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The neural bases for devaluing radical political statements revealed by penetrating traumatic brain injury

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Given the determinant role of ventromedial prefrontal cortex (vmPFC) in valuation, we examined whether vmPFC lesions also modulate how people scale political beliefs. Patients with penetrating traumatic brain injury (pTBI; $N = 102$) and healthy controls (HCs; $N = 31$) were tested on the political belief task, where they rated 75 statements expressing political opinions concerned with welfare, economy, political involvement, civil rights, war and security. Each statement was rated for level of agreement and scaled along three dimensions: radicalism, individualism and conservatism. Voxel-based lesion-symptom mapping (VLSM) analysis showed that diminished scores for the radicalism dimension (i.e. statements were rated as less radical than the norms) were associated with lesions in bilateral vmPFC. After dividing the pTBI patients into three groups, according to lesion location (i.e. vmPFC, dorsolateral prefrontal cortex [dlPFC] and parietal cortex), we found that the vmPFC, but not the dlPFC, group had reduced radicalism scores compared with parietal and HC groups. These findings highlight the crucial role of the vmPFC in appropriately valuing political behaviors and may explain certain inappropriate social judgments observed in patients with vmPFC lesions.

Keywords: political beliefs; radicalism; traumatic brain injury; ventromedial prefrontal cortex; voxel-based lesion-symptom mapping

INTRODUCTION

Patients with focal lesions involving the ventromedial prefrontal cortex (vmPFC) have abnormal social behavior and thinking (Mah *et al.*, 2004, 2005). They may behave or speak inappropriately in social situations or react impulsively to minor forms of stress (Burgess and Wood, 1990). These social impairments also involve inappropriate affect (Harlow, 1848, 1868; Eslinger and Damasio, 1985) despite preserved cognitive functions, such as language, memory and perception (Damasio *et al.*, 1990; Dimitrov *et al.*, 1999). These social impairments also alter how these same individuals value social events. Previous studies showed that lesions to vmPFC impair the ability to judge moral dilemmas (Koenigs *et al.*, 2007; Moretto *et al.*, 2010; Young *et al.*, 2010), accepting dangerous actions to maximize good consequences (i.e. utilitarian moral judgments). Other studies have shown impaired social value judgments in patients with orbitofrontal lesions. For example, these patients struggle to distinguish emotional facial expressions (Hornak *et al.*, 1996, 2003), make abnormal social judgments (Mah *et al.*, 2004; Willis *et al.*, 2010) and frequently make social faux pas (Beer *et al.*, 2006; Leopold *et al.*, 2012). Based on the association between vmPFC and impaired social behaviors and judgments, it would be reasonable to expect that patients with vmPFC would also exhibit impairments in political thinking.

Despite a growing functional imaging literature on the brain basis of political beliefs (Amodio *et al.*, 2007; Zamboni *et al.*, 2009; Gozzi *et al.*, 2010), only one study investigated patients with focal lesions (Coronel *et al.*, 2012). However, this study focused on voting behavior in a small group of focal lesion patients—who had amnesia due to hippocampal damage—and did not examine their underlying political beliefs. To date there have been no studies of political beliefs in patients with focal lesions.

In this report, using a lesion mapping strategy, we investigated whether focal brain lesions crucially affect three dimensions that reflect how people endorse political beliefs. We compared the performance of penetrating traumatic brain injury (pTBI) patients with healthy controls (HCs) on the political belief task (Zamboni *et al.*, 2009). The task consisted of different statements expressing political opinions related to welfare, economy, political involvement, civil rights, war and security. Participants (pTBI patients and HC) rated each statement along three dimensions identified in a previous study, we conducted (Zamboni *et al.*, 2009): radicalism (i.e. whether a statement was radical or moderate), individualism (whether a statement better reflected individual or societal concerns) and conservatism (whether a statement reflected conservative or liberal ideology). They also rated their agreement with each statement. Given that previous findings have shown the PFC to help in shaping political beliefs (e.g. Zamboni *et al.*, 2009), and the fact that the majority of pTBI patients in our sample had marked damage to the PFC, we hypothesized that pTBI patients would differ from controls in their political ratings across the three dimensions. Furthermore, we hypothesized that the patients with vmPFC lesions would demonstrate particular difficulty in scaling political statements along the radicalism dimension given their frequently reported impairments in social and reward valuation (Mah *et al.*, 2005; Moretti *et al.*, 2009).

