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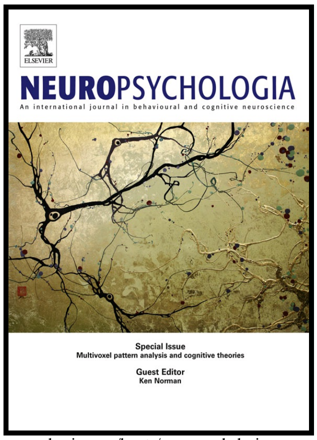

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Lesions to Polar/Orbital Prefrontal Cortex Selectively Impair Reasoning about Emotional Material

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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.

Keywords: Emotions, logical reasoning, decision making, frontal lobe lesions, hot and cold reasoning

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 & 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 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 & Richards, 2004; Blanchette, Richards, Melnyk, & Lavda, 2007; Goel & 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 & Cooper, 2011; Stuss & Levine, 2002) and – despite largely intact cognitive systems – also make poor decisions in real-life situations (with respect to jobs, relationships, finances etc.) (Adolphs, Tranel, Bechara, Damasio, & Damasio, 1996; Fellows & Farah, 2007), perhaps as a consequence of disruptions in the emotional system (A. R. 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, Buchel, Frith, & Dolan, 2000; Goel & Dolan, 2003a; Knauff, Fangmeier, Ruff, & Johnson-Laird, 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 & 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.

METHOD

Subjects

All participants were right handed males selected from Phase 3 of the Vietnam Head Injury Study (Raymont, Salazar, Krueger, & Grafman, 2011). These individuals came from similar socio-economic and educational backgrounds and served in Vietnam during the late 60s and early 70s. 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

[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.

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.

Neuropsychological Assessment

All participants completed the AFQT-7A (Eitelberg, Laurence, Waters, & Perelman, 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, Spitzer, Gibbo, & Williams, 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.

[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 administerested to all members of the USA Armed Forces.

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 comparisons using Bonferroni, indicated that working memory scores were significantly lower ($p = .004$) in the parietal control group (mean 92.13, *SE* 2.81, $n = 23$) than in the normal control group (mean 104.77, *SE* 2.90, $n = 22$), but there were no significant differences ($p = .164$) in WM scores between orbital/polar PFC patients (mean 96.76, *SE* 2.39, $n = 17$) and normal controls or between the two patient groups ($p = .769$).

Table 1

Lesion Size, Location and Extent

The lesion sites, total volume loss, and intersection of lesion sites with BAs, as determined from patient computerized tomography (CT) scans, are specified in summary overlay images in Figure 1; see also Table 1 and Tables 2 & 3. The CT scans were acquired on a GE Light Speed Plus CT scanner in helical mode (150 slices per subject, field of view covering head only). Images were reconstructed with an in-plane voxel size of 0.4 x 0.4 mm, overlapping slice thickness of 2.5 mm, and a 1 mm slice interval. Skull and scalp components were removed using the BET algorithm in MEDx (Medical Numerics Inc., Sterling, VA). Patient CT volumes were imported into ABLe (Medical Numerics Inc.) software (Makale et al., 2002) and displayed as a series of slices in a light box format. A trained neuropsychiatrist manually traced the lesions on all relevant slices. The tracings were then reviewed by J.G., who was blind to the results of the neuropsychological testing. Lesion location and volume were determined from the CT images using the Analysis of Brain Lesion software (ABLe) (Makale et al., 2002; Solomon, Raymont, Braun, Butman, & Grafman, 2007) contained in MEDx v3.44 (Medical Numerics) with enhancements to support the Automated Anatomical Labeling atlas (Tzourio-Mazoyer et al., 2002). Total lesion volume (in cubic centimeters) and lesion volume, as a percentage of total brain volume (Tables 2 & 3), was calculated by voxel count.

The patient volume was then normalized to a reference template volume by a 12-parameter affine linear transformation (allowing for translation, rotation, scaling, and shearing). The lesion voxels were included in the registration process. The ABLe reference volume is an MRI of a 27-year-old normal male transformed to Talairach space with a 12-parameter affine linear transformation. The volume is resliced at 17 degrees relative to the inferior orbitomeatal line, and 11 transverse slices that best match the Damasio & Damasio (1989) templates have been selected by a neuroradiologist and interactively labeled with BAs by reference to the Damasio & Damasio templates. Although the locations of BAs in these templates are approximate, they are widely accepted in the neuropsychology and neurology communities.

The registered patient volume was then resliced at a 17-degree cranial angle, and the 11 sections that matched the ABLe reference volume (and hence the Damasio & Damasio templates) were automatically extracted. Because the BAs are premarked on the 11 slices of the ABLe reference volume (see above) and the patient brain volume has been registered and resliced to conform to this template, the intersection of lesion with BAs was calculated by a simple voxel-by-voxel comparison.

The overlay images in Figure 1a highlight the fact that the frontal lobe patients had lesions centered in left or right BA 10 and 11. On average, 30.98% (16.60) of BA 10 and 13.23% (13.54) of BA 11 were intersected by the lesions. Lesion intersection of lateral and dorsal areas was much more limited (BA 46 = 4.99% (9.22); BA 9 = 3.56% (6.04); BA 44 = 0.11% (0.47); BA 45 = 1.65% (4.84)). Lesion extent by BA for each frontal lobe patient is specified in Table 2. The lesions in the parietal control group were more broadly distributed, but did not involve prefrontal cortex, as illustrated in Figure 1b and noted in Table 3.

