



Lesions to polar/orbital prefrontal cortex selectively impair reasoning about emotional material



Vinod Goel^{a,b,*}, Elaine Lam^a, Kathleen W. Smith^a, Amit Goel^c, Vanessa Raymont^{d,e}, Frank Krueger^{f,g}, Jordan Grafman^h

^a Department of Psychology, York University, Canada

^b IRCCS Fondazione Ospedale San Camillo, Lido, Venice, Italy

^c School of Medicine, University of Western Ontario, Canada

^d Department of Radiology, Johns Hopkins University, Baltimore, MD, USA

^e Department of Medicine, Imperial College, London, UK

^f Department of Molecular Neuroscience, George Mason University, Fairfax, VA, USA

^g Department of Psychology, George Mason University, Fairfax, VA, USA

^h Northwestern University Medical School, Cognitive Neurology and Psychiatry and Behavioral Sciences and Physical Medicine and Rehabilitation, Chicago, IL, USA

ARTICLE INFO

Keywords:

Emotions
Logical reasoning
Decision making
Frontal lobe lesions
Hot and cold reasoning

ABSTRACT

While it is widely accepted that lesions to orbital prefrontal cortex lead to emotion related disruptions and poor decision-making, there is very little patient data on this issue involving actual logical reasoning tasks. We tested patients with circumscribed, focal lesions largely confined to polar/orbital prefrontal cortex (BA 10 & 11) (N = 17) on logical reasoning tasks involving neutral and emotional content, and compared their performance to that of an age and education-matched normal control group (N = 22) and a posterior lesion control group (N = 24). Our results revealed a significant group by content interaction driven by a selective impairment in the polar/orbital prefrontal cortex group compared to healthy normal controls and to the parietal patient group, in the emotional content reasoning trials. Subsequent analyses of congruent and incongruent reasoning trials indicated that this impairment was driven by the poor performance of patients with polar/orbital lesions in the incongruent trials. We conclude that the polar/orbital prefrontal cortex plays a critical role in filtering emotionally charged content from the material before it is passed on to the reasoning system in lateral/dorsal regions of prefrontal cortex. Where unfiltered content is passed to the reasoning engine, either as a result of pathology (as in the case of our patients) or as a result of individual differences, reasoning performance suffers.

1. Introduction

Reasoning is the process of evaluating arguments. Arguments provide rationale/reasons for actions. Real-world human reasoning always occurs against a backdrop of beliefs embedded in an emotional context. Hume suggested that without emotions, reasons may not lead to actions (Cohon, 2010). Seneca held that emotions "unfettered by reason" can have disastrous effects (Vogt, 2013). In the normal healthy population, there is a delicate balance between emotional and rational reasoning processes that is critical to our well-being, social interactions, and indeed survival. We have all experienced situations where this balance has been disrupted, often with significant consequences for our behaviour.

The importance and pervasiveness of emotions on the reasoning process can be illustrated by an advertisement aired by the National Republican Trust Political Action Committee in America, in the Fall of

2010, designed to stop the construction of a mosque in NY near the site of the 9/11 attacks (<https://www.youtube.com/watch?v=mjGJPPRD3u0>):

The call "Allah u Akbar...." rings out from a mosque. The words "The Audacity of Jihad" appear on the screen followed by images of hooded, armed men in Arab/Muslim garb firing guns and engaging in battle. This is followed by images of airplanes crashing into the Twin Towers on September 11. The announcer begins: "On September 11 **they** declared war against us. To celebrate that murder of 3000 Americans **they** want to build a monstrous 13 story mosque at Ground Zero [images of the Dome of the Rock mosque (Jerusalem)]. This ground is sacred [images of Ground Zero debris]. Where we weep [image of a weeping man wrapped in an American flag] **they** rejoice [images of Muslim men rejoicing]. That mosque is a monument to their victory and an invitation for war [images of

* Corresponding author at: Department of Psychology, York University, Canada.

<http://dx.doi.org/10.1016/j.neuropsychologia.2017.03.006>

Received 8 September 2016; Received in revised form 1 March 2017; Accepted 2 March 2017

Available online 03 March 2017

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armed Muslim men marching]. A mosque at Ground Zero must not stand [images of firefighters amid the debris of Ground Zero]. The political class has said nothing [images of Capitol Hill and President Obama]. The politicians are doing nothing to stop it. But we Americans will be heard. Join the fight to kill the Ground Zero mosque [images of the Dome of the Rock mosque]."

The advert used provocative words, images, music and text to arouse fear and hatred and essentially make the following argument:

(A)

All the 9/11 perpetrators were Muslims;
All the 9/11 perpetrators were terrorists;
Therefore all Muslims are terrorists.

Millions of Americans were moved to action by this and similar arguments. Such arguments helped to channel opinion, money, and votes, and had enormous political consequences for congressional elections. Despite its effectiveness, the argument is, of course, fallacious. Among other shortcomings, it uses words and images to facilitate the commitment of a part/whole fallacy.

Many of the Americans convinced by the above argument would probably be less impressed by the following equivalent argument:

(B)

All roses are flowers;
All roses have thorns;
Therefore all flowers have thorns.

The logical form and the truth and falsity of the propositions in each case are identical. Where they differ is that the first arouses our emotions while the second does not. Several studies confirm that emotional content affects the evaluation of logical arguments (Blanchette, 2006; Blanchette and Richards, 2004; Blanchette et al., 2007; Goel and Vartanian, 2010).