MATERIALS AND METHODS

Subjects

One hundred sixty-eight participants (134 pTBI and 34 HC) took part in Phase IV of the W.F. Caveness Vietnam Head Injury Study (VHIS) registry, which is a prospective longitudinal study of veterans

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with focal pTBI and HC veterans with no history of brain injury. Phase IV was conducted from 2008 to 2012, ~40–45 years post-injury, at the National Institutes of Health Clinical Center (Bethesda, MD) (Raymont *et al.*, 2011). Participants underwent medical and neuropsychological evaluations over a 5- to 7-day period. All participants gave their written informed consent, which was approved by the Institutional Review Board at the National Institute of Neurological Disorders and Stroke, Bethesda, MD.

Participants underwent extensive neuropsychological assessment as part of the VHIS Phase IV which included the following measures: Wechsler Abbreviated Scale of Intelligence—WASI for global cognitive functioning (Wechsler, 1999), Token Test (TT) for language comprehension (McNeil and Prescott, 1994), the Frontal System Behavior Scale—FrSBe for disinhibition (Malloy and Grace, 2005) and the Sorting Test for executive functioning (Delis *et al.*, 2001). The visual object and space perception battery (VOSP) was used to assess object and space perception (Warrington and James, 1991; Schintu *et al.*, 2014). Post-traumatic stress disorder was assessed using the Mississippi Scale for Combat-Related Post-Traumatic Stress Disorders (M-PSTD) (Hyer *et al.*, 1991).

In addition, pre-injury intelligence was assessed using the Armed Forces Qualification Test (AFQT-7A, 1960). The AFQT was administered to individuals upon military induction before their brain injury. This test is composed of four subtests (i.e. vocabulary knowledge, arithmetic word problems, object-function matching and mental imagery) using multiple-choice items. It has been standardized within the US military and is highly correlated with full-scale Intelligence Quotient scores (Grafman *et al.*, 1988).

In our study, 140 (i.e. 106 pTBI and 34 HC) out of the total 168 participants of Phase IV were administered the Political Beliefs Task. Participants, who did not complete the Political Beliefs Task ($n=28$ pTBI), were excluded from the analysis. In addition, participants were excluded from the analysis if they had incomplete computed tomography (CT) scan information ($n=2$ pTBI) or intelligence test scores below 80 ($n=2$ pTBI and $n=3$ HC). Therefore, behavioral and voxel-based lesion-symptom mapping (VLSM) analysis was conducted on 102 pTBI and 31 HC. For the group analysis, a subsample of 36 pTBI patients with lesions involving vmPFC ($n=14$), dlPFC ($n=8$) and parietal cortex ($n=14$) were selected. Two-tailed independent *t*-tests were performed to compare veterans with pTBI and HC in age, years of education and neuropsychological measures (e.g. AFQT, WASI, TT, Barret Impulsivity Scale and FrSBe). The pTBI and HC were matched with respect to age [$t(131)=-0.05$, $P=0.95$], level of education [$t(131)=-0.99$, $P=0.32$], handedness [contingency coefficient 1.83, $P=0.39$] and pre- [$t(131)=-0.1.23$, $P=0.21$] and post-injury intelligence [$t(131)=-0.56$, $P=0.57$] (Table 1). There were no between-group differences on the selected neuropsychological measures, except for the sorting card task (Table 2).

The participants' political orientation was measured by a single 7-point Likert scale (from 1 = extremely liberal to 7 = extremely conservative) (Robinson *et al.*, 1999). Individuals with a score between 1 and 3 were defined as liberals. Moderates were defined by a rating of 4 and conservatives had a score between 5 and 7. Of the pTBI patients, 27% ($n=28$) identified themselves as liberal, 49% ($n=50$) identified themselves as conservative and 24% ($n=24$) identified themselves as moderate. Two pTBI patients did not answer the question. Of the HC, 32% ($n=10$) identified themselves as liberal, 45% ($n=14$) identified themselves as conservative and 23% ($n=7$) identified themselves as moderate.

The political belief task

The political belief task requires participants to rate how much they agreed with each of a set of 75 political statements that varied along the three dimensions (radicalism, individualism and conservatism) that were previously identified using a multidimensional scaling procedure (Zamboni *et al.*, 2009). The statements expressed political opinions related to welfare and economy; values and religious beliefs; general politics and political involvement; civil right; crime security and war (e.g. 'Politicians should limit gender discrimination'; 'The government should control the press'; See Supplementary Appendix for the complete list of statements). The sequence of statements for each dimension (i.e. agreement, radicalism, individualism and conservatism) was randomized, and the order of the dimensions counterbalanced across subjects. Lower scores on the radicalism dimension indicated a more 'moderate' judgment, whereas lower scores on the individualism indicated a more 'individual related' judgment and lower scores on the conservatism dimension indicated a more 'conservative' judgment.

