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Asymmetrical involvement of frontal lobes in social reasoning

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Summary

The frontal lobes are widely implicated in logical reasoning. Recent neuroimaging studies suggest that frontal lobe involvement in reasoning is asymmetric (L>R) and increases with the presence of familiar, meaningful content in the reasoning situation. However, neuroimaging data can only provide sufficiency criteria. To determine the necessity of prefrontal involvement in logical reasoning, we tested 19 patients with focal frontal lobe lesions and 19 age- and education-matched normal controls on the Wason Card Selection Task, while manipulating social knowledge. Patients and controls performed equivalently on the arbitrary rule condition. Normal controls showed the expected improvement in the social knowledge conditions, but frontal lobe patients failed to show this facilitation in performance. Furthermore, left hemisphere patients were more affected than right hemisphere patients, suggesting that frontal lobe involvement in reasoning is asymmetric (L>R) and necessary for reasoning about social situations.

Keywords: reasoning; frontal lobes; Wason selection task; social knowledge

Abbreviations: IQ = intelligence quotient; WST = Wason selection task

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Introduction

Logical reasoning is ubiquitous. Consider the following example: upon hearing the exaggerated screams of an 8-year-old girl, I say to my 13-year-old son, ‘If you want dinner tonight, you better stop tormenting your sister.’ He likes having dinner and draws the correct logical inference and peace is eventually restored. Making such inferences quickly and accurately is critical to our functioning in the world. But despite this, very little is known about the underlying neural mechanisms of deductive reasoning. The frontal lobes are widely implicated in reasoning (Shallice and Burgess, 1991; Stuss and Alexander, 2000), particularly in social situations (Anderson *et al.*, 1999, 2000), but the evidence is largely anecdotal (Shuren and Grafman, 2002). There are very few studies of deductive reasoning in patients with focal brain lesions (Golding, 1981; Read, 1981; Waltz *et al.*, 1999; Langdon and Warrington, 2000) and only one study involving patients with focal frontal lobe lesions (Adolphs *et al.*, 1996).

A particularly important issue in understanding the mechanisms of logical reasoning is the role of content. It has long been known that subjects perform better on syllogisms containing sentences with familiar semantic content (e.g. all apples are red fruit; all red fruit are sweet; therefore all apples are sweet) than on syllogisms lacking semantic content (e.g. all A are B; all B are C; therefore all A are C) (Wilkins, 1928). The most widely used task to explore the role of content in reasoning has been the Wason Four-Card Selection Task (WST) (Wason, 1966). In this task, subjects are shown four cards. They can see what is printed on one side of each card, but not the other side. They are given a rule of the form: if p then q (e.g. ‘If a card has a vowel on one side, then it has an even number on the other side.’); and asked which cards they must turn over in order to verify the rule. The visible values on the cards correspond to the p, *not-p*, q, and *not-q* cases of the rule. According to standard propositional logic, the correct choices are p (to verify q is on the other side) and *not-q* (to verify p is not on the other side). Given an arbitrary rule like the above, typically <25% of normal subjects will turn over both the p and the *not-q* cards. However, the introduction

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Table 1 *Characteristics of patient and normal control populations*

	Normal controls	Right hemisphere	Left hemisphere	Bilateral	All patients
Number of patients (*n*)	19	5	6	8	19
Age (years)	47.47	50.0	46.5	52.1	49.8
Education (years)	14.55	12.5	16.0	12.7	13.7
WAIS-R (IQ)					
General		96.0	107.83	90.75	97.53
Verbal		94.6	103.88	88.88	95.11
Performance		98.4	111.33	94.38	100.79
WMS-R					
General		91.0	99.33	90.88	93.58
WM		105.4	108.0	101.38	105.0
WCST					
Categories solved	5.36	4.4	4	4.57	4.33
Perseverative errors	7.24	13.99	12.36	11.82	12.56
Tower of Hanoi (11 patients)		1154.67	1115.36	893.75	1045.49
Brain volume loss (cc) (16 patients)		41.71	59.65	89.29	69.99

WAIS-R = revised Wechsler Adult Intelligence Scale; WMS-R= revised Wechsler Memory Scale; WCST = Wisconsin Card Sorting Test; WM = working memory; See Goel and Grafman (1995) for explanation of Tower of Hanoi scores.

of familiar, meaningful content in a rule (e.g. 'If anyone is drinking beer, then that person must be over 21 years old.') greatly facilitates performance (Wason and Shapiro, 1971; Cox and Griggs, 1982; Griggs and Cox, 1982; Cheng and Holyoak, 1985; Cosmides, 1989; Gigerenzer and Hug, 1992).