This critical balance between the rational and emotional can be permanently disrupted in neurological patients with lesions to the prefrontal cortex (PFC). Some of these patients, often with lesions to orbital PFC, exhibit aberrant emotional responses (Shallice and Cooper, 2011; Stuss and Levine, 2002) and – despite largely intact cognitive systems – also make poor decisions in real-life situations (with respect to jobs, relationships, finances etc.) (Adolphs et al., 1996; Fellows and Farah, 2007), perhaps as a consequence of disruptions in the emotional system (Damasio, 1994). However, there are very few studies directly examining the role of emotional content in logical reasoning processes.

To test for the involvement of PFC in reasoning about emotional content we administered categorical syllogisms, containing neutral content or emotional content, to neurological patients with focal lesions in polar/orbital PFC (BA 10 and 11), patients with focal parietal lesions (PL) and normal controls. Categorical syllogisms are Aristotelian logical forms involving reasoning with quantifiers (all, some) and negation. While we are rarely called upon to solve actual syllogisms in real-life, the underlying principles of quantification and negation are critical for everyday reasoning. Indeed, the part/whole fallacy in the above example is a quantification issue.

Activation in left lateral/dorsolateral PFC (BA 44, 45, 47, 9, 6) is widely reported for syllogistic reasoning tasks with neutral material in neuroimaging studies (Goel, 2007; Goel et al., 2000; Goel and Dolan, 2003a; Knauff et al., 2003; Reverberi et al., 2012; Baggio et al., 2016). One of the few lesion studies of deductive reasoning reported that patients with left lateral and superior medial frontal lesions performed poorly on elementary deductive reasoning problems (Reverberi et al., 2009). However, one imaging study (Goel and Dolan, 2003b) which used both neutral and emotionally salient logical arguments activated left lateral/dorsolateral (BA 46, 8) PFC in the former condition, and medial ventral (BA 25, 11) PFC in the emotion condition. Therefore, we hypothesized that patients with lesions to polar orbital PFC (including BA 11 and 10) would be selectively impaired in reasoning trials involving emotional content but not in reasoning trials involving

neutral content.

2. Method

2.1. Subjects

All participants were right handed males selected from Phase 3 of the Vietnam Head Injury Study (Raymont et al., 2011). These individuals came from similar socio-economic and educational backgrounds and served in Vietnam during the late 60 s and early 70 s. Both normal controls and patients were recruited from this cohort. The patients all received penetrating head injuries during their service in Vietnam. Thus their etiology, injury dates, and recovery periods were similar. Their sensory, motor, cognitive and language functions, as determined by the neuropsychological assessment, were relatively intact (see below). The normal control participants (N = 22) also served in Vietnam but did not receive head injuries.

The selection criteria for the patient group of interest was focal, circumscribed, unilateral lesions (less than 50 cc in extent) confined to polar/orbital PFC (largely BA 10 & 11), and specifically minimizing lateral and dorsal lateral PFC damage (BA 44, 45, 46, and 9). These criteria were based upon findings reported in Goel and Dolan (2003b).¹ Given that we selected for unilateral lesions, it was also important to balance for known hemispheric differences in logical reasoning (Goel, 2007). Seventeen patients (out of a cohort of 130) met these criteria. Of these, nine patients had unilateral lesions to left polar/orbital PFC and eight to right polar/orbital PFC.² A group of patients (N = 24) with posterior lesions, largely confined to parietal lobes (PL), (specifically excluding prefrontal cortex) served as a patient control group. The experimental protocol was approved by the Naval Hospital (Bethesda) Institutional Review Board, and all participants understood the study procedures and gave informed consent.

2.2. Neuropsychological assessment

All participants completed the AFQT-7A (Eitelberg et al., 1984) upon induction into the Armed Forces, and rewrote it as part of their neuropsychological assessment as part of this study.³ Wechsler Adult Intelligence Scale (WAIS-III) (Wechsler, 1997a) and Wechsler Memory Scale (WMS-III) (Wechsler, 1997b) were administered to assess participants' cognitive functioning level. Psychological and emotional functioning was assessed by Beck Depression Inventory (BDI) (Beck, 1987) and Global Assessment Functioning (SCID-GAF) (First et al., 2002). The age, education, cognitive profiles (IQ and Working Memory), including pre-injury and post injury AFQT scores, emotional and psychological measurements (BDI and SCID), along with the size of lesion (see below) are noted in Table 1.

There were no significant group differences in AFQT-7A scores (either pre- or post-injury), volume loss due to lesion (between the two patient groups), years of education, WAIS III IQ, SCID-GAF, or BDI scores. Only WMS-III Working Memory scores differed across groups, $F(2, 59) = 5.716, p = 0.005$. Post-hoc tests, after adjustment for multiple

¹ Based on Goel and Dolan (2003b), we ideally wanted to target patients with anterior medial lesions and left dorsal lateral lesions, and compare the two in neutral and emotion-laden logical thinking tasks. Unfortunately, only two patients in our cohort had lesions restricted to left lateral/dorsal PFC. Thus it was not possible to have a left dorsolateral group. We therefore selected all patients with lesions to anterior medial regions and compared their performance with that of patients with parietal lesions.

² Patients 2218 and 2351, in additions to large lesions in right BA 10 and BA 11, do have sizable lesions in right lateral PFC (Table 2). They were nonetheless included to balance for known hemispheric differences in logical reasoning. The results do not change if these patients are excluded.

³ The Armed Forces Qualification Test (AFQT) is a standardized test that measures a candidate's abilities in the areas of paragraph comprehension, word knowledge, arithmetic reasoning, and mathematics knowledge. It is administered to all members of the USA Armed Forces.

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