One concern with traumatic injury patients is contre-coup brain injury associated with significant force and trauma. However, there is no strong evidence that penetrating traumatic brain injury due to shell fragments, which is the cause of damage to our patient population, routinely results in counter-coup effects (Grafman & Salazar, 1987). Certainly our CT scan analysis only rarely gave such hints. While we cannot eliminate the possibility of any microscopic damage (only an autopsy could do that), based on CT scan data, we believe that most of the injury imparted from the penetrating brain wounds occurred at the point of entry and along the missile path.

Task, Experimental Design, and Stimuli

Participants were presented with 40 categorical syllogisms via a computer script and asked to determine if the conclusion followed logically from the premises. Half the trials contained items with neutral content (e.g. All airplanes can fly; Some boats cannot fly; Some boats are not airplanes) while the other half contained syllogisms with emotionally-charged negative content (e.g. Some terrorists are Iraqis; All Iraqis are Arabs; Some Arabs are terrorists). The logical forms in both conditions were identical.

Whenever we are reasoning about real-world knowledge, that is, content we have beliefs about, we are subject to a robust phenomenon known as the belief-bias effect (Evans, Barston, & Pollard, 1983; Wilkins, 1928). In such situations our reasoning ability is biased by our knowledge of the world (i.e. beliefs). We are much more likely to judge a valid argument with a believable conclusion as valid and an invalid argument with an unbelievable conclusion as invalid, than an invalid argument with a believable conclusion as invalid and a valid argument with a unbelievable conclusion as valid. The former types of arguments are referred to as congruent (because believability of the conclusion facilitates the logical inference) and the latter are referred to as incongruent (because believability of the conclusion inhibits the logical inference). The number of congruent and incongruent trials was matched across conditions.

Deductive arguments are either valid or invalid. They can be invalid by virtue of being either inconsistent or indeterminate. In an inconsistent argument the conclusion is inconsistent with the information stated in the premises (e.g. "No fruit are blue. Some apples are fruit. All apples are blue"). In an indeterminate argument there is no inconsistency, but an indeterminacy in that the premises do not provide enough information to warrant the conclusion (e.g. "No Cuban cigars are dogs. No Cuban cigars are cats. No cats are dogs"). Both types of invalid arguments were included to control for the fact that they draw upon different neural systems (Goel et al., 2007).

To have a sufficient number of trials in the inconsistent invalid and indeterminate invalid categories we increased the number of invalid trials from 8 to 12, resulting in a slight imbalance with valid trials, but allowing sufficient number of trials in each condition for the planned analyses. Overall, we matched the difficulty level of syllogisms within each condition by choosing syllogism moods/figures according to published data (Dickstein, 1978).

Twenty emotionally salient and 20 emotionally neutral syllogisms were organized into a 3 Group x 2 Content x 2 Congruency factorial design.[4] The first factor Group consisted of three levels: polar/orbital PFC group, parietal (PL) group, and healthy

[4] We chose not to use determinacy as a fourth factor due to concerns about sufficient number of trials in each cell. There are known hemispheric differences in the processing of determinate and indeterminate trials (Goel et al., 2007). We chose to deal with this issue by balancing for determinacy across reasoning categories and hemisphere across frontal lobe patient selection. But at the request of a reviewer we've carried out a mixed 3 x 2 x 2 ANOVA with Group (polar/orbital PFC, PL, NC) as a between-subjects factor and Content (Neutral and Emotional) and Invalidity (Inconsistent/determinate and Indeterminate) as within-subjects factors. The results are reported in the supplementary material. To summarize, accuracy was significantly higher (collapsed across all groups) for 'inconsistently invalid' than for 'indeterminately invalid' trials, but there was no significant difference among groups and no significant Group X Invalidity interaction. There was an expected Group by Content interaction.

normal control (NC) group. The second factor Content consisted of two levels: emotionally neutral content and emotionally salient content. All emotionally salient syllogisms contained negative emotion. The logical forms in both conditions were identical. The third factor Congruency contained 10 congruent (i.e., 4 Valid and True + 6 Invalid and False) and 10 incongruent (i.e., 4 Valid and False + 6 Invalid and True) trials. Trials were presented in two blocks of 20 items (for a total of 40), with an opportunity to rest between blocks. Sample stimuli items are reproduced in Table 4 and the complete set of stimuli are reproduced in Appendix A in Supplementary Materials.

Subjects were given an explanation of logical validity along with several examples. Once they understood the concept of validity they were given the task and instructed (in writing) as follows: "Your task is to determine if the 3rd sentence follows logically from, or is entailed by, the first two sentences. If it does follow logically, reply by pressing the designated 'yes' key. Otherwise, press the designated 'no' key. Each trial will remain on the screen until you have responded. Once you have responded, the next screen will appear. Proceed as quickly and as accurately as possible. To begin, press the space bar." There was no time restriction on trials. Once a participant's response was entered, the next trial followed. As will be shown below, participants' accuracy scores during the experiment make it clear that they understood the directions.

After completing the reasoning task, participants were presented with the conclusion of each argument (e.g., All men are smokers) and asked to give it a believability score on a scale of 1 to 5, where 1 was very unbelievable and 5 was very believable. Subsequently participants were also asked to judge the content of each emotional syllogism for valence and arousal, using one keypress, using a categorical scale: negative/high arousal=1, negative/low arousal=2, positive/high arousal=3, positive/low arousal=4.