Table 1 Mean ± standard deviations and statistic of demographic characteristics of pTBI and HC

Group	pTBI = 102	HC = 31	Statistics *t*-value	*P*-value
Age (years)	63.38 ± 3.09	63.42 ± 3.82	−0.055	0.956
Education (years)	14.62 ± 2.20	15.06 ± 2.17	−0.990	0.324
Handedness (R:A:L)	79:2:21	24:2:5	$\chi^2 = 1.836$	0.399
AFQT (percentile)	66.48 ± 22.84	72.90 ± 17.05	−1.23	0.219

R, right-handed; A, ambidextrous; L, left-handed; AFQT, Armed Forces Qualification Test for pre-injury general intelligence administered to individuals upon military induction.

Table 2 Mean ± standard deviations and statistics of neuropsychological tests of pTBI and HC

Group	pTBI = 102	HC = 31	Statistics *t*-value	*P*-value
WASI (full scale)	110.20 ± 23.80	112.7 ± 11.60	−0.562	0.575
TT (total)	98.44 ± 2.18	98.32 ± 1.90	−1.059	0.677
VOSP (total)	19.48 ± .98	19.52 ± 1.52	−0.176	0.861
FrSBe (disinhibition)	62.12 ± 19.85	66.35 ± 18.08	−1.059	0.292
Sorting card (total)	10.61 ± 3.33	12.32 ± 3.10	− 2.546	0.012
M-PSTD	77.60 ± 21.80	83.80 ± 23.30	−1.373	0.172

WASI, Wechsler Abbreviated Scale of Intelligence; TT, Token Test for basic verbal comprehension; VOSP, Visual Object and Space Perception Battery for object and space perception; FrSBe, Frontal System Behavioral Scale and Sorting Card for executive functioning; M-PSTD, Mississippi Scale for Combat-Related Post-Traumatic Stress Disorders.

CT acquisition and VLSM analysis

Axial CT scans used in this article were previously acquired during Phase III of the VHIS study (~6 years before Phase IV), but a clinical reading of CT scans acquired during Phase IV indicated that the lesions were unchanged from Phase III and without any obvious additional pathology of aging. CT scans were acquired without contrast on a General Electric Medical Systems Light Speed Plus CT scanner at the Bethesda Naval Hospital, Bethesda, MD. Structural neuroimaging data were reconstructed with an in-plane voxel size of 0.4 × 0.4 mm, an overlapping slice thickness of 2.5-mm and a 1-mm slice interval. Lesion location and volume from CT images were determined using the analysis of brain lesions (ABLe) software (Makale *et al.*, 2002; Solomon *et al.*, 2007). ABLe was implemented in MEDx v3.44 (Medical Numerics) and supported the automated anatomical labeling (AAL) atlas (Tzourio-Mazoyer *et al.*, 2002). White matter involvement was determined using the International Consortium of Brain Mapping-Diffusion Tensor Imaging-81 atlas (Mori *et al.*, 2008) embedded in ABLe.

Using the ABLe, we created a lesion density map by overlaying individual normalized lesion maps of pTBI to illustrate the number of veterans with lesions at each voxel (Figure 1). We then performed a VLSM analysis that computed *t*-tests on political belief task performance average scores for each dependent variable (i.e. agreement, radicalism, individualism and conservatism) comparing pTBI and HC participants score in each voxel. The VLSM analyses identified voxels, where pTBI with lesions in those voxels performed significantly different from HC. We applied a false discovery rate (FDR) correction of 0.01 for multiple comparisons, and a minimum cluster size of 10 voxels [see (Driscoll *et al.*, 2012; Knutson *et al.*, 2013)]. We set four as the minimum number of cases with overlapping lesions at any voxel [see (Glascher *et al.*, 2009)]. Thus, if fewer than four pTBI patients had lesions in a given voxel, that voxel was excluded from further analysis.

Statistical analysis: pTBI vs HC

In combination with the VLSM analysis, *t*-tests were used to compare the scores between the pTBI and HC participants for each of the four dependent variables (i.e. agreement, radicalism, individualism and conservatism average scores). Behavioral data analysis was performed with Statistical Package for the Social Sciences 21.0 (www.spss.com) and alpha was set to 0.05 (two-tailed). Data were tested for Gaussian distribution (Kolmogorov-Smirnov test) and homogeneity of variance (Levene's test). Unless otherwise specified, data were normally distributed and assumptions for analysis of variance were not violated.

The four variables were analyzed independently since they reflected independent dimensions of political beliefs (Zamboni *et al.*, 2009). Zamboni *et al.*'s multidimensional scaling findings indicated that agreement, radicalism, individualism and conservatism are independent measures of political beliefs. In our study, tests assessing collinearity between the dimensions indicated that multicollinearity was not a concern (Agreement, Tolerance = 0.96, Variance inflation factor (VIF) = 1.03, Radicalism, Tolerance = 0.86, VIF = 1.15; Individualism, Tolerance = 0.87, VIF = 1.15; Conservatism, Tolerance = 0.88, VIF = 1.13).

