trials at the time of bidding at a level of $p < 0.001$ uncorrected and an extent threshold of 10 voxels.

**F. Modulation by surplus₊ and surplus₋ during free and forced bid trials at the time of response
(Regressors M4, M9 and M10)**

No areas showed modulation by surplus₊ or surplus₋ in either free or forced bid trials at the time of bidding at a level of $p < 0.001$ uncorrected and an extent threshold of 10 voxels.

G. Identifying the neural correlates of the forced bid modulator during forced bid trials

To perform this exercise we estimated a general linear model that is identical to the one described in the main text, except that the forced bid trials at picture presentation regressor was modulated by the size of the forced bid instead of by WTP. No areas showed modulation by the forced bid in forced bid trials at the time of picture presentation at a level of $p < 0.001$ uncorrected and an extent threshold of 10 voxels.

H. Identifying the neural correlates of the ‘forced bids – WTP’ modulator during forced bid trials

To perform this exercise we estimated a general linear model that is identical to the one described in the main text, except that ‘forced bid – WTP’ was added as an additional modulator to the forced bid at picture presentation regressor. No areas showed modulation by ‘forced bid – WTP’ in forced bid trials at the time of picture presentation at a level of $p < 0.001$ uncorrected and an extent threshold of 10 voxels.

Table S1. (A) Areas showing more activation in free bid trials than forced bid trials when exposed to the item. **(B)** Areas showing more activation in forced bid trials than in free bid trials when exposed to the item.

Talairach-coordinate (x, y, z)	Region	Side	BA	Z
6, 23, -8	rostral anterior cingulate cortex	R	32	5.24*
6, 25, -11	medial frontal gyrus, VMPFC/anterior medial OFC	R	11	4.53*
4, 38, -20	orbital gyrus, caudal mOFC	R	11	4.50*
-26, 30, -12 30, 28, -15	inferior frontal gyrus, caudal IOFC	L/R	47	4.49*
16, -4, 8	lentiform nucleus	R		4.28*
2 -14 -18	brainstem, midbrain	L/R		4.60*
8, -52, 17	posterior cingulate cortex	R	30	4.10*
3, 39, 15	dorsal anterior cingulate cortex	R	32	4.07*
-8, -4, -7 8, -6, -3	hypothalamus	L/R		3.99*
48, 32, 13	inferior frontal gyrus, DLPFC	R	46	3.90*
-12, 18, 5	dorsal striatum, caudate nucleus	L		3.83
-4, 7, 27 4, 1, 26	cingulate gyrus	L/R	24	3.79*
24, -89, -8	middle occipital gyrus	R	18	3.78*

Height threshold: $T = 3.61$, $p = 0.001$

Extent threshold: $k = 10$ voxels

*indicates that regions survived FDR corrections $p < 0.05$

Talairach-coordinate (x, y, z)	Region	Side	BA	Z
-62, -37, 20 58, 37, 22	superior temporal gyrus	L/R	42	4.82*
-10, -58, -1 10, -57, -1	lingual gyrus	L/R	19	3.84*

Height threshold: $T = 3.61$, $p = 0.001$

Extent threshold: $k = 10$ voxels

*indicates that regions survived FDR corrections $p < 0.05$

Table S2. (A) Areas showing more activation at the time of bidding in free bid trials than in forced bid trials **(B)** Areas showing more activation at the time of bidding in forced bid trials than in free bid trials

A

Talairach-coordinate (x, y, z)	Region	Side	BA	Z
-2, -26, 33	cingulate gyrus	L/R	23	4.72*
6, -69, -20	cerebellum, posterior lobe, declive	R		4.44*
26, -67, -19				3.62*
-48, 41, 13	inferior frontal gyrus	L	46	4.16*
-32, 60, 16	middle frontal gyrus, lateral PFC	L/R	10	4.11*
22, 4, -7	ventral striatum, putamen	R		4.04*
-4, 32, 22	dorsal anterior cingulate cortex	L/R	32	3.91*
4, 32, 24				
-8, 6, 0	dorsal striatum, caudate nucleus	L		3.87*
26, 52, 42	superior frontal gyrus	R	9	3.82*
-4, -21, 7	thalamus, medial dorsal nucleus	L		3.81*
14, -2, 2	lateral global pallidus	R		3.80*
-45, 9, 50	middle frontal gyrus	L	6	3.67*
-8, -6, -5	hypothalamus	L		3.37*

Height threshold: $T = 3.61$, $p = 0.001$ (unc.)