The neural basis of logical reasoning has recently been explored with neuroimaging techniques (Goel *et al*., 1997, 1998, 2000; Osherson *et al*., 1998; Houde *et al*., 2000, 2001; Goel and Dolan, 2001, 2003; Parsons and Osherson, 2001; Knauff *et al*., 2002). Several of these studies have focused on the issue of familiarity of content in reasoning (Goel *et al*., 2000; Goel and Dolan, 2001, 2003). The evidence shows that logical reasoning is implemented in two distinct systems whose engagement can be manipulated by the presence or absence of familiar semantic content. Syllogistic reasoning involving familiar situations (e.g. all apples are red fruit; all red fruit are poisonous; therefore all apples are poisonous) engages a left hemisphere lateral frontal-temporal lobe system. By contrast, in formally identical reasoning tasks involving arbitrary/unfamiliar content (e.g. all A are B; all B are C; therefore all A are C), a bilateral (L>R) parietal system (with limited activation in dorsal prefrontal cortex) is recruited. This suggests that frontal lobe involvement in logical reasoning is asymmetrical (L>R) and increases with familiarity of reasoning material. If this is correct, then patients with focal frontal lobe lesions should fail to show the facilitation effect of familiar content in the WST, and left FL patients should be more affected than right FL patients.

To test this hypothesis, we administered the WST (Wason, 1966) to 19 frontal lobe patients and 19 age- and education-matched normal controls (see Table 1). Specifically, we manipulated the social knowledge involved in the task in the form of 'permission schemas' (Cheng and Holyoak, 1985). Subjects performed the task with: (i) an arbitrary rule condition (''If a card has an 'A' on one side, then it must have a '4' on the other side.'') (Fig. 1A); (ii) an abstract permission condition (''If one is to take action 'A', then one must first satisfy precondition 'P'.'') (Fig. 1B); and (iii) a concrete permission condition (''If a person is to drink alcohol, he or she must be at least 21.'') (Fig. 1C).

Method

Subjects

Nineteen patients (five males, four females) with focal frontal lobe lesions, ranging in age from 29 to 68 years, participated in the study. Fifteen of the patients were drawn from a Vietnam Head Injury population. These patients came from similar socio-economic and educational backgrounds. They all received penetrating head injuries during their service in Vietnam in the late 1960s, and were tested most recently between 1999 and 2001. Thus their aetiology, injury dates and recovery periods are similar. Of the other four patients, two had tumour excisions and were tested 11 years after surgery, one had a closed head injury and was tested 13 years after the accident, and one had a subarachnoid haemorrhage secondary to an anterior communicating artery aneurysm and was tested 3 years after surgery.

The sensory, motor and language functions, as determined by previous neurological and neuropsychological testing (see Table 1), of all patients were relatively intact and all patients were functional to casual observation (in terms of language, behaviour and sensory-motor abilities). The experimental protocol was approved by the National Institute of Neurological Disorders and Stroke (NINDS) Institutional Review Board and all subjects gave informed consent.

The age, education and cognitive profiles of patients, along with the size and laterality of lesions (as determined by MRI) are noted in Table 1. The involvement of specific structures

