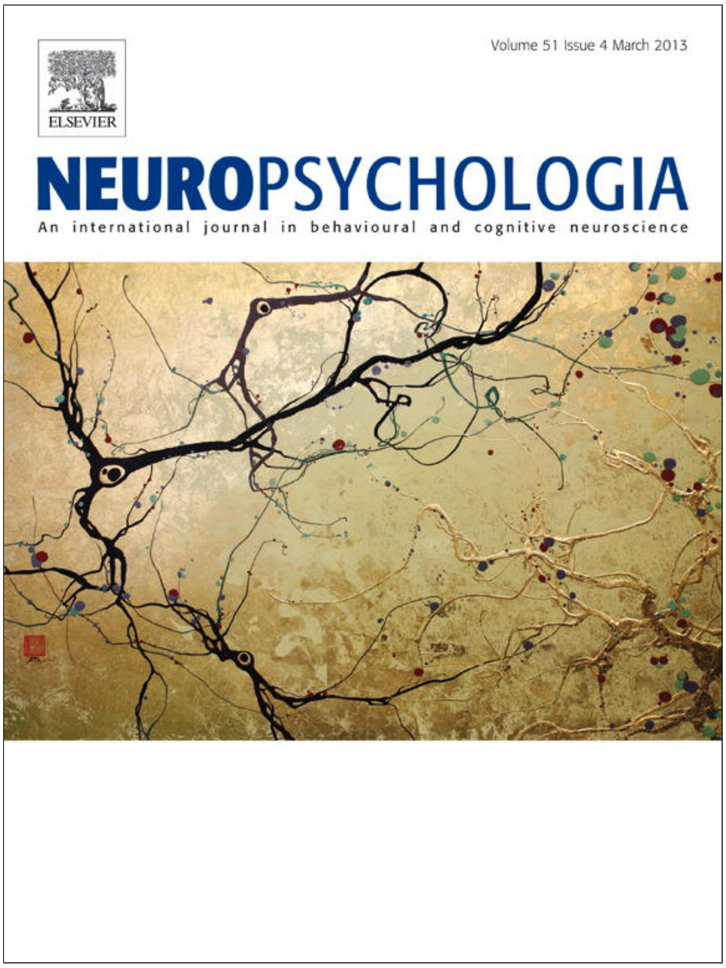
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Lesions to right prefrontal cortex impair real-world planning through premature commitments

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ABSTRACT

While it is well accepted that the left prefrontal cortex plays a critical role in planning and problem-solving tasks, very little is known about the role of the right prefrontal cortex. We addressed this issue by testing five neurological patients with focal lesions to right prefrontal cortex on a real-world travel planning task, and compared their performance with the performance of five neurological patients with focal lesions to left prefrontal cortex, five neurological patients with posterior lesions, and five normal controls. Only patients with lesions to right prefrontal cortex generated substandard solutions compared to normal controls. Examination of the underlying cognitive processes and strategies revealed that patients with lesions to right prefrontal cortex approached the task at an excessively precise, concrete level compared to normal controls, and very early locked themselves into substandard solutions relative to the comparison group. In contrast, the behavior of normal controls was characterized by a judicious interplay of concrete and abstract levels/modes of representations. We suggest that damage to the right prefrontal system impairs the encoding and processing of more abstract and vague representations that facilitate lateral transformations, resulting in premature commitment to precise concrete patterns, and hasty albeit substandard conclusions (because the space of possibilities has not been properly explored).

1. Introduction

The role of the prefrontal cortex in planning processes has been highlighted by several researchers in both patients with focal lesions (Bechara, Damasio, Damasio, & Anderson, 1994; Burgess, 2000; Colvin, Dunbar, & Grafman, 2001; Fellows, 2006; Goel & Grafman, 2000; Goel, Grafman, Tajik, Gana, & Danto, 1997; Miotto & Morris, 1998; Penfield & Evans, 1935; Shallice, 1982) and closed head injury (Bamdad, Ryan, & Warden, 2003; Dritschel, Kogan, Burton, Burton, & Goddard, 1998; Fortin, Godbout, & Braun, 2002, 2003; Shallice & Burgess, 1991a). These studies have confirmed that frontal lobe patients (1) are impaired in planning tasks; (2) exhibit differences, compared to normal controls, in both the ability to formulate and to execute plans (Chevignard et al., 2000); and (3) in terms of plan formulation, the difficulties seem to be more at the "global" or "macro" level (that is, at the level of minutes) than the "local" or "micro" level (at the level of seconds) (Fortin et al., 2003; Goel et al., 1997). However, existing studies have not adequately addressed hemisphere specific involvement of prefrontal cortex.