Post-Experiment Data Adjustments

As noted above, the conditions were balanced for congruency. However, a few adjustments were made before conducting the statistical analysis. First, due to a programming error, participants' response to one of the congruent syllogisms with neutral content was not recorded, resulting in 19 trials in the neutral category. Second, congruency is a function of the reasoners' beliefs. In preparing the stimuli we can guess what these beliefs will be, but we could be wrong for any particular subject. Therefore, congruency of an item was determined on a trial by trial, subject by subject basis according to each individual's response to the believability questionnaire. For example, the argument "Some animals eat children. All animals are pets. Some pets eat children" was initially categorized as an incongruent syllogism (i.e., valid but unbelievable). However, depending on each participant's believability rating, the same argument could be categorized as a congruent syllogism if a participant found the conclusion to be believable. The average number of congruent and incongruent trials remained relatively balanced after the adjustment [i.e., neutral congruent vs. neutral incongruent = 9.62 (1.47) vs. 9.32 (1.30); emotional congruent vs. emotional incongruent = 9.38 (1.41) vs. 10.6 (1.41).]

Results

Overall accuracy (proportion correct:total) in reasoning task performance was 0.733 (*SD* = .171), indicating that participants were able to infer accurately at above chance level (i.e., 0.50) and were engaged in the reasoning task. All reported results are corrected for multiple comparisons.

Group by Content by Congruency: Mean Accuracy Scores

The mean accuracy of responses was first analyzed using a mixed 3 x 2 x 2 ANOVA with Group (polar/orbital PFC, PL, NC) as a between-subjects factor and Content (Neutral and Emotional) and Congruency (Congruent and Incongruent) as within-subjects factors. There was no significant main effect of Content or Group. An expected main effect of Congruency was found ($F_{1, 43}$ = 66.109, p < 0.001), confirming that all groups provided more logical responses in the congruent condition (*M* = .828, *SE* = .022) than in the incongruent condition (*M* =. 621, *SE* =.029). There was no significant three-way interaction (Group x Content x Congruency; $F_{2, 43}$ = 2.402, p = 0.103). A significant interaction effect of Group x Content was observed ($F_{2, 43}$ = 6.678, p = 0.003). See Figure 2.

Two follow-up univariate analyses showed that there were no significant group differences on neutral reasoning ($F_{2, 52}$ = .398, p = 0.674), but that there was a significant difference among groups on emotional reasoning ($F_{2, 51}$ = 5.083, p = 0.01). Post-hoc tests using Bonferroni showed that the mean proportion of correct responses to emotional trials was significantly lower (p = .024) in the polar/orbital group (M = .624, SE = .041) than in the normal healthy control group (M = .772, SE = .037), and significantly lower in the polar/orbital group (p = .015) than in the parietal group (M = 780, SE = .029), but there was no significant difference between the parietal group and the normal control group (p = 1.000). All of these follow-up tests survived correction for multiple comparisons using Bonferroni.

Paired t-tests, comparing the mean proportion of correct responses to neutral *versus* emotional trials within each group indicated that, after Bonferroni correction for multiple comparisons (critical value of p: .05/3 = 0.0166667), there were no significant differences within any of the three groups (polar/orbital p = .049; parietal p = .022; normal controls p = .372).

We also conducted the corresponding analysis of mean reaction time (Group by Content by Congruency). There was no significant effect of Group nor any significant Group by Content by Congruency interaction. See Supplementary Material for details.

Further Investigations

To investigate further the impairment of the polar / orbital group on emotional trials, we pursed several lines of enquiry: a possible effect of congruence (between logic and believability), a possible effect of strength of beliefs about the argument conclusion, a possible effect of differential emotional response to trials, and possible correlations between percentage volume loss in particular BA areas and performance on the reasoning task.

Congruence

To determine whether the congruency of syllogisms plays any role on the effect of interest, we further examined the data by looking at the congruent and incongruent trials separately. Even though the three-way interaction of Group x Content x Congruency was found to be not significant, the pattern of results of the polar/orbital PFC patients reasoning about congruent and incongruent trials differed from that of the controls (Figure 3). Additionally, studies have shown that mediation between belief and emotion can have differential impact on congruent and incongruent reasoning trials (Goel & Vartarnian, 2010).

Therefore, we conducted a mixed ANOVA (3 Group x 2 Congruence, on emotional trials only), and found a significant difference among groups for emotional items ($F_{2, 51}$ = 5.102, p = 0.01). There was a main effect of Congruence ($F_{1, 51}$ = 68.992, p < 0.001); accuracy was significantly higher to emotionally congruent (*M* = .845, *SD* = .02) than to emotionally incongruent (*M* = .605, *SD* = .03) syllogisms. There was a significant Group X Congruency interaction ($F_{2, 51}$ = 6.642, p = 0.003).

Post-hoc tests using Bonferroni showed, after Bonferroni correction for multiple comparisons, that the mean proportion of correct responses was significantly lower (p = .023) in the polar/orbital group (*M* = .624, *SE* = .041) than in the normal healthy control group (*M* = .772, *SE* = .033), and was significantly lower in the polar/orbital group than in the parietal group (*M* = .780, *SE* = .033, *p* = .014). There was no significant difference (*p* = 1.00) between the parietal group and the normal control group (*M* = .772, *SE* = .033).