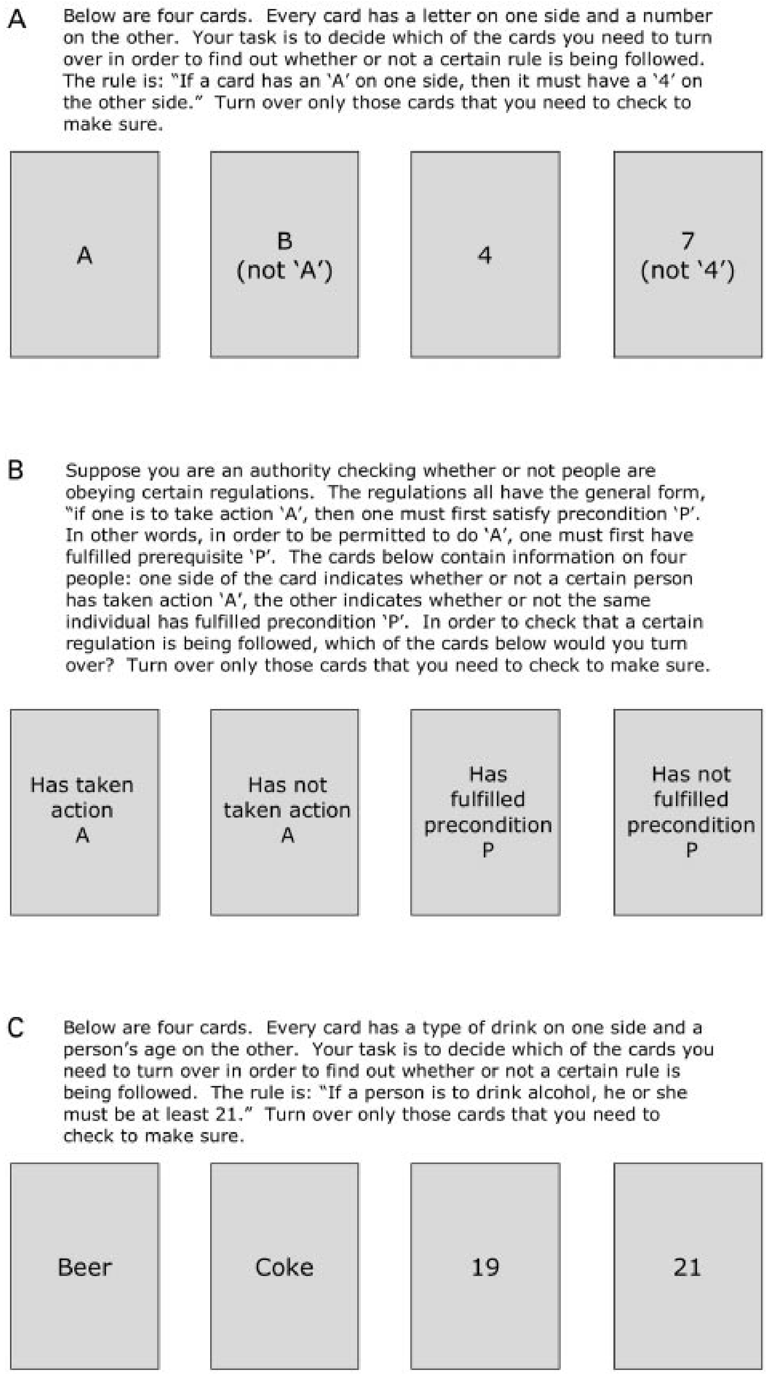

Fig. 1 Wason selection tasks administered to subjects: (**A**) arbitrary rule condition; (**B**) an abstract permission condition; and (**C**) a concrete permission condition.

for 17 of the patients, also determined from MRI (Damasio and Damasio, 1989), are specified in Fig. 2. These patients were matched for sex, age and education with 19 normal volunteers.

Task/procedure

Three WST problems adopted from Cheng and Holyoak (1985) were administered to subjects (Fig. 1). Problems contained either an arbitrary rule (''If a card has an 'A' on one side, then it must have a '4' on the other side.'') (Fig. 1A), an abstract permission schema (''If one is to take action 'A', then one must first satisfy precondition 'P'.'') (Fig. 1B), or concrete permission schema (''If a person is to drink alcohol, he or she must be at least 21.'') (Fig. 1C). The ordering of the three problems was counterbalanced within and across subject groups. Once subjects understood the instructions, the problems were presented on a computer screen one at a