The idea that the left hemisphere is involved (or even dominant) in the critical domains of higher-level thinking processes has been advanced by the split brain patient literature (Gazzaniga, 2000; Gazzaniga 1998). This same literature limits the role of the right hemisphere, and in particular the right PFC, to little more than organization of visual information (Corballis, 2003).

However, this conclusion is much less certain in the context of the broader neuropsychological literature. Four of the above studies (Colvin et al., 2001; Fellows, 2006; Miotto & Morris, 1998; and Shallice, 1982) have specifically grouped patients into left and right hemisphere lesions. These studies report either no difference in the performance of patients with lesions to left or

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right hemisphere (Colvin et al., 2001; Fellows, 2006; Miotto & Morris, 1998), or that the left hemisphere patients do worse than the right hemisphere patients (Shallice, 1982).

A recent review on neuroimaging studies of the popular Tower of London (ToL) planning task (Kaller, Rahm, Spreer, Weiller, & Unterrainer, 2011) noted that, of the 24 imaging studies reporting dorsal lateral PFC activation, 6 report posterior left dorsolateral PFC activation, 3 report right dorsal lateral PFC activation, while 15 report bilateral activation. These data would seem to suggest minimal lateralization of function in PFC, at least as far as planning was concerned. However, planning is a complex, multi-faceted, multi-step task. So another possibility is that the mixed results in the literature are a function of the particular planning steps/functions that a study emphasizes and measures. Indeed, many studies have viewed planning as a unitary construct and not differentiated between individual steps. Kaller et al. (2011) provide a nice neuropsychological demonstration of this in the context of ToL task. In differentiating between different planning steps they find a double dissociation between "goal hierarchy" (the amount of variability/flexibility in a sequence of steps) and "search depth" (looking past intermittent steps or subgoals), with the former activating left dorsolateral PFC and the latter activating right dorsal lateral PFC.

Such dissociations are in keeping with results in the logical reasoning literature that indicate left PFC dominance in logical reasoning (Goel, 2007; Prado, Chadha, & Booth, 2011), but with a critical role for the right PFC in the resolution of conflict (Goel & Dolan, 2003), dealing with unfamiliar content (Goel, Buchel, Frith, & Dolan, 2000), and resolving indeterminate inferences (Goel et al., 2007). Similarly, in the context of problem solving, data suggest that right PFC plays a selective but critical role in situations where problem spaces become underspecified or involve mental set shifts. For example, broadening the search space on scrambled word tasks by broadening semantic categories lexical strings can belong to (e.g., make the word 'knife' with IKFEN; make a word for a kitchen utensil with IKFEN; make a word with IKFEN) reduces task constraints and selectively engages right prefrontal cortex (Vartanian & Goel, 2005). Hypothesis generation tasks, like the Matchstick problems, that involve mental set shifts to overcome implicit misleading cues selectively activate right prefrontal cortex in the misleading condition (Goel & Vartanian, 2005; Reverberi, Lavaroni, Gigli, Skrap, & Shallice, 2005).

It has been noted that there are important differences between the problems administered as part of neuropsychological test batteries and real-world problems encountered in daily life (Bechara et al., 1994; Goel et al., 1997; Shallice & Burgess, 1991b). It has been further argued that one critical difference has to do with the structure of the problem space (Goel, 2010; Goel et al., 1997). Most problem used in the neuropsychological literature are in some important respects a small, special subset of real-world tasks (often called well-structured tasks), characterized by completely specified start states, goal states, and transformation functions (among other things) (Goel, 1995; Reitman, 1964). Classic examples of such tasks are the Tower of Hanoi and Tower of London tasks used to measure executive functions. By contrast, the larger class of real-world problems have a very broad and poorly constrained and defined problem space. This larger problem set, exclusive of the well-structured set, has been referred to as ill-structured.

Goel (2010) has argued that one possible factor in the differential involvement of left and right PFC in different types of problem solving tasks may be the structure of the underlying mental (and external) representations and transformations required by the tasks. The well-structured subset of problems require precise, concrete representations for successful solution while ill-structured problems require more abstract, ambiguous, and vague mental representations for solution (at least initially). In the context of real-world planning problems, which have both ill and well-structured components, the full range of cognitive resources is required.

