The Neural Basis of Loss Aversion in Decision-Making Under Risk

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People typically exhibit greater sensitivity to losses than to equivalent gains when making decisions. We used fMRI to investigate neural correlates of loss aversion while individuals decided whether to accept or reject gambles that offered a 50/50 chance of gaining or losing money. A broad set of areas (including midbrain dopaminergic regions and their targets) showed increasing activity as potential gains increased. Potential losses were represented by decreasing activity in several of these same gain-sensitive areas. Finally, individual differences in behavioral loss aversion were predicted by a measure of neural loss aversion in several regions including striatum and prefrontal cortex.

Symposia Summary

Deal or no Deal? The Neural Basis of Decision Utility and Loss Aversion During Consumer Decision-Making

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EXTENDED ABSTRACTS

"Neural Encoding of WTP Computation During Simple Purchasing Decisions"

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Over 43 trillion dollars in goods and services are exchanged every year in the world economy. An essential component of every marketplace transaction is a willingness-to-pay (WTP) computation in which consumers calculate the maximum amount of resources that they are willing to give up in exchange for the object being sold. This WTP is then used to evaluate whether a proposed purchasing offer is beneficial (e.g., when the WTP exceeds the price at which the product is being offered). Clearly, in order to make good purchasing decisions, individuals must be able to assign a WTP to an item that is commensurate to the utility that it will generate. Otherwise consumers would end up purchasing items for a price that exceeds their worth to them. Despite its pervasiveness and importance for consumer welfare, little is known about how the brain carries out the WTP computation in everyday transactions, or about how its ability to do so is affected by diseases such as addiction or obsessive compulsive disorders. This makes understanding how and where the brain makes these computations one of the most important open questions in the nascent field of Neuroeconomics (Camerer, Loewenstein, and Prelec, 2005).

Based on the results of several previous studies, we hypothesized that activity in the medial orbitofrontal cortex (mOFC) encodes WTP. Monkey electrophysiology studies of binary choice have found that activity in the OFC encodes the expected value of the chosen action (e.g. Padoa-Schioppa and Assad, 2006). Several fMRI studies have found analogous results in humans (e.g. Daw et al. 2006, Knutson et al. 2007, Tom et al., 2007). Although all of these studies suggest that the medial OFC plays a critical role in the evaluation of choices and the computation of reward values, none of them have established that the medial OFC correlates with the subjective economic computation of WTP.

We investigated the neural basis of the WTP computation by scanning hungry subjects' brains using fMRI while they placed bids for the right to eat different junk foods in a Becker-DeGroot-Marshak auction (Becker, DeGroot, and Marschak, 1964). Because of the characteristics of this auction, individuals always bid their exact WTP for the object (Wertenbroch and Skiera, 2002) and thus we get a measure of the WTP computed by the brain for every bidder and item at the time of decision-making, which we can then compare with the BOLD measure of neural activity.

Subjects were asked to place bids in two different conditions: free bidding trials and forced bidding trials. In free bidding trials they chose how much to bid. In forced bidding trials they were told how much to bid. Both types of trials were otherwise identical. Each item received one bid of each kind. The only difference between both types of trials is that the subject needs to perform a WTP computation in the free trials, since she needs to decide how much to bid, but not in the forced trials, since she is told what her bid should be. Every other computation, such as the anticipated taste of the food, should be carried out equally in both types of trials. As a result, we can conclude that a brain area encodes the WTP computation whenever its activity increases with the WTP in the free trials, but not in the forced trials,

As predicted, we found that activity changes within the medial OFC were modulated by the subject's WTP in free as compared to forced bid trials. Unexpectedly, we also found that right dorsolateral prefrontal cortex (DLPFC) involved in this computation. We thus concluded that activity in the medial OFC and DLPFC encode for WTP in everyday purchasing decisions.