Follow-up univariate ANOVA tests showed that there was no significant difference ($F2, 51$ = .383, *p* = .684) among groups on emotional congruent reasoning (polar/orbital *M* = .824, *SE* = .037; parietal *M* = .867, *SE* = .032; normal controls *M* = .845, *SE* = .031). However, there was a significant group difference ($F_{2, 51}$ = 7.824, *p* = 0.001) in emotional incongruent reasoning; Bonferroni post-hoc tests showed that emotional incongruent reasoning accuracy was significantly impaired (*p* = .002) among the polar/orbital group (*M* = .424, *SE* = .062) when compared to normal controls (*M* = .699, *SE* = .054), and when compared (*p* = .003) to the parietal group (*M* = .693, *SE* = .040). There was no significant difference (*p* = 1.000) between the parietal and normal control groups (*M* = .699, *SE* = .054). The results of these univarate and post-hoc tests survive Bonferroni correction for multiple comparisons.[5]

To address the question of whether the two types of incongruent trials (valid/unbelievable; invalid/believable) solicited different patterns or responses from patients, we followed up the incongruency analysis with a separate paired t-test within each group. There were no significant differences within the polar/orbital group (or

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[5] For the sake of completeness, we conducted a mixed ANOVA (3 Group x 2 Congruence, on neutral trials only), and found no difference among the groups for neutral items $F_{2, 52}$ = .398, *p* = .674). The mean proportion of correct responses to neutral items was as follows: polar/orbital group (M = .733, SE = .042); parietal group (M = .698 , SE = .038); normal control group (M = .743 , SE =.034).

within the other groups) in mean accuracy on emotional trials by type of incongruence. (See Figure S1.)

Finally, to examine reaction times we carried out univariate ANOVA tests. The mixed ANOVA (3 Group x 2 Congruency), neutral reaction times only, indicated a significant main effect of Congruency; responses to neutral incongruent trials (*M* = 24976 ms, *SE* = 1488) were significantly slower ($F_{1, 52}$ = 33.342, *p* = .001) than to neutral congruent trials (*M* = 21333 ms, *SE* = 1346). There was no significant Group X Congruency interaction (*p* = .446) for neutral reaction times, and no significant between-groups difference (*p* = .443) in mean reaction times to neutral syllogisms. The mixed ANOVA (3 Group x 2 Congruency), emotional reaction times only, indicated a significant main effect of Congruency; responses to emotional incongruent trials (*M* = 26668 ms, *SE* = 1659) were significantly slower ($F_{1, 51}$ = 9.272, *p* = .004) than to emotional congruent trials (*M* = 22273 ms, *SE* = 1600). There was no significant Group X Congruency interaction (*p* = .584) for emotional reaction times, and no significant between-groups difference (*p* = .892) in mean reaction times to emotional syllogisms.

As the effect on accuracy was driven by the emotional incongruent trials we further explored these by looking at the believability and the emotionality ratings of emotional trials.

Belief Ratings

We considered the possibility that the impaired performance of the polar/orbital group on reasoning in the emotional incongruent condition might be explained by a stronger (or weaker) commitment to beliefs in this group. To explore this possibility, we calculated the mean believability rating for each of the 20 emotional syllogisms separately, across all participants, and separately by each group. Then, we conducted a univariate analysis of mean ratings and found no significant differences in commitment to beliefs among the groups ($F_{2, 57} = .012$, $p = .988$). We also conducted two separate univariate analyses of mean ratings, one of conclusions that were intended to be false, and the other of conclusions that were intended to be true. There were no significant differences among groups in either analysis (intended false: $F_{2, 27} = .160$, $p = .853$; intended true: $F_{2, 27} = .386$, $p = .683$). Thus, there was no difference in the strength (or weakness) of commitment to beliefs that might account for the impaired performance of polar/orbital patients on emotional incongruent reasoning trials.

Emotionality Ratings

Another possibility is that our effect of interest could have something to do with differences in emotional response to trials. To examine this possibility, we calculated, for each participant, for each of the valence/arousal categories, the proportion of the number of emotional trials rated in a specific category to the total number of rated emotional trials. For example, if a participant provided emotion ratings for all 20 trials, and the rating was ‘negative aroused’ for five trials, then the proportion of negative aroused trials for that participant was 5:20, or .25. Then we looked for group differences in the mean proportion of emotion ratings for each of the valence/arousal categories (negative aroused, positive aroused, positive calm, negative calm), using a separate univariate analysis of variance for each category. There were no significant between-group differences in any of these four categories. Next, we repeated these analyses for the emotional incongruent trials only. Here, although we found a significant overall between-group difference for the number of incongruent trials rated negative calm ($F_{2, 53} = 3.409$, $p = .04$), the post-hoc test (with Bonferroni correction) showed no significant differences between any pairs of the three groups; there was only a tendency ($p = .073$) for parietals to have more trials (mean 4.13, *SD* 1.87, $n = 24$) than controls (mean 2.69, *SD* 1.62, $n = 16$).

Correlational Analysis

We carried out a correlational analysis between the extent of damage in Brodmann areas (collapsed across hemispheres) identified in Table 2 and performance accuracy in the reasoning task. The only significant finding was a negative correlation between volume loss in BA 11 (n=13) and performance on emotional reasoning trials (r = -.656, p = .028). Patients with larger lesions to BA 11 performed more poorly on the emotional trials. Furthermore, there was no correlation between performance on neutral reasoning trials and lesion extent in BA 11. There were no significant correlations between lesion extent in BA 10 and performance on neutral (n=15) or emotional (n=13) reasoning trials. Similarly, there were no significant correlations between lesion extent in BA 46, 47, and 9 and performance in either the emotional (n=7, 7, 10 respectively) or neutral (n=9, 8, 9 respectively) reasoning trials.