Real-world problems begin as ill-structured problems and go to become more well-structured as solutions emerge. More specifically, real-world problem solving typically involves four phases: *problem scoping*, *preliminary solutions*, *refinement*, and *detailing* of solutions. Each phase differs with respect to the type of information dealt with, the degree of commitment to generated ideas, the level of detail attended to, the number and types of transformations engaged in, and the mental representations needed to support the different types of information and transformations (Goel, 1995). As one progresses from the preliminary phases to the detailing phases, the problem becomes more structured. This is depicted in Fig. 1.

Problem scoping is the process of bringing background experience and knowledge to understand the problem statement. *Preliminary solution generation* is a classical case of creative, ill-structured problem solving. It is a phase of "cognitive way-finding", a phase of concept construction, where a few kernel ideas are generated and explored through transformations. This generation and exploration of ideas/concepts is facilitated by the *abstract* nature of information being considered, a low degree of commitment to generated ideas, the coarseness of detail, and a large number of *lateral transformations*. A lateral transformation is one where movement is from one idea to a slightly different idea rather than a more detailed version of the same idea. Lateral transformations are necessary for the *widening* of the problem

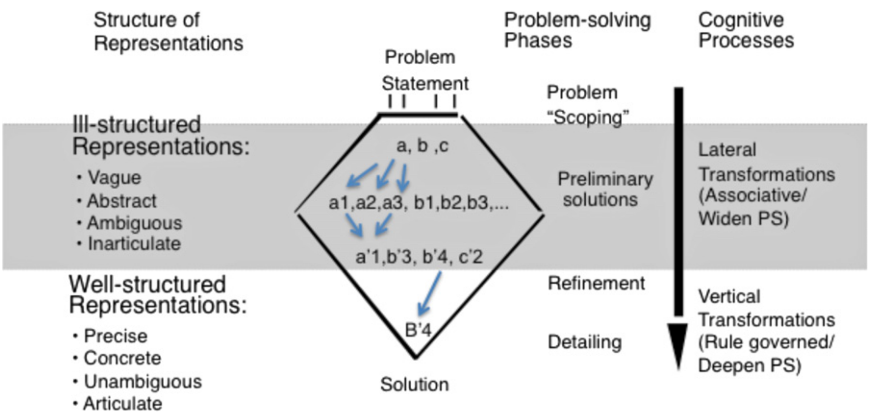

Fig. 1. The state space for real-world problems must support the different problem solving phases, which in turn require different representational systems and cognitive processes.

space and the exploration and development of kernel ideas (Goel, 1995).

The *refinement* and *detailing* phases are more constrained and structured. They are phases where preconstructed concepts are manipulated, and commitments are made to a particular solution and propagated through the problem space. They are characterized by the *concrete* nature of information being considered, a high degree of commitment to generated ideas, attention to detail, and a large number of *vertical transformations*. A vertical transformation is one where movement is from one idea to a more detailed version of the same idea. It results in a *deepening* of the problem space (Goel, 1995).

In summary, fostering and maintaining vague, abstract representations of problem states is critical in the early, formative phases of real-world problem solving, whereas, increasing precision and concreteness becomes more important towards the latter stages of the process. We hypothesize that damage to the right PFC system will impair the encoding and processing of more abstract and vague representations that facilitate lateral transformations, thereby resulting in premature commitment to precise concrete patterns, and quickly drawing conclusions, albeit substandard ones (because the space of possibilities has not been properly explored). To test this hypothesis we administered a real-world travel planning task to five neurological patients with focal lesions to right PFC (RPFC), and contrasted their performance with three comparison groups: five neurological patients with focal lesions to left PFC (LPFC), five neurological patients with posterior lesions, and five healthy normal controls (NC).

2. Method

2.1. Participants

The twenty participants in this study were comprised of five patients (4 males, 1 female) with lesions to right PFC, five patients (3 males, 2 female) with lesions to left PFC, five patients with posterior lesions (2 males, 3 female), and five normal controls (2 males, 3 females). All patients and controls gave written formal consent to participate in this study. All patients were right handed, as ascertained by the handedness Inventory scale (Oldfield, 1971). Patients were selected such that they (a) exhibited normal visuospatial IQ (i.e., scored >20 on Raven Colored Progressive Matrices) (Basso, Capitani, & Laiacona, 1987); (b) were able to make abstraction from single items in order to create semantic categories (i.e., scored >8 on the WAIS Analogy test, range of scores: 8–14) (Wechsler, 1955), and (c): exhibited normal verbal comprehension (i.e., scored >26.5 on the Token Test, range of scores: 30–34) (DeRenzi & Faglioni, 1978).

