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Impulsivity and risk-taking behavior in focal frontal lobe lesions

D. Floden [a,b], M.P. Alexander [a,c,d,e,f], C.S. Kubu [g], D. Katz [h,i], D.T. Stuss [a,b,*]

[a] *Rotman Research Institute, Baycrest, Toronto, Ont., Canada*
[b] *Departments of Psychology and/or Medicine, University of Toronto, Toronto, Ont., Canada*
[c] *Harvard Medical School, Boston, MA, United States*
[d] *Behavioral Neurology Unit, Beth Israel Deaconess Medical Center, Department of Neurology, Boston, MA, United States*
[e] *Youville Hospital, Cambridge, MA, United States*
[f] *Memory Disorders Research Center, Boston University, Boston, MA, United States*
[g] *The Cleveland Clinic, Department of Psychiatry and Psychology, Section of Neuropsychology, Cleveland, OH, United States*
[h] *Department of Neurology, Boston University School of Medicine, Boston, MA, United States*
[i] *Brain Injury Program, HealthSouth Braintree Rehabilitation Hospital, Braintree, MA, United States*

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Abstract

Frontal lobe dysfunction may underlie excessively impulsive and risky behavior observed in a range of neurological disorders. We devised a gambling task to examine these behavior tendencies in a sample of patients who had sustained focal damage to the frontal lobes or nonfrontal cortical regions as well as in a matched sample of healthy control subjects. The main objectives of the study were: (1) to behaviorally dissociate impulsivity and risk-taking; (2) to examine potential associations between specific frontal lesion sites and impulsivity or risk-taking; (3) to investigate the influence of reinforcement and trial timing on both behaviors. Our results indicated that patients and controls were equally likely to perform impulsively. Risk-taking performance strategies, however, were related to left ventrolateral and orbital lesion sites. Moreover, risk-taking was also associated with blunted response alteration following a nonrewarded trial. Patients and control subjects showed identical responses to reward-timing manipulations consistent with formal decision-making theory. These findings suggest that ventrolateral and orbital lesions are related to the reward-based aspects of decision-making (risk-taking) rather than to simple response disinhibition (impulsivity). Reduced reaction to the negative consequences of one's actions may underlie this behavior pattern.

Keywords: Reward processing; Response disinhibition; Decision-making; Orbitofrontal cortex; Common Difference Effect

1. Introduction

Impaired behavioral regulation, such as impulsivity (IMP) and risk-taking behavior (RTB), is commonly observed after injury to the frontal lobes. Attempts to objectively evaluate these behaviors are complicated by the interrelated character of these behaviors. The operational definitions of IMP and RTB are not straightforward, and it is sometimes unclear if a particular behavior represents 'impulsivity' or 'risk-taking' or both (i.e., a spur of the moment leap from a cliff into an unfamiliar lake). For patients with brain injury who exhibit poor behavioral control, it may be important to distinguish between IMP, which may have one set of potential causes (i.e., stimulus-bound responses, poor response inhibition, etc.) and RTB, which may have another set of potential causes (i.e., poor computation of risk, blunted concern about risk, etc.). Single case studies of patients with frontal lobe damage have provided striking descriptions of both behavioral types (Eslinger & Damasio, 1985; Shallice, Burgess, Schon, & Baxter, 1989).

Systematic investigations of IMP and RTB in frontal lobe patients have employed gambling paradigms (Bechara, Damasio, Damasio, & Anderson, 1994; Miller, 1992; Rogers et al., 1999). In particular, the Iowa Gambling Task (Bechara et al., 1994) is sensitive to the behavioral problems that frontal patients may exhibit in their everyday lives. This task does not, however, permit unambiguous behavioral separation of IMP and RTB (although some excellent modeling work has been done to fractionate the contributing mechanisms post hoc; Busemeyer

* Corresponding author at: Rotman Research Institute, Baycrest, 3560 Bathurst Street, Toronto, Ont., Canada M6A 2E1. Tel.: +1 416 785 2500x2938; fax: +1 416 785 2862.
E-mail address: dstuss@rotman-baycrest.on.ca (D.T. Stuss).

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& Stout, 2002). Other gambling tasks designed to separate these behavioral influences have not produced consistent results in frontal lobe patients. Results of one study suggested increased IMP (Miller, 1992) whereas work with a related paradigm suggested increased RTB (Clark, Manes, Antoun, Sahakian, & Robbins, 2003; Manes et al., 2002; Mavaddat, Kirkpatrick, Rogers, & Sahakian, 2000; Rogers et al., 1999). The conflicting data may be due to procedural differences in these two tasks: skilled processing (Miller, 1992) or probabilistic decision-making (Rogers et al., 1999); inverse (Miller, 1992) or independent (Rogers et al., 1999) relations between reward values and probabilities. Substantial differences in lesion distributions and in methodologies for analyzing and reporting lesion site also exist between studies. With these issues unresolved, the relative contribution of impulsivity and risk-taking to behavioral problems in patients with frontal lobe damage remains unclear.