Discussion

The goal of the study was to test the hypothesis that neurological patients with focal lesions largely confined to regions of BA 10 and BA 11 are selectively impaired, compared to normal healthy controls, in reasoning about emotionally charged material but not in reasoning about neutral material. Our results support the hypothesis. Patients with lesions to polar/orbital PFC regions reasoned well about arguments with neutral content but were selectively impaired in reasoning about the identical logical forms with emotionally charged content, in particular, on incongruent reasoning trials. Furthermore, only lesion extent in BA 11 (negatively) correlated with performance on reasoning items with emotionally charged content.

The reasons for the good performance of the polar/orbital patients in reasoning with emotionally neutral material is reasonably clear. Neuroimaging studies have not activated these regions in logical reasoning tasks involving categorical syllogisms (Goel, 2007; Prado et al., 2011).[6] So if they are not recruited by the task, damage to these areas may have minimal impact on task performance. The reasons for their impaired performance in reasoning about emotionally charged material require further discussion.

These results cannot be explained by differences in IQ scores (preinjury or post injury), years of education, or lesion size, as these did not differ among groups. There

[6] There is one imaging study (Monti et al., 2007) that has reported activation in left BA 10 in a deductive reasoning task involving propositional logic connectives using neutral content (rather than the categorial syllogism task we are using). However a meta-analysis study by Prado et al. (2011) questions the robustness of this result, even in the context of propositional connectives. Certainly our patients with lesions to BA 10 are not impaired in the neutral reasoning condition.

was a significant between-group difference in working memory; but only in the parietal group. Nevertheless, the parietal group patients performed as well as the normal controls on all conditions (Figures 2 & 3), suggesting that their levels of working memory were sufficient for the task.

It is also known from the reasoning literature that variables, such as logical form, congruency, and negation can have an impact on reasoning task performance (Dickstein, 1978; Evans et al., 1983; Evans & Over, 1996) and recruit different neural systems (Goel, 2007; Goel et al., 2000; Goel & Dolan, 2003a; Prado et al., 2011). These factors were balanced for (see Methods) and can be discounted as contributing to the results.

Another possibility is that the results are driven by a difference in the level of abstraction between the neutral content and emotional content materials. It might be argued that perhaps the former tend to be more concrete and imageable (i.e. being about fruit, boats, coffee, etc.) than the latter (i.e. being about homosexuals, terrorists, Iraqis etc.). There are known differences in brain regions involved in reasoning about more concrete and more abstract materials (Goel et al., 2000). More concrete reasoning trials tend to activate left lateral frontal systems while more abstract reasoning trials activate bilateral frontal lateral/dorsolateral systems (Goel et al., 2000). This is a hemispheric difference controlled for in our patient selection, by matching up the number of patients with left and right PFC lesions. We are unaware of any data indicating that BA 10/11 may be differentially involved in reasoning about more abstract items.

It is also possible that our effect of interest might be a function of group differences in the perception of emotionality in the syllogisms. However, we found no significant between-group differences in mean self-reported emotionality measures.

Yet another possibility is that differences in performance between the emotional and the neutral items may have nothing to do with emotion. If the orbital/polar PFC patients found emotional items more believable or unbelievable than the neutral items, then the effect of interest could be explained in terms of a stronger evocation of belief (and thus an increased belief-bias effect) (Evans et al., 1983). However, there were no group differences in mean believability ratings.

So even though polar/orbital PFC patients were no more likely to believe emotionally charged statements such as "all Muslims are terrorists" than normal controls, they were more likely to draw incorrect conclusions from emotionally charged arguments such as:

(C)

All Americans are brave people.

No brave people are War Veterans.

No Americans are War Veterans.

but not

(D)

Some apples are sweet fruit.

All sweet fruit are grapes.

Some grapes are apples.

The key to understanding the results may be found by examining the steps involved in solving incongruent reasoning problems (like C & D). As noted previously, in incongruent trials, there is a conflict between the believability of the conclusion and the response dictated by the logic of the argument. The key steps in successfully responding to these trials are (1) detecting the conflict between the believability of the conclusion (unbelievable in C & D) and the logical form/validity of the argument (valid in C & D); (2) suppressing the prepotent urge to respond on the basis of the believability of the conclusion (i.e. the belief-bias effect); and (3) formally/logically evaluating the argument.

What is interesting is that the polar/orbital PFC patients performed as well as the control groups on the neutral content incongruent trials like D. So they are clearly capable of detecting the conflict, overcoming the belief-bias effect, and formally/logically evaluating the arguments, at least in the neutral content condition. This is consistent with the neuroimaging data which do not show activation of polar/orbital PFC in reasoning with neutral content (Goel, 2007; Prado et al., 2011).

In both examples, C and D, the conclusions are equally false and unbelievable. It is patently false that "some grapes are apples" and equally false that "no Americans are War veterans". In both cases the conclusions would elicit an automatic 'no' response. However, the correct logical response to the argument requires a 'yes' response, requiring a suppression of beliefs. In the case of D, suspending the belief that "some grapes are apples" is an intellectual exercise correlated with IQ and working memory (Stanovich & West, 2000). The suppression of the belief "no Americans are War veterans" (especially if you are an American war veteran), however, requires not only suppression of the belief but also suppression of unpleasant emotional content (with valence and arousal components). The polar/orbital patients have no difficulty in dealing with simple falsity, but when the falsity involves unpleasant emotional content they are unable to suppress it. In the case of the normal controls, also Vietnam War veterans, suppression of the two beliefs in the conclusions of C and D seem to be equally successful.