The complete demographic data for each individual participant appear in Table 1. There was no significant difference in the distribution of males and females between the four groups, $\chi^2(3)=2.22$, $p=.528$. In addition, there was no significant difference between the four groups in age ($F[3, 16]=2.05$, $p=.084$) and education ($F[3, 16]=2.64$, $p=.146$).

2.1.1. Patient etiology

Patients were recruited and tested at the neurological outpatient wards of the Universities of Modena and at the Faenza Hospital. Of the 5 RPFC patients, 4 had suffered from strokes and 1 from an aneurysm. Of the 5 LPFC patients, 4 had suffered from strokes and 1 from a combination of aneurysm and ischemic attack. Of the 5 posterior patients, 3 had suffered from strokes, 1 from a hematoma, and 1 from a combination of aneurysm and ischemic attack. Patients were tested a mean of 494 days after onset ($SD=734$). There was no significant difference in mean time of testing since onset between the three patient groups, $F(2, 12)=.86$, $p=.449$.

2.1.2. Patient lesion profile

Patient MRI or CT scans were processed with MEDx (Medical Numerics Inc., Sterling, VA). Skull and scalp components were removed using the BET algorithm (Smith, 2000) in MEDx. The deskulled volumes were imported into ABLe (Medical Numerics Inc., Sterling, VA) software (Makale et al., 2002) and displayed as a series of slices in a light box format. Lesions were manually outlined on the slices. Total lesion volume (in cc) 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 re-sliced at 17 degrees relative to the inferior orbitomeatal line, and 11 transverse slices that best match the Damasio (Damasio & Damasio, 1989) templates have been selected by a neuroradiologist and interactively labeled with Brodmann areas by reference to the Damasio templates. Although the locations of Brodmann areas 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 templates) were automatically extracted. Since the Brodmann areas are pre-marked on the 11 slices of the ABLe reference volume (see above) and the patient brain volume has been registered and re-sliced to conform to this template, the intersection of lesion with Brodmann areas was calculated by a simple voxel-by-voxel comparison. The calculated lesion sites are specified in the summary overlay image in Fig. 2. Percentages of intersection between lesions and Brodmann areas for the patient groups are listed in Table 2. There is no significant difference in brain volume loss ($M=20.64$cc, $SD=32.00$) between the three patient groups, $F(2, 12)=1.33$, $p=.307$.

Table 1
Demographic data for each individual participant.

Participant	Group	Sex	Age	Education
BM	LPFC	Female	64	5
RM	LPFC	Male	52	13
DG	LPFC	Male	42	11
MV	LPFC	Female	51	5
GG	LPFC	Male	72	8
PF	RPFC	Male	54	13
CR	RPFC	Male	58	8
PG	RPFC	Male	55	5
RF	RPFC	Female	64	5
SR	RPFC	Male	66	5
GL	Posterior	Female	64	13
CM	Posterior	Male	44	11
SU	Posterior	Male	52	17
BM	Posterior	Female	44	11
SS	Posterior	Female	69	11
LF	NC	Female	42	17
PM	NC	Male	24	17
PM	NC	Female	59	8
BC	NC	Male	32	8
AA	NC	Female	52	10

Note: LPFC=left prefrontal cortex lesion, RPFC=right prefrontal cortex lesion, NC=normal control, Education (in years).

2.1.3. Neuropsychological profile of participants

Apart from the visual and verbal tasks that served as tasks for inclusion criteria described above, participants were also administered a series of neuropsychological tasks to evaluate their (1) *memory*: verbal and spatial short-term memory (Orsini et al., 1987), verbal long term memory, and paired-word associate learning (De Renzi, Ruggerini, & Faglioni, 1977); (2) pre-morbid intelligence: TIB (Test di Intelligenza Breve) (Sartori, Colombo, Vallar, Rusconi, & Pinarello, 1997); (3) *executive function*: cognitive estimation (Nichelli et al., 2002), the Wisconsin Card Sorting Task (WCST) (Heaton, Chelune, Talley, Kay, & Curtiss, 1993); (4) verbal abilities: the vocabulary subtest of the WAIS (Wechsler, 1955), and verbal fluency; (5) attention: attention matrices test (Spinnler & Tognoni, 1987), (6) mood disturbances: Beck depression inventory (BDI) scale (Beck, 1987).

For all cognitive baseline measures, we computed the difference between the four groups using univariate ANOVAs. The groups did not differ on any of the cognitive baseline measures. Exact *p*-values for each measure are indicated in Table 3.