Based on our VLSM results (see Results), we assessed the contribution of specific brain areas to radicalism. We defined regions of interests (ROIs) in terms of AAL structures (Tzourio-Mazoyer *et al.*, 2002). The selected ROIs were vmPFC, dorsolateral prefrontal cortex (dlPFC) and parietal cortex. As a part of this process, the CT image of each pTBI's brain was normalized to a CT template brain image in Montreal Neurological Institute (MNI) space. Consequently, the percentage of AAL structures that were intersected by the lesion was defined by analyzing the overlap of the spatially normalized lesion image with AAL atlas. The procedure of tracing the lesions has been previously described (Krueger *et al.*, 2011).

The vmPFC ROI included the following AAL structures: superior frontal gyrus (SFG; medial part), (SFG; orbital part), (SFG; medial orbital part), middle frontal gyrus (MFG; orbital part), inferior frontal gyrus (IFG; orbital part), gyrus rectus, olfactory cortex, anterior cingulate and paracingulate gyri. Of the 14 vmPFC patients, 5 had bilateral, 5 had left and 4 had right vmPFC lesions. The dlPFC ROI included the following AAL structures: (SFG; dorsolateral part), MFG (lateral part) and IFG (triangular part). Of the 8 dlPFC patients, 3 had bilateral, 2 had left and 3 had right dlPFC lesions. The parietal ROI included the following AAL structures: inferior parietal gyrus, parietal operculum and superior parietal gyrus. Of the 14 parietal patients, 4 had bilateral, 5 had left and 5 had right parietal lesions. A more detailed description of the criteria used to define the ROIs has been previously reported (Koenigs *et al.*, 2008; Krueger *et al.*, 2009). One-way analysis of variances (ANOVAs) were performed to compare radicalism intensity scores between the lesions subgroups.

RESULTS

VLSM analysis

Figure 1 shows the lesion density overlap map for all 102 veterans with pTBI. The maximum overlap of 37 subjects occurred in prefrontal areas. Figure 2 and Supplementary Table S1 show that the results of the VLSM analysis for the radicalism dimension. Lesions in the left and right superior, middle and inferior orbitofrontal cortex (OBF), left and right anterior cingulate, left superior and middle frontal cortex and left insula were all associated with diminished scores on the radicalism dimension (i.e. patients with lesions in these regions rated the political beliefs as more moderate than HC). In addition, lesions in the bilateral anterior corona radiata were significantly associated with lower radicalism scores (Supplementary Table S2 for *z*-values). There were no regions associated with an increased radicalism score (i.e. statements scored as more radical than HC). This finding was selective as brain lesion location or volume did not affect scores on the agreement, individualism or conservatism variables.

To further examine the VLSM results for the radical dimension, we also performed a conjunction analysis between the two radicalism categories (i.e. most and middle radical statements). This conjunction analysis produced three maps: two maps unique to lesion-deficit areas for most and middle radical statements, and one map showing common areas shared between most and middle radical statements. Because the conservatism and individualism dimensions were not associated with specific lesion locations, we did not perform additional VLSM analyses on these two dimensions.

Middle and extreme radical statement judgments were primarily associated with lesions in frontal sectors [i.e. bilateral IFG, bilateral MFG, bilateral SFG, bilateral OBF, left insula and bilateral anterior cingulate cortex (ACC); see green areas in Supplementary Figure S1]. We also examined the voxels selectively associated with middle or extreme radical statements. The voxels significantly associated with

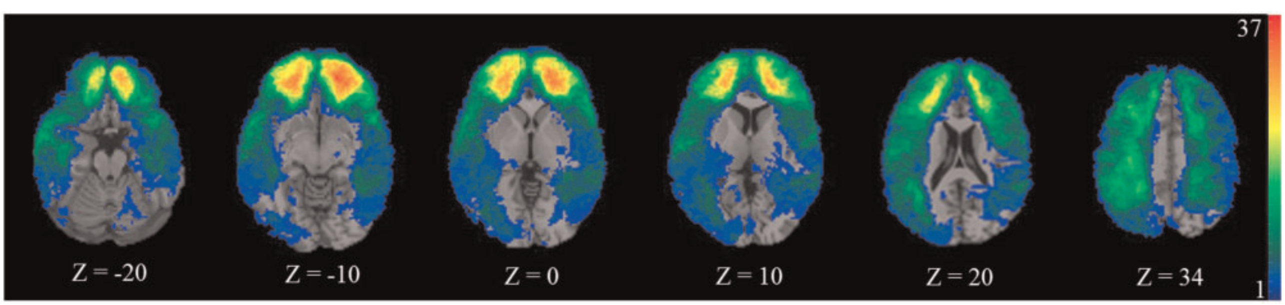

Fig. 1 Map shows the overlap density of the lesions in pTBI patients. Color depicts the number of patients with the overlapping lesion at each voxel. Orange indicates more subjects and blue indicates fewer subjects. The right hemisphere is shown on the reader's left side