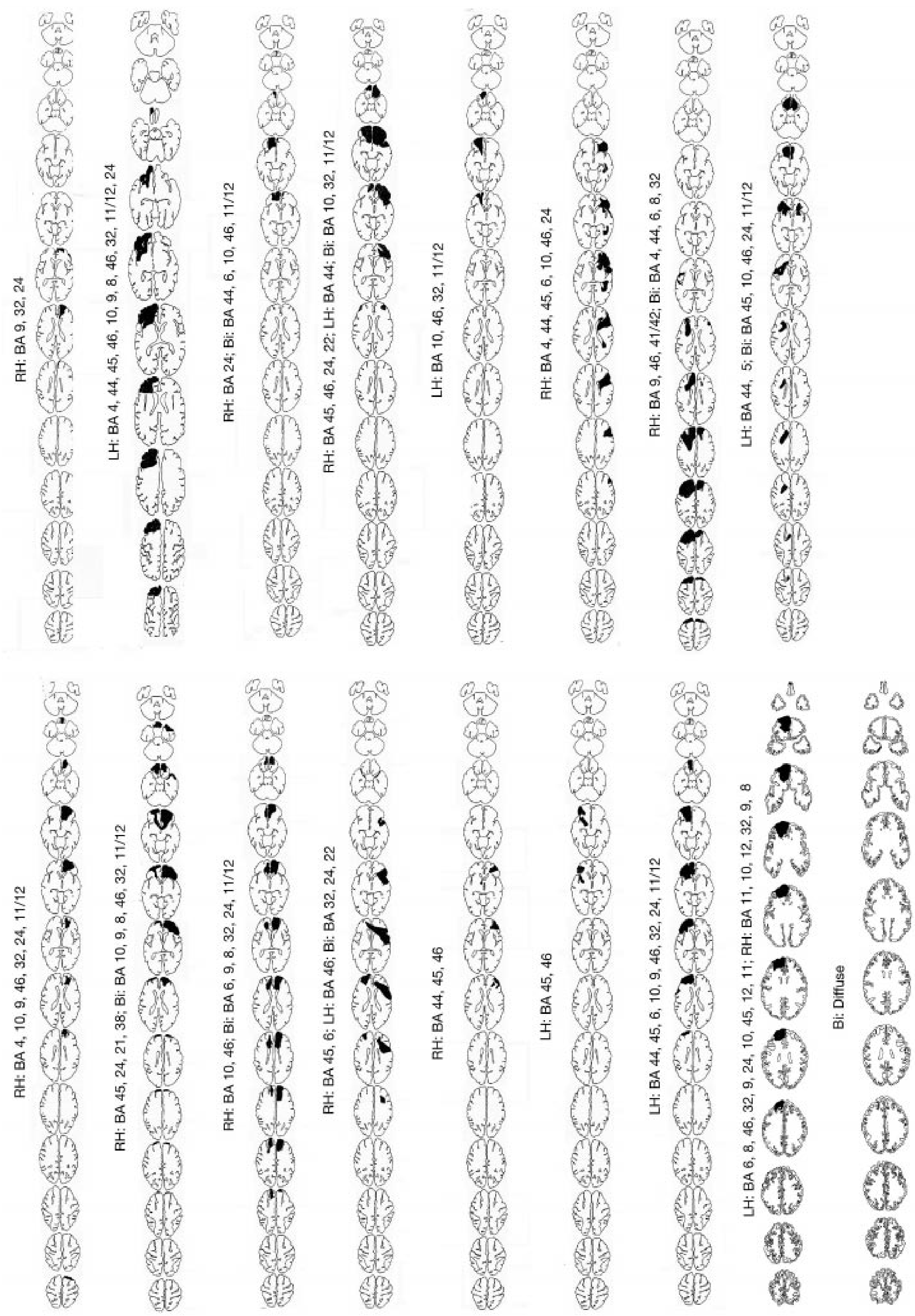

Fig. 2 Lesion locations of patients.