Part of the research agenda in neuroscience related to behavioral decision research is to understand how the brain evaluates potential goals and outcomes at the time of decision-making, and how do other cognitive, emotional, and visceral processes affect the computation of economic utility. A first step in this research agenda is to understand what are the brain structures involved in the computation of (decision) utility in simple everyday purchasing decisions. Our results suggest that the medial OFC and DLPFC are places where a variety of variables computed in other brain regions are integrated into a single representation of utility. If this hypothesis is correct, other brain processes may be able to influence decision-making by modulating activity in the medial OFC and DLPFC.

Additionally, our results have also implications for decision-making disorders and transformative consumer research. From a neuroeconomic point of view, addiction and compulsive gambling, eating, or purchasing behavior can be characterized as diseases in which the brain miscomputes the WTP of drugs, gambles, food and goods. Given our findings, these diseases might act through brain mechanisms modulating activity within mOFC and DLPFC (further preliminary evidence for this hypothesis comes from Volkow et al., 2005).

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Many decisions, such as whether to invest in the stock market or to accept a new job, involve the possibility of gaining or losing relative to the status quo. When faced with such decisions, most people are strikingly risk averse. For instance, people typically reject gambles that offer a 50/50 chance of gaining or losing money, unless the amount that could be gained is at least twice the amount that could be lost (e.g., a 50/50 chance to either gain $100 or lose $50) (Tversky, 1992). Prospect theory explains risk aversion for "mixed" (gain/loss) gambles using the concept of loss aversion: People are more sensitive to the possibility of losing objects or money than they are to the possibility of gaining the same objects or amounts of money. Thus, people typically require a potential gain of at least $100 to make up for exposure to a potential loss of $50 because the subjective impact of losses is roughly twice that of gains. Similarly, people demand substantially more money to part with objects they have been given than they would have been willing to pay to acquire them in the first place (Kahneman, 1990). Loss aversion has been used to explain a wide range of economic behaviors outside the laboratory (e.g. Benartzi, 1995) and is seen in trading behavior of young children (Harbaugh, 2001) and capuchin monkeys (Chen, 2006), suggesting that it may reflect a fundamental feature of the primate brain.

In the current study we aimed to isolate activity associated with the evaluation of a gamble when choosing whether or not to accept it (i.e., decision utility) without the expectation that the gamble would be immediately resolved. This allowed us to test whether neural responses during the evaluation of potential outcomes are similar to patterns previously reported in studies of anticipated and experienced outcomes. Moreover, we explore whether enhanced sensitivity to losses is driven by negative emotions, such as fear or anxiety (e.g., Camerer, 2005) that might be mediated by enhanced activity in brain areas such as the amygdala or anterior insula, cf., (Kahn, 2002; Kuhnen, 2005) or whether loss aversion reflects an asymmetric response to losses versus gains within a single system that codes for the subjective value of the potential gamble, such as ventral striatum (e.g. Breiter, 2001).

We collected functional magnetic resonance imaging (fMRI) data while participants decided whether to accept or reject mixed gambles that offered a 50/50 chance of either gaining one amount of money or losing another amount. The sizes of the potential gain and loss were manipulated independently, with gains ranging from \$10 to \$40 (in increments of \$2) and losses ranging from \$5 to \$20 (in increments of \$1). To introduce incentive-compatible payoffs, we endowed participants with \$30 one week prior to scanning and told participants that one decision from each of three scanning runs would be honored for real money.

We assessed behavioral sensitivity to gains and losses by fitting a logistic regression to each participant's acceptability judgments collected during scanning, using the size of the gain and loss as independent variables. We computed a measure of behavioral loss aversion (λ) as the ratio of the (absolute) loss response to the gain response, yielding a median λ=1.93 (range: 0.99-6.75). This finding is consistent with the observation that participants were on average indifferent to gambles in which the potential gain was twice the potential loss and also accords well with previous findings (Tversky, 1992).