We propose that an intact polar/orbital prefrontal cortex is required to filter the emotional content from the argument, and if this is done prior to the logical evaluation, the two conclusions should be equally easy, or difficult, to suppress. To the extent that filtering is successful, the content will be treated as neutral by the reasoning system. To the extent that filtering is not successful, as a result of individual differences or pathology, as in the case of our polar/orbital PFC patients, to that extent the unfiltered emotionally charged content will pass on to the reasoning system and cause disruptions in the detection of conflict between the believability of the conclusion and the logical form/validity of the argument; and/or overcoming the prepotent belief-bias effect; and/or the logical evaluation of the argument. Our experimental design does not allow us to differentiate between these three possibilities.

The finding that polar/orbital PFC patients perform well on neutral reasoning trials is consistent with a large number of imaging studies which implicate the left lateral PFC (BA 44, 45, 47) but not BA 10/11 in logical reasoning tasks using categorical syllogisms (Baggio et al., 2016; Goel, 2007; Goel et al., 2000; Goel et al., 2000; Goel & Dolan, 2003a; Prado et al., 2011; Reverberi et al., 2012; Waechter, Goel, Raymont, Kruger, & Grafman, 2013). The finding that polar/orbital PFC patients are impaired in reasoning with emotional content is consistent with the findings of a number of studies implicating orbital cortex in impaired affective processing in various tasks, including affective theory of mind reasoning (Shamay-Tsoory, Tibi-Elhanany, & Aharon-Peretz, 2006), mentalizing (Shamay-Tsoory & Aharon-Peretz, 2007), emotional perspective-taking (Hynes, Baird, & Grafton, 2006), moral reasoning/decision making (Greene, Sommerville, Nystrom, Darley, & Cohen, 2001; Harenski & Hamann, 2006; Moll, de Oliveira-Souza, Bramati, & Grafman, 2002; Schaich Borg, Hynes, Van Horn, Grafton, & Sinnott-Armstrong, 2006), and decision making (Bar-On, Tranel, Denburg, & Bechara, 2003; Bechara, Damasio, Tranel, & Damasio, 1997).

Interestingly, while it is widely accepted that lesions to orbital prefrontal cortex lead to impairments in emotional processing, basic details of how they do so are still largely unclear. For example, in one study involving a moral judgment task (not a rational decision making task) the authors argue that damage to ventral medial PFC leads to a blunting or muting of emotional response and an increase in utilitarian responses compared to normal controls (Koenigs et al., 2007). However, some of the same authors, in another study involving a rational decision making task (the Ultimatum Game), conclude that lesions to ventral medial PFC lead to responses guided by enhanced, unbridled emotions (Koenigs & Tranel, 2007). The latter is in line with our own conclusion that damage to polar/orbital PFC results in a failure of filtering of emotional content from the logical arguments before they are passed on to the reasoning system. Perhaps, the larger point here is that much remains to be understood about how polar/orbital frontal cortex interacts with task and contextual demands to modulate emotional processing.

As a final point, it is also worth emphasizing the importance of our negative result: i.e. that there is no difference between patients with lesions to the parietal lobes and normal controls in reasoning about categorical syllogisms. This is an important finding in that several imaging studies suggest that the parietal cortex (in particular ßBA 7 & 40) is critical for logical reasoning (Knauff et al., 2003). Most of our parietal patients did have lesions to BA 7 & 10 (Table 3), yet performed as well as normal controls in all conditions of the reasoning task. These negative results reinforce the point that recruitment of different brain regions for logical reasoning is a function of the content and logical form of arguments (Goel, 2007; Prado et al., 2011). For categorical syllogisms, the critical region seems to be prefrontal cortex, while for transitive inference parietal lobes play a necessary role (Waechter et al., 2013).

In conclusion, it is widely accepted that lesions to orbital prefrontal cortex lead to emotion-related disruptions and poor decision-making. Our patients with polar/orbital lesions were cognitively intact, as measured by standard neuropsychological tests. Their logical reasoning abilities, in the absence of emotional content, were as good as that of normal controls. Their self-reported judgments of the emotionality of statements were similar to that of normal controls. Furthermore, they were no more likely to believe emotionally charged statements such as "all Muslims are terrorists." But nonetheless, their ability to reason about emotionally charged content was selectively impaired. We suggest that the polar/orbital prefrontal cortex serves a role in filtering emotional content from arguments before they are passed on to the reasoning system in more 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.

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Figure legends

Figure 1. a) Lesion overlay maps for patients displayed on transverse slices (L=R) of the AAL Atlas, found in ABLe software (Medical Numerics Inc.) (Makale et al., 2002). a) Slices 54-89 of polar/orbital lesions patient group at overlap threshold of 2. b) Slices 110-149 of parietal lesions patient group at overlap threshold of 2. See text.

Figure 2. Group by Content interaction. Orbital/polar PFC patients are selectively impaired in reasoning with emotional content.

Figure 3. a) Accuracy rate on congruent trials as a function of content; b) Accuracy rate on incongruent trials as a function of content.

