Neuron
Previews

Shopping Centers in the Brain

Alain Dagher[1,*]
[1] Montreal Neurological Institute, 3801 University Avenue, Montreal QC, Canada H3A 2B4
*Correspondence: alain@bic.mni.mcgill.ca
DOI 10.1016/j.neuron.2006.12.014

Knutson et al. performed functional MRI on individuals while the subjects were deciding whether or not to purchase various items. Their results, reported in this issue of *Neuron*, support the theory that the decision to purchase involves the integration of emotional signals related to the anticipation of both obtaining the desired product and suffering the financial loss of paying for it.

Human financial behavior is often seemingly irrational, a fact that provides employment for advertisers, casino workers, insurance salesmen, and economists. Behavioral economics aims to explain financial decision-making by appealing to psychology to explain these "nonrational" behaviors. The relatively young field of neuroeconomics attempts to bring together economics and cognitive neuroscience to uncover the neural correlates of financial decision making (Sanfey et al., 2006). It can make two important contributions to neuroscience: first, it brings several well-validated paradigms drawn from real-world financial behavior that are often easy to administer in a laboratory environment; second, the view of human (and animal) behavior as a constant attempt by the individual to maximize utility allows specific predictions to be made and encourages scientists to look at brain function in novel ways (Shizgal, 1997). The existence of mathematical formulas that depict utility or value based on behavior is particularly apt for functional MRI (fMRI) analysis, since it allows the generation of continuous variables that can easily be used as covariates in general linear models.

One neuroeconomic theory that is well suited to investigation by fMRI is that potential gains and losses are evaluated independently (i.e., by different neural systems), and, more specifically, that financial decisions are guided by emotional biases, which are presumably related to neural activity in brain regions involved in the processing of positive and negative emotion.

In this issue of *Neuron*, Knutson et al. (2007) used fMRI to test this theory. Their premise was that the decision to buy a product on offer was the result of a "hedonic competition between the immediate pleasure of acquisition and an equally immediate pain of paying." They measured the neural correlates of financial decision-making in a shopping task. Subjects were shown pictures of products that were available for purchase. After a short interval the price of the product was displayed, and subjects were given the opportunity to make the purchase. Importantly, the paradigm separated three periods in time: product presentation, price, and decision, allowing the investigators to identify the different neural signals that contribute to decision-making in this case. After the scanning session subjects rated each product for desirability and the price they would be willing to pay for it. These two behavioral measures, along with the actual decision to purchase the product, were then used as regressors to extract neural signals of interest. The main result is that product preference correlated with activation of the nucleus accumbens (NAcc), while price differential activated an area of medial prefrontal cortex (MPFC). In addition, greater activity in the insula was associated with nonpurchases. Moreover, the blood oxygen level dependent (BOLD) signal in these three regions was strongly predictive of the decision to purchase.

While other brain regions were also found to be activated in each of these contrasts, these three regions are of particular interest. The NAcc has been implicated in reward processing in numerous human and animal studies: in human fMRI studies it consistently responds to the anticipation of monetary gain (Breiter et al., 2001) and desired foods (O'Doherty et al., 2002) or to the administration of addictive drugs (Breiter et al., 1997). The NAcc is part of the striatum, and it receives extensive cortical projections mostly from limbic and paralimbic cortex (Alexander et al., 1986). It has been described as a key node in the conversion of motivation into action (Mogenson et al., 1980). Indeed, in the current study, NAcc activation while viewing the product predicted the later decision to purchase it. Similarly, the insula has been linked to anticipation of monetary loss, pain, and emotionally aversive pictures (Paulus and Stein, 2006) and may play an analogous role to the NAcc in producing an appropriate behavioral response in risky or disadvantageous situations (Sanfey et al., 2003). It is interesting that a previous study demonstrated that activation in these two regions was predictive of risk-seeking and risk-averse financial decisions in a stock-picking paradigm (Kuhnen and Knutson, 2005), confirming their role not only in generating an affective response, but also in guiding behavior. Finally, in the current study, MPFC activation was greatest when the price of the product was lower than the price individuals were willing to pay. This is consistent with data showing that the MPFC tracks the difference between expected and actual outcome in monetary reward tasks (Knutson et al., 2003).