We next analyzed the imaging data to identify regions whose activation correlated with the size of the potential gain or loss, using parametric regressors. This analysis isolated a set of regions responsive to the size of potential gains when evaluating gambles (averaging over levels of loss). The gain-responsive network included regions previously shown to be associated with the anticipation and receipt of monetary rewards, including dorsal and ventral striatum, ventromedial prefrontal cortex (vmPFC), ventrolateral PFC (vlPFC), anterior cingulate (ACC), orbitofrontal cortex (OFC), and dopaminergic midbrain regions. There were no regions that showed decreasing activation as gains increased.

Surprisingly, no brain regions showed significantly increasing activation during evaluation of gambles as the size of the potential loss increased (averaging over all levels of gain). Instead, a group of brain regions including the striatum, vmPFC, ventral ACC, and medial OFC, most of which also coded for gains, showed decreasing activity as the size of the potential loss increased. A conjunction analysis between increasing activity for gains and decreasing activity for losses demonstrated joint sensitivity to both gains and losses in a set of regions, including the dorsal and ventral striatum and vmPFC.

Examination of regions of interest in the striatum and vmPFC from the gain/loss conjunction analysis revealed that these regions exhibited a pattern of "neural loss aversion"; that is, the (negative) slope of the decrease in activity for increasing losses was greater than the slope of the increase in activity for increasing gains in a majority of participants (striatum: loss>gain for 14/16 participants, p=.004; vmPFC: loss>gain for 13/16 participants, p=.021). In order to more directly assess the relationship between neural loss aversion and behavioral loss aversion, we performed a whole-brain robust regression analysis with these measures. This analysis revealed significant correlations between behavioral and neural loss aversion in several regions, including bilateral ventral striatum (r=.85) as well as bilateral lateral and superior PFC (pre-SMA), and right inferior parietal cortex. These results demonstrate that differences in behavior were strongly predicted by differences in neural responses.

The present study replicates the common behavioral pattern of risk aversion for mixed gambles that offer a 50/50 chance of gaining or losing money, and shows that this pattern of behavior is directly tied to the brain's greater sensitivity to potential losses than gains, consistent with prospect theory. The study also shows that potential losses are represented by decreasing activity in regions that seem to code for subjective value rather than by increasing activity in regions associated with negative emotions.

"Neural Predictors of Purchases"

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The decision whether to purchase a product is the fundamental unit of economic analysis. The success of economic theory rests on its ability to characterize this repeated and elementary decision process. While some neuroeconomic research (e.g., McClure et al., 2004) has examined how people choose between well-defined immediate and delayed rewards, note that consumers rarely face such explicit choices. Although the standard economic perspective assumes that the price of a good represents how much future pleasure must be foregone to finance immediate consumption, it is not at all clear that people spontaneously consider such "opportunity costs" in their purchasing decisions. Consider, for instance, a study by Frederick et al. (2006) in which participants were asked if they would (hypothetically) be willing to purchase a desirable video for \$14.99. The researchers simply varied whether the decision not to buy it was framed as "not buy this entertaining video" or "keep the \$14.99 for other purchases." Although the two phrases represent equivalent actions, the latter highlights the pleasure that is foregone by purchasing the video. Frederick et al. (2006) found that drawing attention to opportunity costs significantly reduced the proportion of participants willing to purchase the video, suggesting that some participants are not spontaneously considering opportunity costs.

If prices do not deter spending through a deliberative consideration of opportunity costs, then what role do prices play in spending decisions? Prelec and Loewenstein (1998) propose that prices deter spending through an immediate "pain of paying." According to their model, people consume immediately if the anticipated benefits of doing so exceed the pain of paying for the good. We examined these competing perspectives in an experiment in which participants chose whether or not to purchase a series of discounted consumer goods while having their brains scanned with fMRI. Before each of two sessions participants were given \$20 to spend and were told that one of their decisions would be randomly selected to count for real. In order to isolate participants' reactions to the different components of purchasing decisions, participants first saw the available good for four seconds, then saw its price for four seconds, and then had four seconds to decide whether or not to purchase it. Goods ranged from hedonic (e.g., The Simpsons DVDs) to utilitarian (e.g., Crest Whitestrips), retailed from \$10-

$80, and were offered at a 75% discount in order to encourage spending. At the conclusion of the experiment, participants indicated how much they liked each product and how much they would be willing to pay for it.