Table 1. *Characteristics of Patient and Normal Control Participants*

	Polar/Orbital PFC *M (SD)*	Parietal Lobe *M (SD)*	Normal Controls *M (SD)*
Number of Participants (n)	17	24	22
Education (Year)	14.00 (1.68) (*n*= 16)	15.61 (2.54) (*n* = 23)	15.00 (2.82) (*n* = 21)
Pre-injury IQ (AFQT-7A) in percentile rank	59.12 (24.17)	60.45 (27.09) (*n* = 22)	65.95 (21.81)
Post_injury IQ (AFQT-7A) in percentile rank	65.93 (23.77) (*n* = 15)	67.19 (28.57) (*n* = 21)	75.33 (18.62) (*n* = 18)
WAIS-III			
Full Scale (IQ)	103.24 (9.74)	103.13 (14.93)	106.68 (11.03)
Verbal (IQ)	103.71 (9.28)	105.46 (14.63)	108.55 (12.56)
Performance (IQ)	102.00 (11.83)	101.17 (16.76)	106.68 (11.03)
WMS-III			
General Memory	102.82 (19.67)	100.58 (17.08)	105.59 (14.77)
Working Memory	96.76 (9.86)	92.13 (13.46) (*n* = 23)	104.77 (13.60)
BDI	12.24 (12.41)	6.50 (5.54)	11.36 (8.22)
SCID – GAF	74.93 (11.70) (*n* = 15)	77.25 (11.86)	73.73 (11.60)
Lesion Volumes Loss (cc)	20.14 (10.84)	28.94 (25.20)	0

AFQT-7A = Armed Forces Qualification Test; WAIS = Wechsler Adult Intelligence Scale; WMS = Wechsler Memory Scale; BDI = Beck Depression Inventory; SCID-GAF = Structural Clinical Interview for DSM-IV – Global Assessment Function.

Table 4. *Sample Syllogisms. The full set of syllogisms are provided in the Appendix in Supplementary Material.*

	Neutral Content	Emotional Content
Congruent	All gods are immortal. No immortal beings are men. No men are gods. (valid, believable conclusion)	Some terrorists are Iraqis. All Iraqis are Arabs. Some Arabs are terrorists. (valid, believable conclusion)
	No skiers are smokers. Some men are not skiers. All men are smokers. (invalid, unbelievable conclusion)	No Americans read the Bible. Some Americans are homosexuals. All homosexuals read the Bible. (invalid, unbelievable conclusion)
Incongruent	Some apples are sweet fruit. All sweet fruit are grapes. Some grapes are apples. (valid, unbelievable conclusion)	All Americans are brave people. No brave people are Vietnam veterans. No Vietnam veterans are Americans. (valid, unbelievable conclusion)
	No coffee contains nicotine. No nicotine is found in tea. No tea contains coffee. (invalid, believable conclusion)	No Americans are vicious. Some serial killers are Americans. All serial killers are vicious. (invalid, believable conclusion)

Table 2. Percentage of each Brodmann Area (BA) lesioned in PFC patients.

	Right Hemisphere							Left Hemisphere						
Patient ID#	**BA 10**	**BA 11**	**BA 47**	**BA 46**	**BA 9**	**BA 44**	**BA 45**	**BA 10**	**BA 11**	**BA 47**	**BA 46**	**BA 9**	**BA 44**	**BA 45**
1095	32.1	5.2	5.6	13.2	0.6	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2034	54.5	31.0	1.9	0.9	1.5	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2101	16.8	0.0	0.0	0.0	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2196	26.1	9.7	0.0	0.3	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2218	46.6	22.0	16.7	26.8	9.6	2.0	19.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2351	29.5	3.2	0.3	28.2	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0

3003	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3013	46.2	21.4	0.0	2.2	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
267	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.5	28.7	0.4	0.0	0.0	0.0	0.0
309	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.3	0.0	0.0	9.1	1.0	0.0	0.0
318	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.1	33.0	10.6	0.0	2.2	0.0	0.0
1216	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.2	36.4	0.0	3.0	0.5	0.0	0.0
1364	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.1	0.9	0.0	0.0	2.8	0.0	0.0
1561	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	24.7	10.0	1.2	0.0	0.0	4.3
2122	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.8	3.6	0.0	0.0	23.8	0.0	0.0
2164	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	1.8	0.0	0.0	0.0	0.0	0.0
2354	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.7	3.4	1.3	0.0	2.3	0.0	0.0

Table 3. Percentage of each Brodmann Areas (BA) lesioned in parietal patients.

	Right Hemisphere									Left Hemisphere								
Patient ID#	**BA 1**	**BA 2**	**BA 3**	**BA 5**	**BA 7**	**BA 31**	**BA 39**	**BA 40**	**BA 43**	**BA 1**	**BA 2**	**BA 3**	**BA 5**	**BA 7**	**BA 31**	**BA 39**	**BA 40**	**BA 43**
103	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.2	1.3	0.0
1510	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	1.12	0.0	0.0	27.2	0.0
1621	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.03	0.01	0.0	0.8	0.2	53.5	6.8	0.0
2104	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.51	6.31	3.11	0.0	0.0	0.0	0.0	14.7	20.9
3024	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	4.2	2.4	0.0	0.0	0.0	0.0	3.4	21.1
173	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
408	0.04	0.26	2.84	0.62	1.3	0.0	42.1	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
439	1.42	5.11	4.7	8.4	1.6	0.7	0.0	19.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1061	3.2	5.5	2.2	0.6	0.0	0.0	0.0	15.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1206	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1298	0.0	0.0	0.0	0.0	0.0	0.0	21.5	23.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1366	0.0	0.0	0.0	0.0	0.0	0.0	37.4	20.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1434	0.03	0.06	0.01	0.0	0.0	3.3	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1443	9.0	2.2	5.9	8.9	1.2	0.0	0.0	33.6	21.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1461	0.0	0.0	0.0	0.0	0.0	1.1	39.4	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1580	0.0	2.5	0.01	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3054	0.7	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
230	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	2.4	24.8	28.0	42.2	45.1	0.3	4.4	0.0
1081	0.	0.	1	6	2	6.	0.	0.	0.	0.	0.	2	5	5	7.	14	1.	0.