Extent threshold: $k = 10$ voxels

*indicates that regions survived FDR corrections $p < 0.05$

B

Talairach-coordinate (x, y, z)	Region of activation	Side	BA	Z
-40, -6, -9	temporal lobe, sub-gyral	L	21	3.34*

Height threshold: $T = 3.61$, $p = 0.001$

Extent threshold: $k = 10$ voxels

*indicates that regions survived FDR corrections $p < 0.05$

Figure S1. Areas showing more activation in free bid trials than forced bid trials when exposed to the item. (A) Lateral orbitofrontal cortex. (B) Medial orbitofrontal cortex. (C) Time course of the hemodynamic response in the lateral OFC for free and forced bid trials. (D) Time course of the hemodynamic response in the medial OFC for free and forced bid trials (error bars denote s.e.).

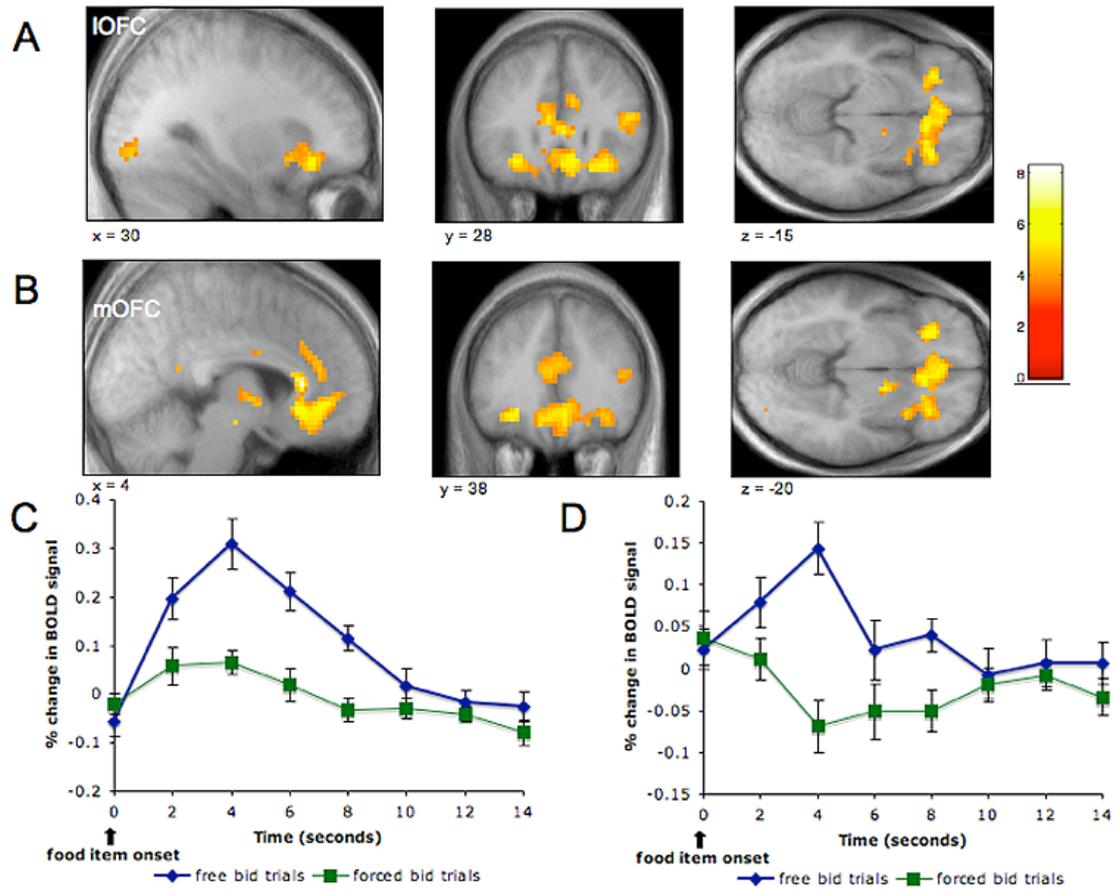
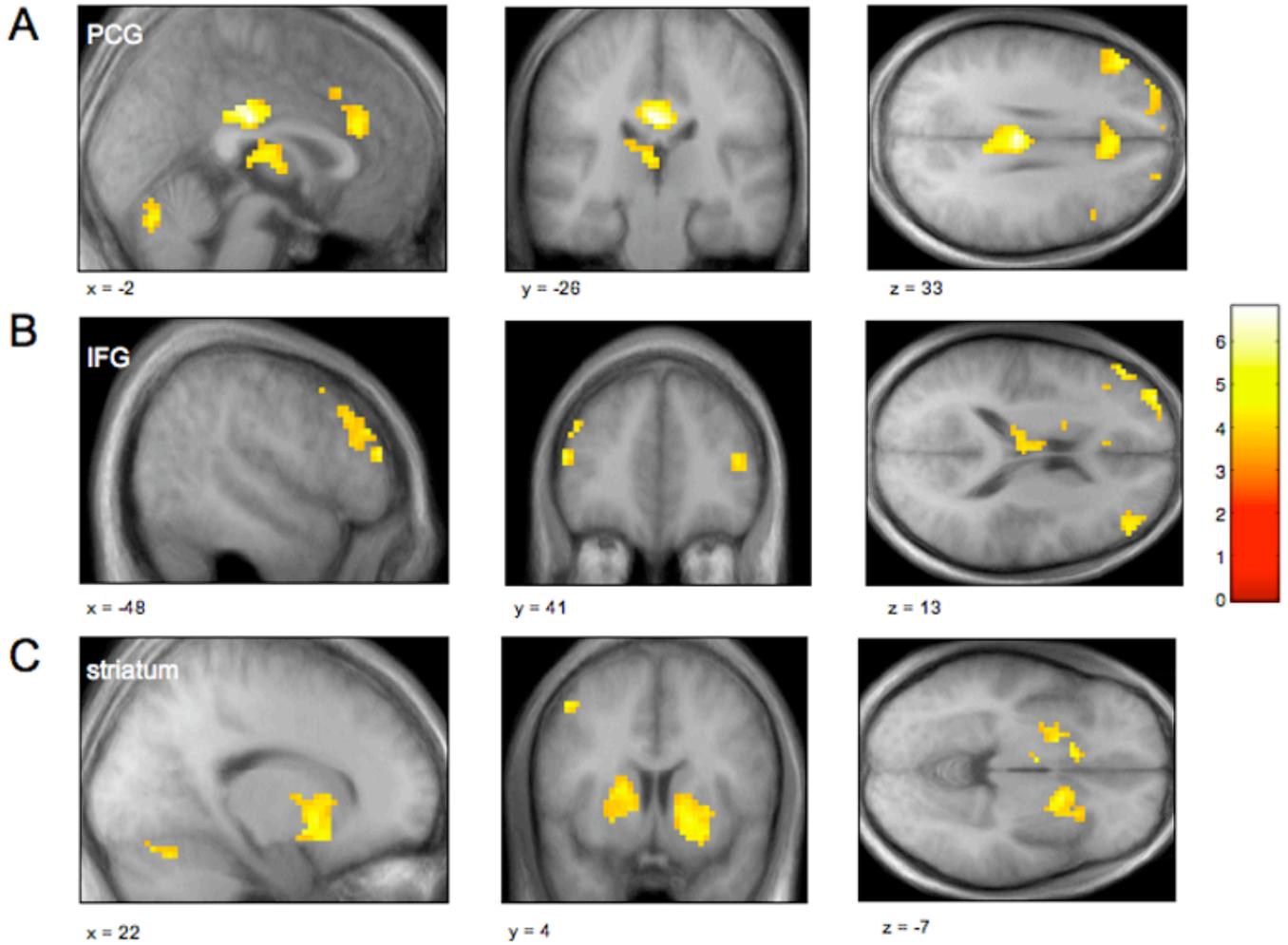