So, are there shopping centers in the brain? One must be careful in

interpreting fMRI data from individual experiments. For example, although the NAcc was activated by product preference in this study, it does not necessarily follow that it encodes this value. Other fMRI studies have demonstrated a dependence of NAcc activation on novelty, unpredictability, salience (Zink et al., 2003), or a change in contingency (Cools et al., 2002), independently of reward or preference. We must remember that the BOLD signal is dependent on the activity of neural inputs into an area (Logothetis and Pfeuffer, 2004). Therefore, the BOLD signal in the NAcc (or any other region) in response to a visual cue predicting some reward (e.g., a food picture) might be expressed as a weighted sum of inputs

$$y = \sum_{i=1}^{N} a_i \cdot x_i$$

where the x_i could represent sensory features, satiety, motivation, novelty, attention, motor planning, and the concurrent availability of other potential rewards. If in an experiment all but one of the x_i are kept constant, the BOLD signal will be proportional to the remaining variable ($y = a_1 x_1$). However, one would be wrong to then conclude that the NAcc "does" or "encodes" x_1. Indeed, one might conclude that x_1 (say, preference for the food) might be encoded elsewhere in the brain, and that this information was then relayed to the NAcc for integration with other data. Similarly, the MPFC has been implicated in experiments that do not involve reward, suggesting that brain activity here may also be related to attention (Small et al., 2003) or anxiety (Simpson et al., 2001).

Certain questions remain unanswered. This study emphasizes the role of affective responses to product and price; however, in real life purchasing decisions are also the result of planning, reflection, and deliberation, functions that are likely mediated by associative and lateral prefrontal cortical areas. How do these systems interact with limbic structures to produce behavior? Is there a neural currency that the brain uses to assign value to different rewards and behaviors? Which neurotransmitters are involved? What types of dysfunction in these neural systems explain pathological disorders such as compulsive shopping and problem gambling?

A better understanding of the brain regions involved in financial decision-making, along with their role in other nonfinancial behaviors, could also help explain the irrational economic behaviors alluded to earlier. The brain network implicated in the study by Knutson et al. existed long before the development of commerce. Perhaps optimum function related to finding food or mates and avoiding predators is what leads to nonoptimum behaviors when deciding to obtain insurance, buy a product by credit card, or walk into a casino.

REFERENCES

Alexander, G.E., DeLong, M.R., and Strick, P.L. (1986). Annu. Rev. Neurosci. *9*, 357–381.

Breiter, H.C., Gollub, R.L., Weisskoff, R.M., Kennedy, D.N., Makris, N., Berke, J.D., Goodman, J.M., Kantor, H.L., Gastfriend, D.R., Riorden, J.P., et al. (1997). Neuron *19*, 591–611.

Breiter, H.C., Aharon, I., Kahneman, D., Dale, A., and Shizgal, P. (2001). Neuron *30*, 619–639.

Cools, R., Clark, L., Owen, A.M., and Robbins, T.W. (2002). J. Neurosci. *22*, 4563–4567.

Knutson, B., Fong, G.W., Bennett, S.M., Adams, C.M., and Hommer, D. (2003). Neuroimage *18*, 263–272.

Knutson, B., Rick, S., Wimmer, G.E., Prelec, D., and Loewenstein, G. (2007). Neuron *53*, this issue, 147–156.

Kuhnen, C.M., and Knutson, B. (2005). Neuron *47*, 763–770.

Logothetis, N.K., and Pfeuffer, J. (2004). Magn. Reson. Imaging *22*, 1517–1531.

Mogenson, G.J., Jones, D.L., and Yim, C.Y. (1980). Prog. Neurobiol. *14*, 69–97.

O'Doherty, J.P., Deichmann, R., Critchley, H.D., and Dolan, R.J. (2002). Neuron *33*, 815–826.

Paulus, M.P., and Stein, M.B. (2006). Biol. Psychiatry *60*, 383–387.

Sanfey, A.G., Rilling, J.K., Aronson, J.A., Nystrom, L.E., and Cohen, J.D. (2003). Science *300*, 1755–1758.

Sanfey, A.G., Loewenstein, G., McClure, S.M., and Cohen, J.D. (2006). Trends Cogn. Sci. *10*, 108–116.

Shizgal, P. (1997). Curr. Opin. Neurobiol. *7*, 198–208.

Simpson, J.R., Jr., Drevets, W.C., Snyder, A.Z., Gusnard, D.A., and Raichle, M.E. (2001). Proc. Natl. Acad. Sci. USA *98*, 688–693.

Small, D.M., Gitelman, D.R., Gregory, M.D., Nobre, A.C., Parrish, T.B., and Mesulam, M.M. (2003). Neuroimage *18*, 633–641.

Zink, C.F., Pagnoni, G., Martin, M.E., Dhamala, M., and Berns, G.S. (2003). J. Neurosci. *23*, 8092–8097.