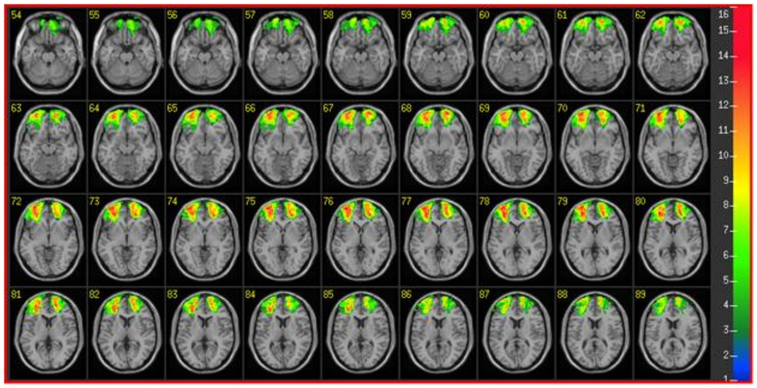
	0	0	8.0	0.3	6.1	1	0	1	0	0	0	1.3	0.8	0.6	9	.7	2	0
1288	0.0	0.0	0.0	0.02	0.01	0.0	0.2	0.0	0.0	8.1	21.8	0.11	0.28	9.25	4.1	48.3	77.2	0.0
1341	0.0	0.0	0.0	0.4	1.2	0.0	0.0	0.0	0.0	0.0	2.9	4.2	0.83	1.4	24.9	0.0	1.7	0.0
2028	0.0	0.01	0.2	0.6	0.0	0.0	0.0	27.3	0.0	0.8	5.13	2.7	3.61	0.42	0.0	0.0	0.0	0.0
2116	0.0	3.8	5.3	0.6	0.0	31.9	28.9	33.5	0.0	1.7	0.6	0.6	4.1	2.23	28.0	0.0	32.2	0.0
2341	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	9.7	2.8	1.9	2.5	17.1	0.0

Highlights

Polar/orbital lesions selectively impair logical reasoning about emotionally charged material

P/O lesions do not impair logical reasoning with neutral content

It is proposed that P/O cortex filters emotional content for rational thought



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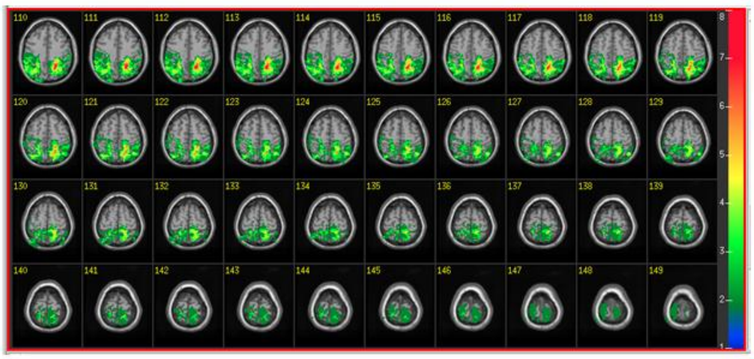

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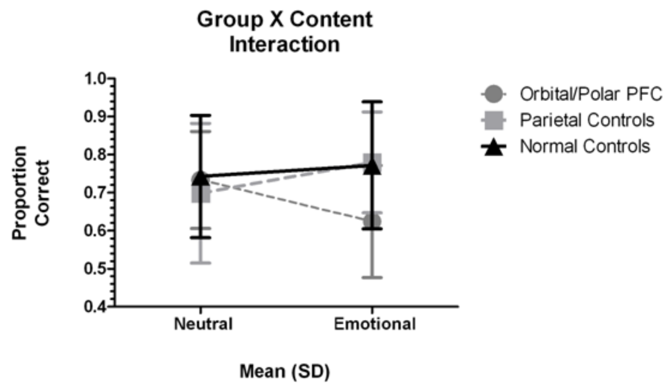
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Proportion
Correct
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0.9
0.8
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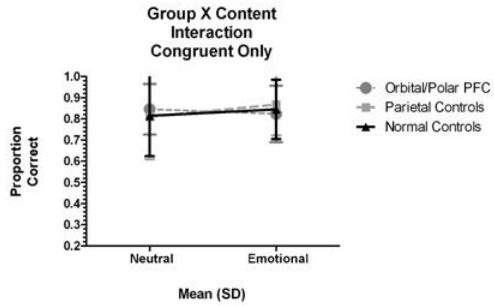
0.6
0.5
0.4
Neutral
Emotional
Mean (SD)
Orbital/Polar PFC
Parietal Controls
Normal Controls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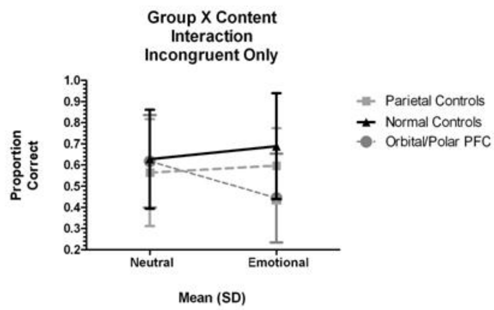
Neutral
Emotional
Mean (SD)
Orbital/Polar PFC
Parietal Controls
Normal Controls

A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0.2
Neutral
Emotional
Mean (SD)
Parietal Controls
Normal Controls
Orbital/Polar PFC

B