Consistent with both the standard economic perspective and Prelec and Loewenstein's (1998) Red and Black model, we found that the extent to which participants reported liking the products correlated positively with activation in nucleus accumbens, a region previously associated with anticipation of gains and positive arousal (Knutson et al. 2001). Nucleus accumbens activation was also positively correlated with purchasing decisions. However, inconsistent with the standard economic account, we also found that activation in insula, a region previously associated with experiencing a variety of painful stimuli such as disgusting odors (Wicker et al., 2003), unfairness (Sanfey et al., 2003), and social exclusion (Eisenberger et al., 2003), correlated negatively with purchasing decisions. The difference in insula activation between purchased and non-purchased products occurred as soon as participants saw the good's price, four seconds before the actual purchase decision was made. The difference remains significant controlling for price, willingness to pay, and activation in related brain regions. The results suggest that an anticipatory pain of paying plays a critical role in consumer choice.

The pain of paying may explain a variety of market phenomena. For example, people may spend more with credit than they would with cash (on hedonic goods, at least; Prelec and Simester, 2001; Soman, 2003) partly because swiping a credit card is simply less painful than forking over money. The pain of paying may also differ across individuals; indeed, such individual differences may explain why "tightwads" find it so difficult to indulge themselves (excessive pain of paying) and why "spendthrifts" find it so difficult to control their spending (insufficient pain of paying). Motivated by the findings of this study, Rick, Cryder, and Loewenstein (in press) developed a "Tightwad-Spendthrift" scale to assess individual differences in the pain of paying. Contrary to the media's persistent attention toward over-spending and credit card debt, Rick, Cryder, and Loewenstein (in press) found that tightwads outnumber spendthrifts by a 3:2 ratio in a sample of over 13,000 people. If prices deter spending through a pain of paying, understanding how and why that pain varies across situations and individuals is a crucial task for future research.

REFERENCES:

Becker, Gary S., Morris H DeGroot, and Jacob Marschak, (1964). "Measuring utility by a single-response sequential method,: *Behavioral Science*, 9, 226-232.

Benartzi, Shlomo and Richard H. Thaler (1995), "Myopic loss aversion and the equity premium puzzle. *Quarterly Journal of Economics,*" 110: 73-92.

Breiter, Hans C., Itzhak Aharon, Daniel Kahneman, Anders Dale, and Peter Shizgal (2001), "Functional Imaging of Neural Responses to Expectancy and Experience of Monetary Gains and Losses,"*Neuron* 30, 619-639.

Camerer, Colin F. (2005), "Three cheers—psychological, theoretical, empirical—. for loss-aversion", *Journal of Marketing Research* 42, 129-133.

Camerer, Colin F. George Loewenstein, and Drazan Prelec (2005), "Neuroeconomics: How Neuroscience Can Inform Economics, Journal of Economic Literature, XLIII, 9-64.

Chen, M. Keith, Venkat Lakshminarayanan, and Laurie R. Santos (2006), "How Basic Are Behavioral Biases? Evidence from Capuchin Monkey Trading Behavior," *Journal of Political Economy,* 114, 517–537.

Daw, Nathaniel D., John P. O'Doherty, Peter Dayan, Ben Seymour, and Ray J. Dolan (2006). "Cortical substrates for exploratory decisions in humans," *Nature, 441* (7095), 876-879.

Eisenberger, Naomi I., Matthew D. Lieberman and Kipling D. Williams (2003), "Does Rejection Hurt: An fMRI Study of Social Exclusion," *Science*, 302 (5643), 290-2.

