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What might have been? The role of the ventromedial prefrontal cortex and lateral orbitofrontal cortex in counterfactual emotions and choice

Sara M. Levens [a,*], Jeff T. Larsen [b], Joel Bruss [c], Daniel Tranel [c], Antoine Bechara [d], Barbara A. Mellers [e]

[a] Department of Psychology, University of North Carolina Charlotte, 4033 Colvard, 9201 University City Boulevard, Charlotte, NC 28223, United States
[b] University of Tennessee, Knoxville, TN 37996, United States
[c] University of Iowa, Department of Neurology, 2007 Roy Carver Pavilion, 200 Hawkins Drive, Iowa City, IA 52242, United States
[d] University of Southern California, SGM 501, 3620 South McClintock Ave. Los Angeles, CA 90089-1061
[e] Solomon Labs, 3720 Walnut St, Room C1. University of Pennsylvania, Philadelphia, PA 19104

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ABSTRACT

Counterfactual feelings of regret occur when people make comparisons between an actual outcome and a better outcome that would have occurred under a different choice. We investigated the choices of individuals with damage to the ventral medial prefrontal cortex (VMPFC) and the lateral orbital frontal cortex (LOFC) to see whether their emotional responses were sensitive to regret. Participants made choices between gambles, each with monetary outcomes. After every choice, subjects learned the consequences of both gambles and rated their emotional response to the outcome. Normal subjects and lesion control subjects tended to make better choices and reported post-decision emotions that were sensitive to regret comparisons. VMPFC patients tended to make worse choices, and, contrary to our predictions, they reported emotions that were sensitive to regret comparisons. In contrast, LOFC patients made better choices, but reported emotional reactions that were insensitive to regret comparisons. We suggest the VMPFC is involved in the association between choices and anticipated emotions that guide future choices, while the LOFC is involved in experienced emotions that follow choices, emotions that may signal the need for behavioral change.

> "Let's not forget that little emotions are the captains of our lives and we obey them without even realizing it."
>
> Vincent Van Gogh, 1889

1. Introduction

Our emotional responses depend on the lives we live as well as the lives we could have lived. Counterfactual possibilities often serve as reference points against which we evaluate what actually occurred. Two counterfactual comparisons are particularly relevant to risky choice—disappointment and regret. Disappointment refers to the comparison between an actual outcome and a counterfactual one under a different state of the world (i.e., if a coin comes up heads instead of tails) (Bell, 1982; Loomes & Sugden, 1982). Negative comparisons are called disappointment, and positive ones are called elation. Regret refers to the comparison between an actual outcome and one that would have occurred if another option had been chosen (Bell, 1985; Loomes & Sugden, 1986). Negative comparisons are called regret, and positive ones are called rejoicing.

Research on emotions of pleasure and pain shows that regret comparisons typically have greater impact than disappointment comparisons (Mellers, Schwartz, & Ritov, 1999). Unlike disappointment comparisons, regret comparisons are under the control of the decision maker (i.e., who could have made the other choice) and are likely to be associated with a sense of personal responsibility and remorse. In this way, regret—even more than disappointment—may be beneficial for learning (Roese & Olsen, 1995; Zeelenberg & Pieters, 2007). In this paper, we investigate the unique contributions of the ventromedial prefrontal cortex (VMPFC) and lateral orbitofrontal cortex (LOFC) to risky choice and post-decision emotions indicative of regret comparisons.

The VMPFC has long been implicated in decision making and emotion (see Kringelbach, 2005; Fellows, 2007 for review). Emerging and existing theories claim the VMPFC is involved in the integration of bodily signals that influence decisions (Bechara, Damasio, & Damasio, 2000; Damasio, 1996). The VMPFC is also critical in the representation of stimulus value and the expected value of options (Fellows, 2007). Recent fMRI studies building on connections between VMPFC and decision making (Sommer, Peters, Gläscher, & Büchel, 2009; Lie et al., 2007; Chua, Gonzalez,

* Corresponding author. Tel.: +1 704 687 1965; fax: +1 704 687 1317.
E-mail address: slevens@uncc.edu (S.M. Levens).

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Taylor, Welsh, & Liberzon, 2009; Ursu & Carter, 2005) have reported distinct activation patterns in the medial and lateral OFC during periods of regret. Coricelli et al. (2005) for example, found that medial OFC activity increased with both immediate regret and cumulative regret experienced throughout the task, whereas, lateral OFC activity increased only with immediate regret of the outcome. This pattern of neural activity suggests that the medial OFC may be involved in forming associations between an anticipated response and future behavior, whereas the lateral OFC may be involved in the counterfactual comparisons that follow choice.

Collectively the aforementioned results suggest unique roles for the VMPFC and LOFC in post-decision regret; however no human lesion research has compared the effects of VMPFC and LOFC damage on post-decision emotions. Existing work by Gomez Beldarrain, Garcia-Monco, Astigarraga, Gonzalez, and Grafman (2005) showed that ventral prefrontal cortex patients reported fewer spontaneous counterfactual thoughts in response to questions. In addition, In addition, Camille et al. (2004) found that medial OFC patients reported emotions in a gambling task that were insensitive to regret. In neither study was it known whether lesions in the VMPFC extended to the LOFC.

