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MONETARY REWARD ACTIVATES HUMAN PREFRONTAL CORTEX

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We present a rCBF PET activation study, in which we demonstrated that reward processing in humans activates a cortical-subcortical network including dorsolateral prefrontal, orbital frontal, thalamic and midbrain regions. It is suggested that, as found for non-human primates, the basal ganglia-thalamo-cortical system is implicated in reward processing.

Rewards serve as goals of voluntary behavior. They elicit approach behavior, increase and maintain the frequency of behavior leading to reward (positive reinforcement), and induce subjective feelings of pleasure. Nonhuman primates process reward information in specific regions of the brain, including the amygdala, ventral striatum, midbrain dopaminergic neurons, and dorsolateral and orbital frontal cortex. In this report, we examined the issue of neural activation selectively related to reward processing in humans using positron emission tomography (PET).

Regional cerebral blood flow (rCBF), an index of neural activity, was measured in 10 healthy, right-handed, male volunteers, aged 22-37 years (mean 28 years). rCBF distribution was recorded in each subject while performing a prelearned delayed go-no go task in two different reinforcement conditions. Correct responses were either rewarded by money or a simple 'ok' reinforcer. The accumulated sum of money or 'ok' was continuously displayed on a screen during each scan testing the corresponding reinforcer. Subjects were instructed before the scans that they would receive the finally indicated sum of money.

PET scans were obtained after injection of radiolabelled water ($H_2{}^{15}O$) into a left forearm vein. Radial arterial blood was continuously sampled by means of a peristaltic pump. rCBF was calculated with emission and blood data of the first 90 s after arrival of radioactivity in the brain [1]. Data were analyzed using statistical parametric mapping [2,3].

Behavior rewarded by money, as compared to the 'ok' reinforcement, was associated with significant rCBF increases in the left dorsolateral prefrontal (Brodman's areas 10, 44), left lateral orbitofrontal (area 47) and right occipital cortex (area 19). Processing of monetary reinforcement was also associated with rCBF increases in the left thalamus and the left midbrain. The midbrain focus was located slightly anterior but close to the subthalamic nucleus (see also Fig. 1).

The observed pattern of reward-related frontal activation in humans agrees with recent findings in monkeys and indicates that information concerning the value of the outcome of behavior is integrated into prefrontal mechanisms in order to direct voluntary behavior toward goals.

The frontal lobe is closely connected to the basal ganglia, subthalamic nucleus and thalamus through several loops forming a basal ganglia-thalamo-cortical system, identified to be essentially involved in animal reward processing. Our result that reward-related prefrontal lobe activation is accompanied by activation of the thalamus and possibly the subthalamic nucleus also suggests involvement of several subcortical components of the basal ganglia-thalamo-cortical system, although the frontal activation appears to play the dominant role.

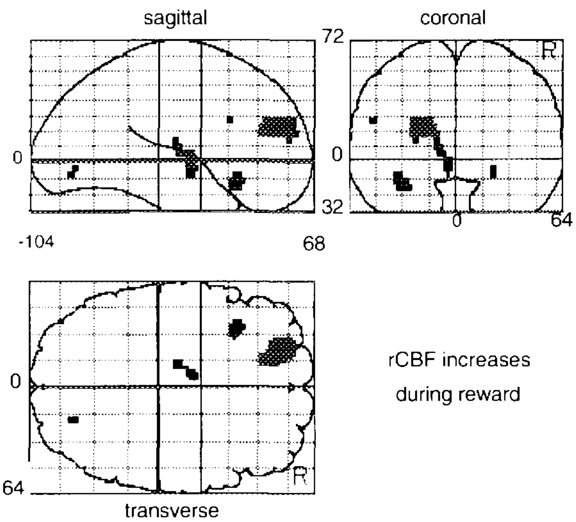

Fig. 1: Cerebral regions associated with reward processing. Foci of significant rCBF increases during task performance for money compared to 'ok' reinforcement are displayed as statistical parametric maps in sagittal, coronal and transverse projections of the brain. Pixels which were significantly different in the two reinforcement conditions at a level of $p<.01$ are shown.

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