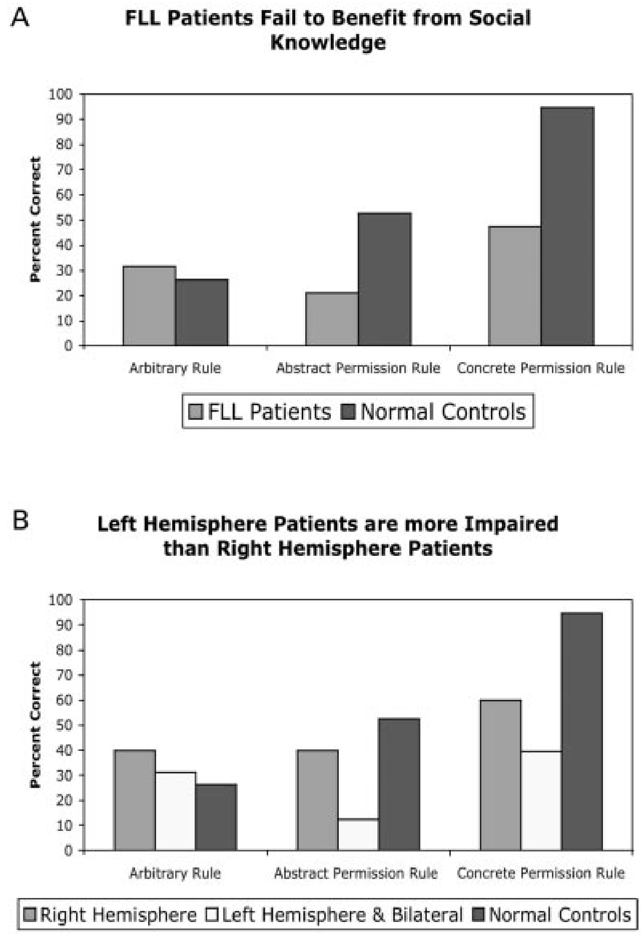

Fig. 3 Results showing: (**A**) frontal lobe patients perform the same as normal controls in the arbitrary rule condition, but fail to benefit from the introduction of abstract and concrete permission schema (social knowledge); and (**B**) hemispheric subgrouping results in a group by social knowledge interaction, driven by the poor performance of left hemisphere patients in the permission schema conditions. FLL = frontal lobe lesions.

time. Subjects indicated their response verbally, and these were recorded by the experimenter.

Results

An analysis of variance with repeated measures was carried out on response accuracy. Subjects were deemed to have responded correctly if they chose both and only the *p* and *not-q* cards. (We also analysed accuracy on a four-point system, allowing for partial points, for partially correct responses. The results remained the same.)

We tested for the main effects of group and social content, and for the group (patients and controls) by social content (arbitrary rule, abstract permission rule and concrete permission rule) interaction. There was a main effect of group [$F(1, 36) = 6.3$, $P < 0.05$]. Overall, controls performed more accurately on the reasoning tasks than the frontal lobe patients (mean 57.9%, SD = 50.0 for the controls versus mean 33.3%, SD = 47.6 for the patients). There was a main effect of social content [$F(2,72) = 11.9$, $P < 0.05$], with subjects performing at 28.9% (SD = 46.0) in the arbitrary rule condition, 36.8% (SD = 49.0) in the abstract permission rule condition, and 71.1% (SD = 46.0) in the concrete permission rule condition.

Most importantly, there was a significant group (patients and controls) by social content (arbitrary rule, abstract permission rule, and concrete permission rule) interaction [$F(2, 72) = 4.5$, $P < 0.05$]. There was no difference in the performance of patients and normal controls in the arbitrary rule condition (Fig. 3A). The interaction occurred because the normal controls displayed dramatic improvement with the introduction of permission schemas [$t(36) = 5.88$, $P < 0.05$). There were no significant differences between any of the three rule conditions for the frontal lobe patients.

Hemispheric subgrouping of patients into left, right and bilateral frontal lobe lesion compared with normal controls revealed a significant subject group by social content interaction [$F(3,68) = 3.1$, $P < 0.05$], driven by reciprocal pattern of performance scores for normal controls and left hemisphere patients. The interaction remains when bilateral patients are collapsed into the left hemisphere group (by virtue of having left hemisphere lesions) [$F(2,70) = 2.7$, $P < 0.05$].

As Fig. 3B indicates, the patterns of response for normal controls and right lesion patients are the same, with no significant differences, and no group by social content interaction. However, left hemisphere (and bilateral) patients' performance drops in the abstract permission and concrete permission rule conditions, resulting in the group by social content interaction and a significant difference in accuracy scores between normal controls and left hemisphere patients.

For the patient group, we also calculated correlations between lesion size, intelligence quotient (IQ), memory scores, years of education and accuracy of performance on the reasoning task (Table 2). The only significant correlations were between the arbitrary rule condition and IQ (0.53, $P < 0.05$) and memory scores (0.48, $P < 0.05$).

Table 2 *Correlations between lesion size and cognitive measures and the arbitrary rule, abstract permission rule and concrete permission rule trials in patients*

	Arbitrary rule	Abstract permission rule	Concrete permission rule
Volume loss	–0.29	0.24	–0.33
WAIS III (IQ)	0.53*	0	0.16
WAIS III (memory)			
General	0.48*	–0.17	0.27
WM	0.41	0.32	0.20
Education	0.03	–0.03	–0.25

*$P < 0.05$. WAIS-III = Wechsler Adult Intelligence Scale, third edition; WM = working memory.