To compare the functions of the VMPFC and LOFC regions, we administered a gambling task to patients with specific VMPFC and LOFC damage. On each trial, participants choose which of two gambles they preferred to play, each gamble having the possibility of a win or loss (Mellers et al., 1999). After making a choice, participants learned their outcome and that of the foregone gamble. Then they rated their pleasure with the outcome on a category rating scale from −50 ("Extremely Unhappy") to 50 ("Extremely Happy").

We expected that both the VMPFC and the LOFC group would report emotions that were less sensitive than other groups to regret comparisons. Our prediction was based on previous findings that VMPFC patients were less sensitive to regret, fMRI research linking LOFC to emotions involving, and the general tendency for negative emotions to signal behavioral change. We also predicted that the gamble choices made by the VMPFC patients would have lower expected values than those of the LOFC patients. This prediction is derived from past research showing that VMFPC patients made choices with lower chances of financial rewards, and damage to the VMPFC—not the LOFC—was linked to impairment in expected value calculations.

2. Experimental procedures

2.1. Subjects

Neurological patients with focal brain lesions ($n=18$) were participants in a gambling task. Lesion patients were recruited from the Patient Registry in the Department of Neurology at the University of Iowa. All patients had focal, stable, adult-onset lesions sustained at least 1 year prior to testing, and had previously undergone extensive screening and evaluation with background measures of neuropsychological function, reported previously in Bechara, Damasio, Tranel, and Anderson (1998), Tranel, Damasio , Denburg, and Bechara (2005) and Bar-On, Tranel, Denburg, and Bechara (2003). A brief survey of the basic neuropsychological functions is presented in Table 1. Exclusion criteria were a history of mental retardation, a learning disability or a psychiatric illness including substance abuse. Patients were selected for eligibility on the basis of neuroanatomical status obtained from an MRI or a computed tomography (CT) scanning (see neuroanatomical analysis section subsequently).

Patients in the VMPFC group ($n=7$) had bilateral damage in portions of the mesial orbital/ventromedial sector of the prefrontal cortex and/or the frontal pole (Fig. 1). Lesion etiology in the VMPFC group was hemorrhage due to ruptured aneurysm of the anterior communicating artery or tumor resections. Inclusion in the LOFC lesion group ($n=6$) was based on unilateral damage (left $n=3$, right $n=3$) to any part of the ventrolateral sector (including lateral orbital) of the prefrontal cortex, but spared bilateral damage to the mesial orbital/ventromedial prefrontal cortex and frontal pole, albeit in cases the damage extended to the mesial region, but only on one unilateral side (Fig. 2). All lesions were due to either tumor resection or strokes in the overlapping territories of the middle and anterior cerebral arteries.

Although some overlap in the damaged areas cannot be ruled out (i.e., individual lesions from a LOFC group may overlap with a lesion from a VMPFC group or vice versa), the VMPFC and LOFC groups are distinct in terms of lesion location. The area of maximal lesion overlap in the VMPFC group (i.e., the area coded in red color in Fig. 1, slice 3) has no overlap with the area of maximal lesion overlap in the LOFC group (i.e., the area coded in red color in Fig. 2, slice 3).

The non-frontal lesion comparison group ($n=5$) had damage in any part of the occipital and or temporal lobes that did not include the hippocampus, entorhinal cortex or amygdala (Fig. 3). These participants had left unilateral ($n=3$) or bilateral ($n=2$) damage due to strokes or tumor resections.

The three lesion groups were compared to 26 normal age-matched comparison subjects who were recruited through community advertising. Demographic characteristics for all groups are displayed in Table 1. Subjects were paid for their participation and tested in quiet laboratory conditions with task responses recorded via a touch-sensitive monitor. The study was approved by the human subjects committee at the University of Iowa. Before enrollment in the study, written informed consent was acquired in accordance with the Declaration of Helsinki.

2.2. Lesion analysis

Lesion location was confirmed with either an MRI scan or a CT scan if MRI scanning was not possible or available. Two of the seven VMPFC patients had CT scans because of clipped aneurysms (tilt angle was optimized per subject to avoid clip-related artifact (zoom 2.4, field of view 51 cm, fovea 212.5 mm, slice thickness 2–4 mm)). Two of the six LOFC patients had only CT scans, and no MRI scans were available. All patients form the lesion control group had MRI scans. Lesions of individual patients who had MRI scans were transferred manually onto a normal reference brain using the MAP-3 technique (Damasio & Frank, 1992; Damasio, 1995; Frank, Damasio, & Grabowski, 1997) that involved (i) slicing a normal 3D brain in such a way that the slices match those of the MRI scan of the subject with the brain lesion; (ii) transposing the lesion onto the slices of the normal brain, taking into consideration the relation of the lesion and the identified pertinent anatomical landmarks; (iii) rendering each transposed lesion as an 'object' that can intersect in space, and thus yield a maximal overlap relative to both surface and depth extension of damage. The few patients with only CT scans were inspected visually and assigned, based on the neuro-radiologist report, as belonging to the VMPFC or LOFC group.

2.3. Stimuli and design

Participants were told that the experiment involved choices between gambles with real monetary wins and losses. Their payments would be the total of their 84 outcomes, making it unlikely that participants would be able to keep track of their payment total during the study. Stimuli were two-outcome gambles, presented on a computer screen, as shown in Fig. 4. Each gamble appeared as a pie chart with colored regions representing the probabilities of different outcomes. Monetary outcomes were specified in or near the region. On each trial, participants selected the gamble they preferred to play.