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The neuropsychology of ventral prefrontal cortex: Decision-making and reversal learning

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Abstract

Converging evidence from human lesion, animal lesion, and human functional neuroimaging studies implicates overlapping neural circuitry in ventral prefrontal cortex in decision-making and reversal learning. The ascending 5-HT and dopamine neurotransmitter systems have a modulatory role in both processes. There is accumulating evidence that measures of decision-making and reversal learning may be useful as functional markers of ventral prefrontal cortex integrity in psychiatric and neurological disorders. Whilst existing measures of decision-making may have superior sensitivity, reversal learning may offer superior selectivity, particularly within prefrontal cortex. Effective decision-making on existing measures requires the ability to adapt behaviour on the basis of changes in emotional significance, and this may underlie the shared neural circuitry with reversal learning.

Keywords: Orbitofrontal; Basal ganglia; Parkinson's disease; Addiction; Psychopathy; Risk taking

1. Introduction

Following brain injury to the orbitofrontal and ventromedial prefrontal cortex (PFC), human patients display gross alterations in social and emotional behaviour with largely preserved perception, language, memory, and even executive function (Bechara, Tranel, & Damasio, 2000; Damasio, 1994; Malloy, Bihrle, Duffy, & Cimino, 1993; Rolls, 1999). Characterisation of this profile using cognitive testing has been the target of considerable research, not least because the behaviour of patients with ventral prefrontal lesions resembles aspects of symptomatology seen in psychiatric conditions including psychopathy (Lapierre, Braun, & Hodgins, 1995) and substance abuse (Bechara & Damasio, 2002). Two cognitive domains have received particular attention in recent years: decision-making and reversal learning. The development of several measures of decision-making has stemmed largely from observations by Damasio, Bechara and colleagues, that patients with ventromedial prefrontal cortex damage are impaired in their ability to make successful everyday decisions regarding employment, relationships, and personal finances. Specifically, it has been proposed that these patients are unable to use past experiences to guide their ongoing decision-making ('myopia for the future') (Bechara et al., 2000; Damasio, 1994). Recent interest in reversal learning, in contrast, has developed from pre-clinical research over more than three decades demonstrating that rodents and non-human primates with lesions to the orbitofrontal cortex are unable to adapt their responding following changes in stimulus–reward contingencies (Butter, 1969; Jones & Mishkin, 1972).

The purpose of this article is to review converging evidence for the involvement of ventral prefrontal cortex in decision-making and reversal learning, from (1) human lesion studies, (2) animal lesion studies, and (3) human functional neuroimaging studies. Evidence for the contribution of the ascending 5-HT and dopamine neurotransmitter systems to these domains will also be described. Recent cognitive research in a number of clinical groups has begun to investigate the sensitivity and selectivity of decision-making and reversal learning deficits as indices of ventral prefrontal dysfunction.

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2. The cognitive neuroscience of decision-making

Decision-making requires the evaluation of multiple response options, followed by the selection of the response considered optimal. Each response option may be characterised in terms of the reward and punishment outcomes with which it is associated. Response options may vary in terms of (1) the magnitude of reward and punishment, (2) the probability of receiving reward or punishment, and (3) the delay to reward or punishment. This framework provides scope for a range of decision-making abnormalities in clinical groups. Deficits may become apparent in terms of increased sensitivity to reward or reduced sensitivity to punishment, or at a more complex level under situations of conflict; for example, a failure to avoid rewards with long-term negative consequences, or the preference for a small immediate reward over a larger but delayed reward. This latter phenomenon is known as temporal (or delay) discounting, and exemplifies the relationship between decision-making and impulsivity, given that an operational definition of impulsive behaviour is the tendency to choose a small or inferior immediate reward over a larger delayed reward (Evenden, 1999; Logue, 1988).