Figure S2. Areas showing more activation at the time of bidding in free bid trials than in forced bid trials. (A) Posterior cingulate gyrus. (B) Inferior frontal gyrus. (C) Dorsal and ventral striatum (crosshair points at putamen in ventral striatum).



Appendix – Instructions

The goal of this experiment is to study food preferences. The next few screens provide detailed instructions about the experiment.

By agreeing to participate, you have already earned a show-up fee of \$35 dollars.

It is very important that you understand the instructions, since additional rewards from participating in the experiment will depend on your ability to make good decisions.

At the end of the experiment, about 60 minutes from now, we will ask you to sit in an adjacent room for another 30 minutes. During this time you can read a magazine or any other materials that you might have brought with you.

In addition, you will be given the opportunity to have a snack during this time. However, the only food that you will be allowed to eat is whatever snack you buy from us during the experiment.

Next to your computer station is an envelope with 3 one-dollar bills. During the experiment you will be allowed to use this money to buy a snack from us. In fact, we would like you to think of us as your own personal convenience store. Whatever money you do not spend is yours to keep.

How do you buy food from us?

During the experiment we will show you pictures of 50 different snacks, each one on a separate trial. After each presentation, you will be allowed to bid either \$0, \$1, \$2, or \$3 dollars for the item.

We will show you each picture twice.

Although you will make 100 decisions, on 50 different foods, you will be allowed to buy at most one food from us.

At the end of the experiment we will select a trial at random by picking a ball from an urn. That will be only trial that counts.

Since you don't know which trial it will be, you should treat every trial as if it were the only one.

In fact, as you will see in a moment, whenever given a choice the best thing you can do is to always bid the number that is CLOSEST to your true valuation for eating that food (and only that food) at the end of the experiment.