To address these questions, we developed a gambling task which represents a compromise between the techniques used in other studies. The current procedure removed all elements of skilled performance and carried an explicit, consistent, *inverse* relationship between success probability and reward values (high probability-low reward, and vice versa). The conflict between reward size and probability of obtaining that reward ensures that preference for high reward values reflects actual risk-taking; preferences for large rewards where there is a high probability of obtaining them would reflect an adaptive decision-making process rather than true risk-taking. Moreover, previous decision-making research has demonstrated that decision options phrased in terms of possible gains promote risk-aversive responding whereas options phrased in terms of possible losses result in risk-seeking response tendencies—a phenomenon referred to as the Framing Effect (Kahneman & Tversky, 1984). To maximize our ability to detect risk-taking and minimize additional influences on decisions, the task did not involve losses.

This study had three main objectives. The first was to determine whether patients with frontal lobe lesions were more likely than control subjects to exhibit IMP or RTB. To best address this question within the context of prior work, we designed a gambling task to separate IMP, which we defined as a failure to suppress an immediate reaction to a stimulus (i.e., a lack of control over behavior), from RTB, which we defined as a preference for responses associated with a low probability of obtaining a large reward (i.e., a type of poorly calibrated control over behavior). The underlying assumption is that RTB is a strategic response which is *selected* whereas IMP reflects reduced control over behavior and is *evoked*. We recognize that IMP, in particular, is a complex construct and many different types of impulsivity may exist. As a check on the ecological validity of our impulsivity measure, subjects also completed the Barratt Impulsiveness Scale (Patton, Stanford, & Barratt, 1995).

The second objective, closely allied with the first, was to examine whether specific lesion locations in our small sample were associated with IMP or RTB. We identified individual subjects with excessive IMP or RTB and compared their lesion locations to identify critical lesion sites. We anticipated that RTB would be more frequent with lesions encroaching on ventral frontal regions that constitute part of the reward circuitry (Rolls, 2000). IMP, on the other hand, was hypothesized to be related to more dorsal and medial regions of the frontal lobes that play a role in attentional and motor control (Floden & Stuss, 2006; Ullsperger, 2006). The third objective was to characterize response patterns that might provide insights into the processes underlying IMP or RTB. Specifically, we investigated how subjects modified their behavior following positive or negative outcomes. Positive and negative feedback are crucial elements in acquiring and altering stimulus-reward associations. In fact, people tend to use feedback to guide behavior even in contexts that do not require stimulus-reward learning (i.e., the Gambler's Fallacy). There is growing evidence that some patients with frontal lobe damage fail to make use of this feedback (Bechara et al., 1994; Fellows & Farah, 2005a).

We also evaluated how the timing of reward opportunities may influence performance on this task. Our task manipulation was based on the Common Difference Effect (Loewenstein & Prelec, 1992) from formal decision-making theory. Research in both humans and non-human animals has demonstrated that imposing a delay between reinforcement opportunities biases decisions towards larger rewards. This is best illustrated by contrasting two decisions: given a choice between one dollar today and two dollars tomorrow, most people will chose the small but immediate reward. However, if a time constant is added to both options, one dollar in 50 days or two dollars in 51 days, preferences switch and most people will choose the larger delayed reward. This effect is observed in decision contexts involving choice between two delayed options (in contrast to simple temporal discounting contexts involving choice between an immediate and a delayed option) but has not, to our knowledge, been investigated in the decision contexts similar to the current type of gambling task involving serial presentation of multiple options. We manipulated the intertrial interval to evaluate the influence of delayed reinforcement opportunities on performance in the patient and control groups. Our procedure is idiosyncratic in that we use probabilistic options rather than surety of rewards. The probabilistic nature of the choices means that, in effect, choice of any gamble is a selection of reward delay. Extending the intertrial adds a temporal constant to each choice, although it does not change the expected value of each choice.

2. Methods

The Research Ethics Board of Baycrest Centre for Geriatric Care and University of Toronto approved the study. All participants gave written consent in accordance with the Declaration of Helsinki.

2.1. Subjects

Eleven patients with chronic focal frontal lobe damage, six brain-damaged controls with cortical lesions outside the frontal lobes, and 11 age- and education-matched neurologically normal control subjects participated in the study (see Table 1). Exclusion criteria included history of neurological or psychological