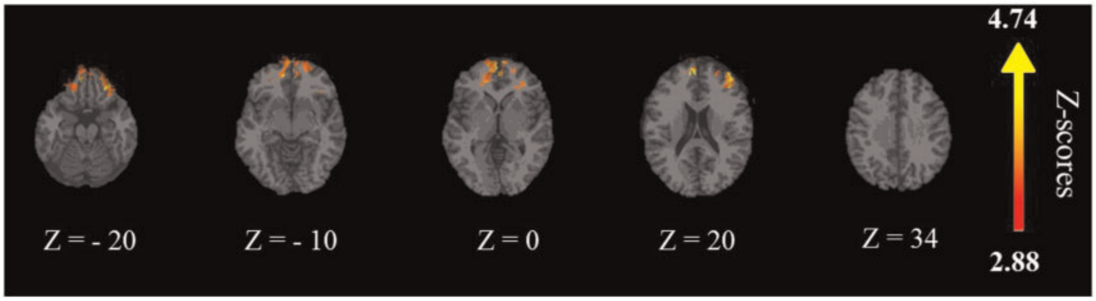

Fig. 2 VLSM of judgments about radicalism in the political belief task. VLSM analysis compares voxel by voxel the average score in the radicalism dimension in pTBI patients *vs* controls. Colored areas indicate a significant association between presence of lesion in that location and lower radicalism score. Color bar indicates *z*-scores; yellow indicates areas with the highest *z*-score

middle radical statement judgments (see yellow areas in Supplementary Figure S1) were in temporal lobe sectors, including bilateral middle temporal gyrus (MidTG), bilateral inferior temporal gyrus (ITG) and right superior temporal gyrus (STG). On the other hand, voxels significantly associated with extreme radical statement judgments (see blue areas in Supplementary Figure S1) were in the left frontal inferior operculum. Supplementary Table S3 details the significant clusters associated with judgments about middle and most radical statements. In addition, lesions to certain white matter tracts were associated with middle and most radical statement judgments. For the middle radical statements, they included the body of the corpus callosum, the bilateral anterior, superior and posterior corona radiata, the right posterior thalamic radiation and the right superior longitudinal fasciculus. For the most radical statements, they included the left and right corona radiata (Supplementary Table S4 for *z*-values). The superior longitudinal fasciculus is in the dorsal part of the anterior corona radiata and has connections with the frontal, parietal and temporal lobes. The white matter results were consistent with the gray matter results and reflected the extension of the lesion more deeply to adjacent white matter tracts. More widespread lesions were involved with middle radical statements, whereas scores on the most radical statements were selectively associated with frontal lesions.

Behavioral analysis

Patients with pTBI had significantly lower scores than HC on the radicalism dimension of the statements, meaning that they tended to judge the political beliefs as more moderate (Supplementary Table S5). The conservatism and individualism dimensions were not significantly associated with lesions to a particular region but could be affected by other factors. For example, we found that the conservatism rating scores and political orientation (i.e. liberal, moderate and conservative), were significantly correlated [r (98) = −0.28, $P < 0.01$], meaning that pTBI with a more conservative orientation evaluated the statements as more conservative. Individualism rating scores and political orientation had a tendency toward significant correlation [r (98) = −0.177, $P = 0.07$], whereas radicalism rating scores and political orientation were not significantly correlated [r (98) = −0.040, $P = 0.69$]. To investigate whether particular statements were more difficult to interpret for the patients with pTBI, we performed an analysis comparing groups of sentences with different degrees of radicalism (most radical, middle radical and least radical statements). We selected the 10 most radical, 10 middle radical and 10 least radical sentences, according to prior norms (Zamboni *et al.*, 2009). For example, the most radical statements included statements such as ‘Every nation should have the death penalty’; the middle radical statements included statements such as ‘Citizens should support candidates of the same race’ and the least radical statements included statement such as ‘The U.N. should keep the world in peace’. This analysis allowed us to determine if a specific set of sentences accounted for the behavioral findings. We found that patients with pTBI had lower scores than HC only for the middle and most radical statements (Supplementary Table S6). In addition, when all the statements were divided, according to their category (i.e. welfare and economy; values and religious beliefs; general politics and political involvement; civil right; crime security and war), patients with pTBI gave significantly lower radicalism scores to the welfare & economy, general politics & involvement, civil rights and crime security & war statements (Supplementary Table S7). The behavioral results suggested that pTBI patients, as a group, tended to rate the most radical statements as more moderate than HC, with little regard for the specificity for the category of statement.