Forced vs. Free Bid Trials

The experiment is divided into two types of trials: “Free Bid” trials and “Forced Bid” Trials.

In Free Bid Trials you choose how much you want to bid for the food item. As you will see in a moment, your best strategy is to bid your true value for the item. In Free Bid Trials you will see a question mark below to the item

In contrast, in Forced Bid Trials we will tell you how much to bid and YOU HAVE NO CHOICE BUT TO BID THAT AMOUNT. In particular, in Forced Bid Trials you will see a number below to the item and you will HAVE TO bid that amount when the time to bid comes. In this case your decision is simpler and more mechanical: see the item, see the bid, and then bid that amount.

Note that the forced bids might be above or below your true value. In either case we ask you to enter that bid.

Importantly, both types of trials count towards the purchase decision. If a forced trial is selected at the end of the experiment, you will still get to play the auction described below, but your bid will be given by the amount of the “forced bid”.

About Free Bid Trials.

Note that, since we will only sell you at most one food, you do not have to worry about spreading your \$3 dollar budget over the different items. Every trial you should ask yourself how much of the \$3 dollars you want to spend in that food since it may be the only one that you are given a chance to buy.

In every auction there is a rule that determines the price at which the items are sold. This auction is no different.

The rule is a bit unusual, but its implications are straightforward. There is no way of gaming the auction, the BEST thing that you can do in every trial is to ask yourself how much you would be willing to pay to eat THAT item at the end of the experiment, and then bid the number closest to that value.

What is the rule? At the end of the experiment, after the trial that counts has been selected, you will choose a ball from an urn with four balls. The balls are marked \$0, \$1, \$2, and \$3.

If your bid is greater than the ball that you draw, you will get the snack for a price equal to the number in the ball.

If your bid is less or equal than the number that you draw, you will NOT get the snack, and won't have to pay anything.

Why is it in your interest to bid the number closest to your true value for eating the item at the end of the experiment?

You might think that your best strategy is to bid less than the item is worth to you. This is INCORRECT.

The price that you pay is determined by the ball that you draw and NOT by your bid. Thus, if you lower your bid you would not be able to affect the price that you pay, but might end up losing the opportunity to buy the item at a “good” price.

For example, suppose that having the chance to eat the snack at the end the experiment is worth \$2 for you. If you bid your true value, you will get the item if the ball is \$0, or \$1, and pay that price. You will not get the item if the ball is \$2, or \$3. It follows that by bidding your true value you make a “profit” since you always end up paying less than the item is worth to you.

Clearly, you should never bid more than your true value.

What happens if you bid less than your true value? For example, suppose that you bid \$0 even though your true value is \$2. In this case you never get the item, which is not a good strategy since, when you bid your true value, you always end up paying less than the item is worth to you!

Note another attractive property of the auction rules: conditional on getting the item (i.e., conditional on the number on the ball being less or equal to your bid), the price that you pay is on average half of your bid.

Thus, if you follow your best strategy and always bid the true value, on a typical Free Bid Trial you will get to buy the item at approximately half its true value!

Don't let the details of the experiment confuse you, Free Bid Trials are actually very simple:

1. You will make bids for purchasing a snack on 100 trials, but one of those trials will count.
2. You should treat each decision as if it were the only one.
3. Your best strategy is to always bid the number closest to your true value for eating that item, and only that item, at the end of the experiment.

4. If you follow the best strategy, on average the price that you pay for an item will be half of the value that it has for you.

About Forced Bid Trials

In this case things are even simpler: you are asked to bid the amount that we tell you to, regardless of whether or not this is a good deal for you. Look at the screen, notice the item and bid, and then enter that bid when the time comes.

Note that, as before, conditional on getting the item the expected price that you will pay is approximately half of the bid. Thus, for example, if you are asked to bid \$3, the average price conditional on getting the item is \$1.5.

Control

Do you have any questions relating to the instructions? If so, please ask the experimenter

If not please answer the following questions:

Imagine your true value is 2\$. Which amount should you bid?

- 1) 1\$
- 2) 2\$

Press 1 or 2 according to your answer

Under which of the following two conditions will you get the item?

- 1) When you bid 2\$ and a ball marked \$1 is drawn from the urn
- 2) When you bid 2\$ and a ball marked \$3 was drawn from the urn

Press 1 or 2 according to your answer

Reminder of instructions in scanner

Reminder:

1. You will make bids for purchasing a snack on 100 trials, but only one of those trials will count.
2. You should treat each decision as if it were the only one.
3. In the Free Bid Trials, your best strategy is to always bid the number closest to your true value for eating that item (and only that item) at the end of the experiment.
4. In Forced Bid Trials bid the number, which is shown below the item.