Frederick, Shane, Nathan Novemsky, Jing Wang, Ravi Dhar and Stephen Nowlis (2006), "Neglect of Opportunity Costs in Consumer Choice," working paper, Massachusetts Institute of Technology.

Harbaugh, William T., Kate Krause, and Lise Vesterlund (2001), "Are adults better behaved than children? Age, experience, and the endowment effect", *Economic Letters* 70, 175-181 .

Kahn, Itamar, Yehezkel Yeshurun, Pia Rotshtein, Itzhak Fried, Dafna Ben-Bashat, and Talma Hendler (2002), "The Role of the Amygdala in Signaling Prospective Outcome of Choice," *Neuron* 33, 983-994.

Kahneman, Daniel, Jack L. Knetsch, and Richard H. Thaler, (1990), "Experimental Tests of the Endowment Effect and the Coase Theorem," *Journal of Political Economy* 98, 1325-1348.

Knutson, Brian, Grace W. Fong, Charles M. Adams, Jerald L. Varner and Daniel Hommer (2001), "Dissociation of Reward Anticipation and Outcome with Event-Related fMRI," *NeuroReport*, 12(17), 3683-7.

Kuhnen, Camelia M. and Brian Knutson (2005) "The Neural Basis of Financial Risk Taking," *Neuron* 47, 763-770

McClure, Samuel M., David I. Laibson, George Loewenstein and Jonathan D. Cohen (2004), "Separate Neural Systems Value Immediate and Delayed Monetary Rewards," *Science*, 306, 503-7.

Padoa-Schioppa, Camillo and John A. Assad (2006). "Neurons in the orbitofrontal cortex encode economic value," Nature, 441, 223-226.

Prelec, Drazen and George Loewenstein (1998), "The Red and the Black: Mental Accounting of Savings and Debt," *Marketing Science,* 17 (1), 4-28.

Prelec, Drazen and Duncan Simester (2001), "Always Leave Home Without It: A Further Investigation of the Credit-Card Effect on Willingness to Pay," *Marketing Letters*, 12(1), 5-12.

Rick, Scott, Cynthia Cryder and George Loewenstein (in press), "Tightwads and Spendthrifts," *Journal of Consumer Research.*

Sanfey, Alan G., James K. Rilling, Jessica A. Aronson, Leigh E. Nystrom and Jonathan D. Cohen (2003), "The Neural Basis of Economic Decision-Making in the Ultimatum Game," *Science*, 300 (5626), 1755-8.

Tom, Sabrina M., Craig R. Fox, Christopher Trepel, and Russell A. Poldrack (2007) "The Neural Basis of Loss Aversion in Decision-Making Under Risk," Science, 315, 515-518.

Tversky, Amos and Daniel Kahneman (1992), "Advances in Prospect Theory: Cumulative Representation of Uncertainty," *Journal of Risk and Uncertainty* 5, 297.

Soman, Dilip (2003), "The Effect of Payment Transparency on Consumption: Quasi-Experiments from the Field," *Marketing Letters*, 14(3), 173-83.

Volkow, Nora D., Gene-Jack Wang, Yeming Ma, Joanna S. Fowler, Christopher Wong, Yu-Shin Ding, Robert Hitzemann, James M. Swanson, and Peter Kalivas (2005) "Activation of orbital and medial prefrontal cortex by methylphenidate in cocaine-addicted subjects but not in controls: relevance to addiction. Journal of Neurosci, 25(15), 3932-3939.

Wertenbroch, Klaus and Bernd Skiera (2002), "Measuring consumers' willingness to pay at the point of purchase", Journal of Marketing Research, 39, 228-241.

Wicker, Bruno, Christian Keysers, Jane Plailly, Jean-Pierre Royet, Vittorio Gallese and Giacomo Rizzolatti (2003), "Both of Us Disgusted in *My* Insula: The Common Neural Basis of Seeing and Feeling Disgust," *Neuron*, 40 (3), 655-64.