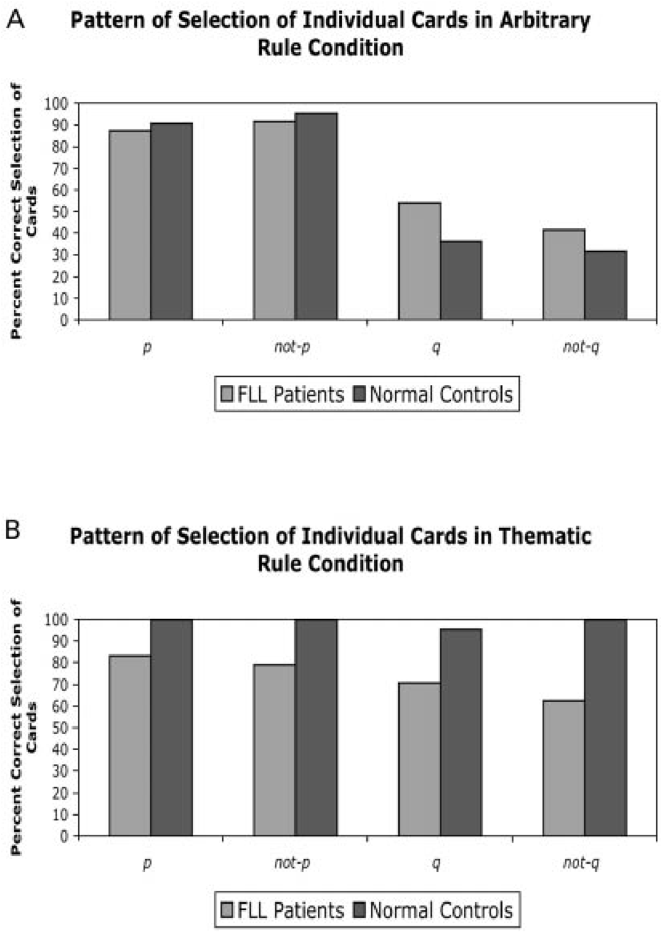

Fig. 4 Results showing: (**A**) frontal lobe patients exhibit the same pattern of card selection as normal controls in the arbitrary rule condition; and (**B**) frontal lobe patients fail to match the dramatic improvement displayed by normal controls in the correct selection of *q* and *not-q* in the permission schema conditions. (Correct selection of *not-p* and *q* designates a non-selection.)

Discussion

The performance of our normal controls is consistent with that reported in the literature (Cheng and Holyoak, 1985). They performed poorly (but above chance) in the arbitrary rule condition, and improved dramatically in the abstract permission rule and further in the concrete permission rule conditions. The cognitive literature offers a range of explanations for the asymmetrical performance of normal controls on the Wason task (Stenning and Lambalgen, 2001), including 'matching bias' (Evans and Lynch, 1973), misinterpretation of the task (Osman and Laming, 2001), pragmatic reasoning schemas (Cheng and Holyoak, 1985) and social contracts theory (Cosmides, 1989). Despite the important differences in the particulars of these explanations, they all accept that the asymmetrical performance is a 'content effect' and it is particularly strong in situations involving social content. (An exception to this consensus is a recent account by Fodor (2000) that argues there is a material difference between the two forms of the Wason task.)

Our results show that patients with focal frontal lobe lesions do not exhibit this asymmetry in performance. In the arbitrary rule condition, frontal lobe patients perform the same as normal controls. However, patient performance does not improve with the introduction of social knowledge in the form of abstract or concrete permission schemas, as does normal control performance. Additionally, the effect is being driven by the particularly poor performance of left hemisphere patients. Given that there was no significant correlation between volume loss, IQ scores, memory scores or years of education and performance in the abstract or concrete permission schema conditions, the overall failure of patients to benefit from social knowledge cannot be explained in terms of volume loss, IQ scores, memory scores or years of education. Furthermore, the higher Wechsler Adult Intelligence Scale (WAIS) scores of left hemisphere patients suggest that their significantly poorer performance cannot be attributed to general problems with verbal reasoning, but is task specific.