Lesion subgroups

Because the VLSM analysis indicated that regions of the PFC are crucial for scaling radicalism in statements, we performed an additional analysis, dividing our group of pTBI patients into three subgroups based on their lesion location: (i) a vmPFC group, with primary damage to the vmPFC ($N = 14$); (ii) a dlPFC group, with primary damage to the dlPFC ($N = 8$); (iii) and a parietal group, with primary damage to the parietal lobe ($N = 14$). Because the radicalism dimension was not associated with lesioned voxels in the parietal cortex, we have chosen the parietal cortex as a control brain region.

Figure 3 displays a horizontal view of the overlapping lesions in the three subgroups: vmPFC (a), dlPFC (b) and parietal (c). We conducted a one-way ANOVA, comparing the percentages of total brain volume loss between these three pTBI subgroups and found that there were no between-group differences on this measure [vmPFC: 3.61 ± 0.70 *vs* dlPFC: 3.45 ± 0.76 *vs* parietal: 2.34 ± 0.63), $F(2, 33) = 1.07$, $P = 0.354$]. The previous behavioral analysis indicated that scaling the middle and the most radical statements differentiated pTBI patients from HC (Supplementary Table S6). Similarly, a one-way ANOVA showed a significant between lesion groups effect for the middle $F(3, 63) = 5.38$, $P = 0.002$, $\eta_p^2 = 0.20$ and high radical statements $F(3, 63) = 3.87$, $P = 0.013$, $\eta_p^2 = 0.17$. The post-hoc comparison demonstrated that middle radical statements had significantly lower scores (i.e. more moderate) in the vmPFC group (M = 3.64, s.d. = 0.26) compared with the parietal (M = 4.27, s.d. = 0.13) and HC groups (M = 4.54, s.d. = 0.10). The same pattern was found for most radical statements: the vmPFC group (M = 4.27, s.d. = 0.34) rated these statements with significantly lower score compared with the parietal (M = 5.20, s.d. = 0.21) and HC groups [M = 5.22, s.d. = 0.14 (Figure 3)]. Despite the performance differences in evaluating radicalism statements, the

