The investigation of neural correlates of monetary reward by using functional neuroimaging techniques

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Abstract: Money is a specifically human incentive. However, functional imaging techniques bring striking evidence that neural circuits pertaining to more "natural" addictive and rewarding processes are involved in response to monetary reward. Main results are evoked here, with specific brain responses demonstrated along the different stages of the process.

With regard to a drug theory of money, Lea & Webley (L&W) address the question: "Is there a biological reason why money is such a powerful incentive?" (sect. 1.5). Interesting results related to this question have emerged from modern neuroimaging techniques, and these results have converged with studies about decision processes in fields such as neuroeconomics (Glimcher & Rustichini 2004).

Studies developed by Breiter and colleagues are of primary interest. After a focus on the effects of cocaine on brain circuits in a cocaine users sample (Breiter et al. 1997), neural circuits involved in monetary gain and losses were investigated (Breiter et al. 2001). A game of chance performed in the scanning session included an "expectation" phase where different possible monetary amounts were presented and an "outcome" with the presentation of the gain or loss. A striking result of this study was that an incentive unique to humans (i.e., money) induced brain activations in areas such as the nucleus accumbens, the sublenticular extended amygdala, and the orbital gyrus (in the prospect and outcome phases) that overlap brain activations observed in response to cocaine infusions in addicted subjects (Breiter et al. 1997) or to low doses of morphine in drug-naïve individuals (Breiter et al. 2000). Such an overlap could partly explain that a dysfunction in this cerebral network could contribute to impulse disorders, such as compulsive gambling.

The study performed by Breiter et al. in 2001 identified an overlap between cerebral areas involved in monetary rewards and those involved in drug addiction, but few differences were recorded in brain activations for different stages (e.g., the prospect and outcome phases) of cerebral processes related to monetary reward. The growing development of neuroimaging techniques has allowed several studies to focus on specific properties of the cerebral networks involved in response to monetary stimuli, and some results have identified brain activation differences occurring during different stages of the process. Based on primate work, Knutson et al. (2001a) used a parametric task that elicited anticipation of monetary reward or punishment. Within a sample of eight healthy volunteers, this study was the first to demonstrate a selective recruitment of the nucleus accumbens (a part of the ventral striatum) for monetary gain but not for loss; moreover, the activation was proportional to the amount of the reward. Most often, neuroimaging studies on the neural correlates of monetary reward have used tasks that involve prospect, choice, and outcome phases. As theses phases can be temporally close, the event-related functional magnetic resonance imaging (fMRI) method with a good temporal resolution should allow identification of specific brain activations related to these phases.

On this topic, a recent study by Ernst et al. (2004) brought very interesting results: whereas the prominent recruitment of the ventral striatum was confirmed, the choice phase involved more "cognitive" areas such as parieto-occipital ones (visuospatial attention), the dorsal part of the anterior cingulate cortex (conflict monitoring), parietal (manipulation of quantities) and premotor areas. This study also showed that high risk/reward conditions are associated with greater neural response during the choice phase but not the prospect phase. Likewise, were there specific brain activations that characterized the outcome of a monetary reward? With the same parametric task described earlier, Knutson et al. (2003) showed that a particular region of the mesial prefrontal cortex is *activated* when an expected reward is obtained, and a previous study (Knutson et al. 2001b) showed that this particular region is *deactivaed* in response to reward omission. Thus, the use of fast neuroimaging techniques would allow demonstration of a dissociation between ventral striatum areas involved in the prospect phase of the reward and more prefrontal ones involved in the outcome phase.

Clearly, neural circuits involved in the prospect and the outcome phases, although partly distinct anatomically, should be functionally linked. This point has been addressed in studies seeking to identify the reaction of monetary reward circuits when a difference occurs between the expected value and the real value of the monetary reward obtained. Still using event-related fMRI, Ramnani et al. (2004) examined cerebral activity related to the failure of expected rewards and the occurrence of unexpected rewards, independently of any goal-directed actions or decisions. Principally, this study showed that each type of prediction error evokes activity in a distinct frontotemporal circuit: whereas unexpected reward failure evokes activity in the temporal cortex and frontal pole (Brodmann area 10), unpredicted rewards evoke activity in the orbitofrontal cortex, the frontal pole parahippocampal cortex, and the cerebellum. The study also showed that the activity time-locked to prediction errors in frontotemporal circuits is involved in encoding the associations between visual cues and monetary reward. For the purpose of this commentary, this result is very important because it shows that neural mechanisms are not only temporary and activated either during the prospect phase, the stimulus presentation, or the outcome phase, but also that networks are devoted to the association between these successive phases.

Since 1999 several neuroimaging studies have explored the neural circuits involved in other goal-directed behaviors such as human sexual motivation (Mouras & Stoléru, in press; Stoléru & Mouras, in press). Following these reviews, several brain areas have been shown to be related to both monetary reward and sexual motivation. For example, most studies on neural correlates of sexual motivation have identified anterior cingulate cortex activations (often interpreted as involved in action preparatory processes), and a recent study by Williams et al. (2004) reported a similar role for monetary reward processes.

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Avoiding drug dependency

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Abstract: If Tool Theory is buttressed by fundamental concepts of conditioned reinforcement and extinction, a dependence on Drug Theory may not be necessary.

Lea & Webley (L&W) insist that a Tool Theory of money, which encompasses only purely ontological behavior, is inadequate to deal with the profound motivational power displayed by human behavior in relation to money. In their provocative analysis, the authors depend much on the notion that money "can mimic the satisfaction both from the instinct to play and from the