There are several possible interpretations of our results. One is that in the arbitrary rule condition, normal controls performed poorly; therefore, the fact that patient performance was the same does not imply that they are not impaired in logical reasoning with arbitrary material. Indeed, their general reasoning impairment is evident in their failure to benefit from the permission schemas. This interpretation is weakened by the fact that, although relatively poor, the performance of both controls and patients on the arbitrary version of the task was well above chance. Furthermore, if we look at the selection of each of the four cards, we find that, in the arbitrary rule condition, the pattern and accuracy of card selection is identical for patients and controls (Fig. 4A). However, in the concrete permission rule condition (Fig. 4B), normal controls exhibit a dramatic increase in the non-selection of *q* and the selection of *not-q* cards that the patients fail to do. This selection pattern suggests that patients are performing normally in the arbitrary content condition, but fail to benefit from the introduction of permission schemas. This leads to our second (preferred) interpretation that patients have a selective (or at least increased) impairment in reasoning about situations involving familiar knowledge, including social knowledge.

The first interpretation assumes a single reasoning mechanism and a constant contribution of prefrontal cortex to logical reasoning. A series of neuroimaging studies do not support this view. There is emerging evidence for a dynamic neural system, where the contribution of the prefrontal cortex increases as a function of the familiarity of the reasoning material (Goel *et al.*, 2000; Goel and Dolan, 2001, 2003). On this account, one would expect the permission schema trials of the WST to result in greater engagement of a frontal-temporal lobe system compared with the arbitrary rule condition that involves greater activation of the parietal lobe system (and less activation in prefrontal cortex). The normal controls have both mechanisms intact, and can take advantage of social knowledge cues to facilitate the reasoning process. The patients' parietal system is intact; hence, their performance on the arbitrary rule trial is largely unaffected. Their frontal lobe system is disrupted, preventing them from taking advantage of social knowledge cues in the permission schema trials, as per our prediction. Not only do we find that frontal lobe patients are unable to take advantage of social knowledge schemas to facilitate reasoning, left frontal lobe patients are particularly impaired, just like the neuroimaging data predict.

This interpretation is also consistent with the managerial knowledge unit/structured event complex theory of frontal lobe functions (Grafman, 1989, 2002). Structured event complexes are large-scale knowledge structures that are thought to account for much of our routine behaviour. Frontal lobe dysfunction results in an impairment in the ability to access and retrieve these data structures. The theory recognizes the importance of knowledge in reasoning and predicts that frontal lobe patients will have difficulty in solving knowledge-rich problems, as in the pattern of results displayed by our patients.

One limitation of the study is the absence of a non-frontal control group. In the absence of such a control group, we cannot be certain that the general effect is specific to the prefrontal cortex. In fact, we do not believe the effect is specific to the prefrontal cortex. Indeed, neuroimaging studies implicate a left frontal-temporal system in logical reasoning about familiar situations (Goel *et al*., 1997, 1998, 2000; Goel and Dolan, 2003) and several patient studies indicate that left temporal lobe lesions alone can result in reasoning deficits (Read, 1981; Langdon and Warrington, 2000). This leads us to postulate that, while left prefrontal cortex involvement is necessary for reasoning about familiar situations, it is probably not sufficient.

It is also worth emphasizing that, in the absence of a further experiment to directly compare patient performance in reasoning involving familiar social content and familiar non-social content (e.g. if the brakes are pressed, then the car will stop), one cannot conclude that the involvement of the prefrontal cortex is specific to social knowledge. Again, we do not believe this to be the case. On the contrary, neuroimaging studies suggest that the prefrontal cortex is implicated in reasoning about many types of familiar content (Goel *et al*., 1997, 1998, 2000; Goel and Dolan, 2001, 2003) and that the dorsolateral prefrontal cortex may be more relevant to non-social reasoning situations, while the medial prefrontal cortex is more responsive to social reasoning situations (Fletcher *et al*., 1995; Goel *et al*., 1995; Frith and Frith, 2003).

In summary, our study provides much needed lesion data on logical reasoning and clarifies the role of the prefrontal cortex. Consistent with neuroimaging studies that suggest the involvement of prefrontal cortex in logical reasoning is selective and asymmetrical, we found that, although frontal lobe patients performed as well as normal controls on the arbitrary content condition, these patients (particularly those with left hemisphere lesions) failed to show the facilitatory effect of social knowledge, suggesting that frontal lobe involvement in reasoning is asymmetric and increases with the involvement of knowledge, including social knowledge.

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