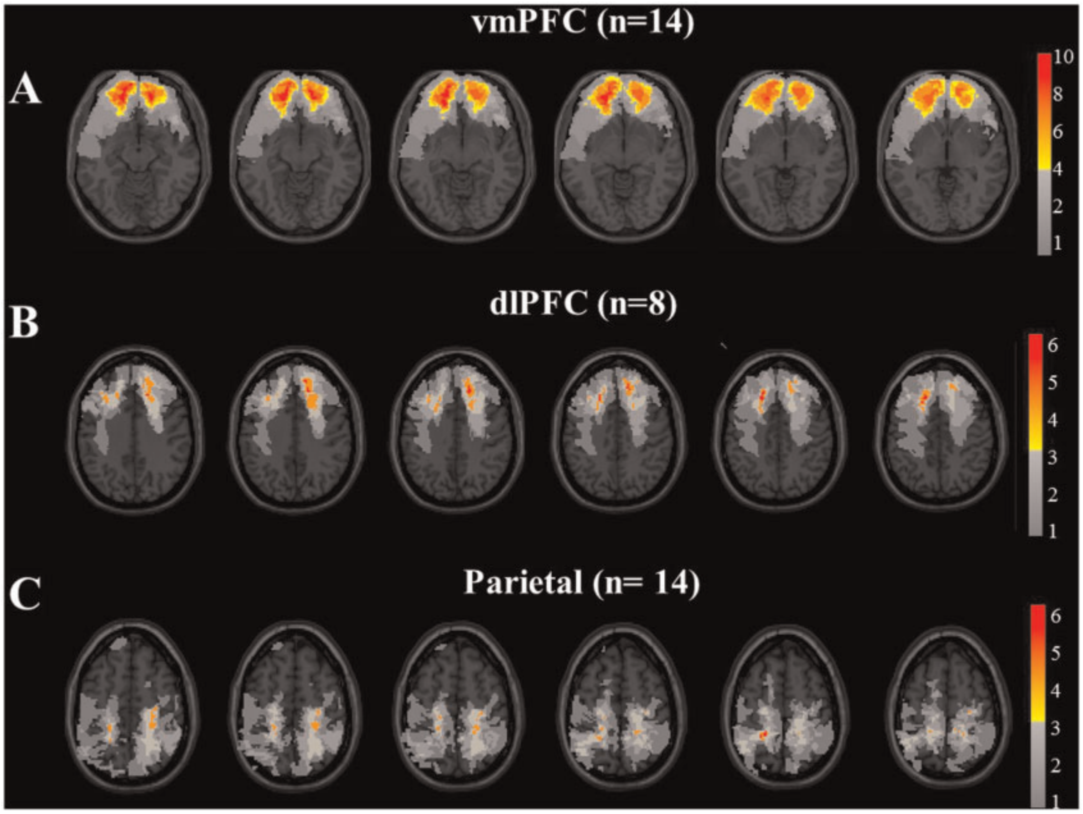

Fig. 3 Map shows the overlap of the lesions in the (**A**) vmPFC, (**B**) dlPFC and (**C**) parietal pTBI group. The maximum overlay is 10, 6 and 6 subjects for the vmPFC, dlPFC and parietal group, respectively. Right hemisphere is shown on the left side

vmPFC, dlPFC, parietal and HC groups did not differ on neuropsychological measures (Supplementary Table S8).

DISCUSSION

Our results provide evidence that vmPFC lesions lead to devalued judgments about the radicalism of political beliefs. The VLSM analysis revealed that lesions in the orbitofrontal cortex, middle frontal cortex and anterior corona radiata were all associated with diminished scores on the radicalism dimension. When we examined a subsample of 36 pTBI patients—divided according to vmPFC, dlPFC and parietal cortex lesions—the group analysis confirmed the VLSM findings and specified that vmPFC pTBI patients devalued the middle and most radical statements, compared with the parietal and HC group. Thus, patients with vmPFC lesions tend to undervalue the inherent extreme radicalness of certain political beliefs.

Previous research has shown that damage to the vmPFC is associated with impairments in social judgments and beliefs (Greene *et al.*, 2004; Ciaramelli *et al.*, 2007; Koenigs *et al.*, 2007; Young *et al.*, 2010). For example, Koenigs *et al.* (2007) asked patients with vmPFC lesions to solve moral dilemmas and found that they favored utilitarian judgments, promoting harmful actions in exchange for the greater good. Did they choose utilitarian harmful actions because of altered values that diminished the harmfulness of their own actions? Our finding that patients with vmPFC lesions devalued their political radicalism ratings could perhaps offer one explanation for why patients with vmPFC lesions may on occasion appear to behave with little regard for social norms if they perceive radical behaviors as more permissible. A complementary explanation for patients' increased tendency to judge statements as less radical could be a failure to anticipate the emotional or behavioral implications of their beliefs (Amodio and Frith, 2006; Tangney *et al.*, 2007). Another possible explanation depends upon the vmPFC's role in encoding emotional value (Ciaramelli *et al.*, 2013; Winecoff *et al.*, 2013).

Importantly, our subjects did not show differences in other domains of political beliefs such as conservatism, demonstrating that they were able to discriminate, similar to HC, if a statement endorsed a more conservative or a more liberal point of view.

Our results may be related to previous studies showing that patients with focal vmPFC lesions occasionally violate moral rules (Saver and Damasio, 1991; Mah *et al.*, 2004, 2005), at least partly because they evaluate the moral violations as acceptable (Mendez *et al.*, 2005; Ciaramelli *et al.*, 2007). This devaluing of radical behaviors could have implications for daily life. For example, adults with vmPFC lesions may tend to diminish the seriousness of a child's social violations, leading to conflicts with the other parent and the inconsistent application of punishment for a child who misbehaves.

Are extreme radical statements more difficult to score? Only the moderate and most radical statements challenged pTBIs' ability to rate radicalism. Compared with the most radical statements, a larger set of brain regions (including vmPFC regions and temporal sectors) were involved in reduced ratings for moderate radical statements, suggesting that it was more difficult to rate these items. On the other hand, judgments about the most radical statements appear to be selectively associated with frontal regions. The temporal lobe is essential for certain aspects of social cognition and judgments about moral behavior (Zahn *et al.*, 2007). For example, recent studies have shown that lesions to the temporal lobe impair decision-making under ambiguity (Delazer *et al.*, 2011). Perhaps the potential values for