2.1. Human lesion studies

Neuropsychological studies of decision-making in humans have utilised two paradigms in recent years: the Iowa Gambling Task (Bechara, Damasio, Damasio, & Anderson, 1994) and the Cambridge Gamble Task (Rogers, Everitt, et al., 1999). The Iowa Gambling Task is described in detail elsewhere in this issue (Bechara, this issue). The task emphasises the *learning* of reward and punishment associations in order to guide ongoing decision-making. Healthy subjects performing the Iowa Gambling Task learn to avoid 'risky' card decks that offer high immediate rewards with a concomitant risk of occasional very high punishment. They develop a preference instead for 'safe' card decks where the immediate rewards are smaller but there is a low risk of punishment. Patients with bilateral damage to the ventromedial PFC do not acquire a preference for the safe decks on the Iowa Gambling Task, but instead prefer the risky decks for the duration of the task (Bechara et al., 1994, 2000). On the basis of these findings, ventromedial PFC has been posited to mediate the learning and retrieval of the affective information that guides decision-making (Damasio, 1994).

The Cambridge Gamble Task was developed to quantify decision-making outside of a learning context. The information needed to make each decision is presented to the subject on each trial, and hence the learning demand across trials is minimised. On each trial the subject first makes a relatively simple probabilistic judgment on whether a token is hidden under a red or a blue box. Ten boxes are presented in total on each trial, and the ratio of red to blue boxes varies across trials (9:1, 8:2, 7:3, and 6:4). Second, the subject is required to bet a proportion of their points total, reflecting their confidence in that judgment (see Fig. 1). The betting stage of the Cambridge Gamble Task provides a direct measure of high-risk behaviour, uncontaminated by learning. Fixed bets are offered to the subject in an ascending or descending sequence, and the subject must delay their response until the amount displayed is the amount they would like to bet. For example, in the ascending sequence, the first bet offered is very small and the amount increments every few seconds. The discrepancy between bets placed in the ascending and descending conditions provides an index of impulsivity: the impulsive subject may be less able to delay responding to place an appropriate bet, and therefore would be expected to place high bets in the descending condition, and low bets in the ascending condition. A non-impulsive subject, in contrast, would show similar betting in the ascending and descending conditions.

Four studies to date have examined performance on the Cambridge Gamble Task in patients with frontal lobe pathology affecting the ventral PFC. Increased betting relative to matched controls has been shown in patients with (1) subarachnoid haemorrhage of the anterior communicating artery, the blood vessel that supplies ventral PFC (Mavaddat, Kirkpatrick, Rogers, & Sahakian, 2000), (2) frontal variant fronto-temporal dementia (Rahman, Sahakian, Hodges, Rogers, & Robbins, 1999; described in more detail below), and (3) large prefrontal lesions including orbitofrontal cortex,

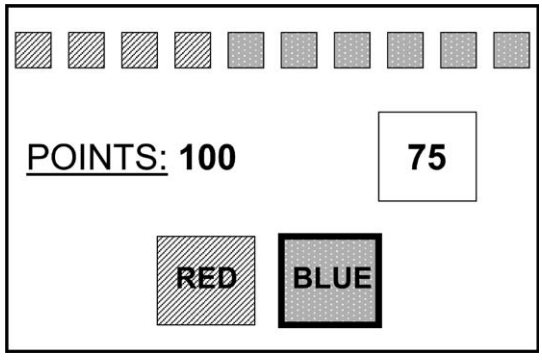

Fig. 1. A schematic representation of the computer screen display from the Cambridge Gamble Task. Subjects are presented on each trial with 10 red and blue boxes (in this example 4 are red and 6 are blue), where one box hides a token. They must first make a probabilistic judgment of whether they think the token is under a red or blue box (on the trial depicted they have selected BLUE). Latencies to make these judgments are recorded. Second, they must place a bet on their confidence in their red/blue decision. Bets are generated automatically by the computer in the box on the right side of the screen (reading 75 in the example). Bets are presented in an ascending or descending sequence, incrementing or decrementing in percentages of the points total every 5 s.