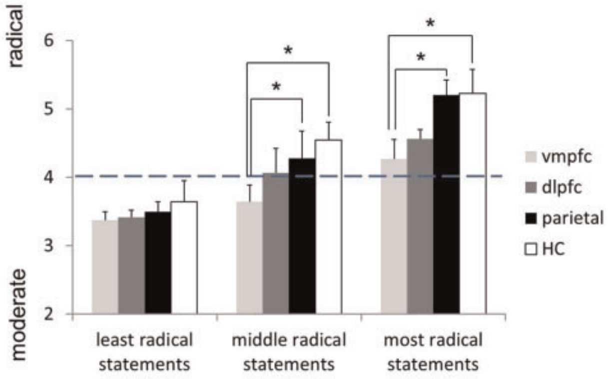

Fig. 4 Radicalism ratings on statements grouped by different degrees of radicalism for the four groups: vmPFC, dlPFC, parietal and controls. The vmPFC group judged the middle and high radical statements as significantly more moderated compared with the parietal and HC groups (*P* values < 0.005). The dashed line indicates a neutral rating (i.e. neither moderate nor radical)

moderate radical statements are more uncertain, requiring a more extensive network for their processing. A recent study by Feldmanhall *et al.* (2014) supports this theory by showing that processing ambiguous moral scenarios recruited a network of temporal regions, while processing unambiguous moral scenarios only recruited the vmPFC (Feldmanhall *et al.*, 2014). Difficulty in scaling moderate radicalism statements could impose a greater cognitive demand, requiring a deliberative and reflective linguistic working memory system to interact more with frontal sectors concerned with the social valuation of political statements. The extreme radical statements, on the other hand, would be less ambiguous, thus reducing the cognitive load on non-frontal networks.

However, in the group analysis, the lack of significant difference between vmPFC and dlPFC lesion patients limits our conclusions. This lack of difference may be because the dlPFC is the smallest group, and this could have limited the power of this comparison. Although it is possible that the vmPFC and dlPFC combine their functions to influence radicalism, this would reduce any meaningful difference between the two regions. Given past dissociations between these two regions in other domains, it is more likely that they make distinct contributions to influencing political beliefs.

Our previous study in healthy individuals (Zamboni *et al.*, 2009) identified brain regions that mediate political decision-making, including the frontal and temporal lobes, the anterior cingulate, the ventral striatum and associated white matter tracts. In this study, judgments about radicalism were associated with lesions to the anterior corona radiata. The anterior corona radiata includes white matter tracts connecting the prefrontal regions to the striatum (Mori *et al.*, 2008). Zamboni *et al.* found that brain activity in the ventral striatum was associated with moderating judgments about political statements. It is possible that cortical lesions sparing the ventral striatum could influence scaling judgments by making people more dependent upon ventral striatal processes that favor moderating valuations for their reinforcing features, leading to the diminished values we observed for the more extreme radical statements in patients with vmPFC and corona radiata lesions.

The VLSM analysis did not identify voxels associated with the conservatism or individualism dimensions. Although we measured ideology and individualism by using a Likert scale approach, these political dimensions are often expressed in terms of dichotomous choices (e.g. liberal *vs* conservative) and are influenced by a combination of factors besides valuation, including genetics, early experience and environmental influences (Hibbing *et al.*, 2014). In general, they may be less susceptible to the location or size of brain lesions compared with the radicalism dimension. Whereas the tendency to consider statements as more individual instead of society-related might reflect a tendency to be more individualistic and less concerned about society's rules, this would be less likely to affect social behavior aversively than devaluing statements reflecting radicalism. We suggest that this error of underestimating radical situations or behaviors is related to the vmPFC's specific roles in decision-making and valuation.

In this study, we found that the conservatism rating scores and political orientation (i.e. liberal, moderate and conservative) were significantly correlated. Patients with pTBI with a more conservative orientation evaluated the statements as more conservative. Conversely, the radicalism rating scores and political orientation were not significantly correlated, indicating that the radicalism dimension is independent of political orientation.

Lesion mapping studies are important in ascertaining whether a brain structure is necessary for mediating a particular behavior. Yet, it is important to acknowledge that there are some limitations to our study. We only studied male Vietnam War combat veterans, although the patient subgroups were matched for age, ethnicity, brain volume and a host of other variables. This homogeneity constitutes in part the strength of the study, but it is also a limitation regarding generalizability of findings to the general population.

To conclude, we report that patients with vmPFC lesions were more prone to judge radical behaviors and/or thoughts as more moderate and presumably acceptable. This finding suggests that the vmPFC plays an important role in appropriately scaling values for stimuli beyond those used in typical reward paradigms (Rangel and Clithero, 2012), and when this form of valuation is impaired, it may have repercussions that extend to how an adult, for example, can determine the appropriate degree of punishment for a child's social infraction. A complete description of the range of evaluation deficits that result from vmPFC lesions also has important clinical implications and may help patient caregivers prepare for expected changes in social judgments that can affect their day-to-day lives.

SUPPLEMENTARY DATA

Supplementary data are available at *SCAN* online.

Conflict of Interest

None declared.

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