2.2. Materials and procedure

We administered a Travel Planning Task (TPT) to all participants. This task involved organizing a trip to Italy for an American couple. The task was constrained by time (one week), the budget (€3500), and the differing interests of the couple. The task instructions and the problem scenario are reproduced in Appendix A.

2.2.1. Data collection

Participants were presented with the TPT, and given written instructions that explained the experimental procedure (see Appendix A). After reading the problem scenario, participants were given a pamphlet containing all the relevant information necessary for planning a trip, including a list of interests, flights,

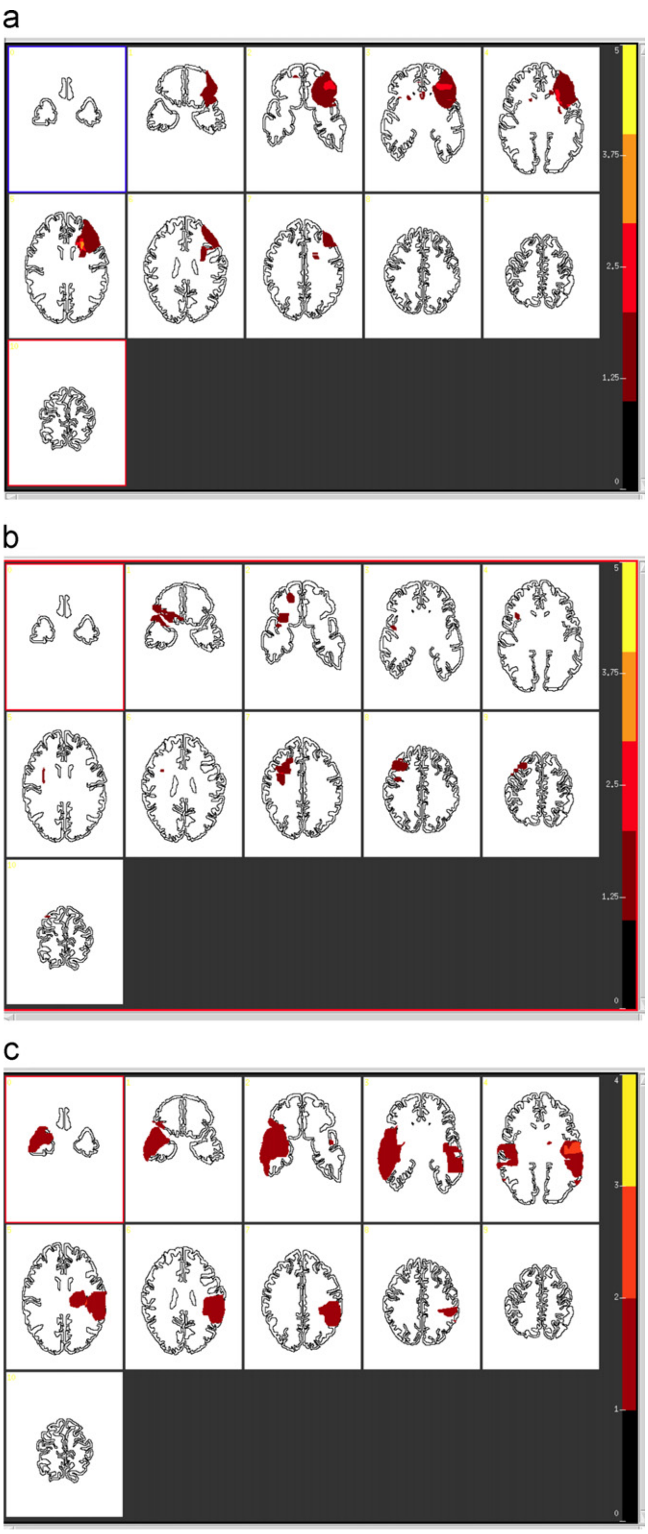

Fig. 2. Summary overlay images of the calculated lesion sites (in neurological convention, L=R). See text for method of calculation. (a) Left Prefrontal Cortex Patients, (b) right prefrontal cortex patients and (c) posterior patients.

trains, car rental, accommodations, restaurants, attractions, maps, and distances between cities. They were encouraged to ask questions if any aspect of the task was unclear. The experimenter responded on behalf of the couple.

The task was administered in two parts with no time restrictions. The first part required participants to read through the problem scenario and the pamphlet and to complete a questionnaire designed to familiarize them with the presented information (example questions: "What is the travel budget?"; "What are Paolo's main interests?"), and to ascertain that they could cope with the material. At this

Table 2
Mean percentages of intersection between lesions and Brodmann areas for patient groups.

	3	4	6	8	9	10	20	21	22	25	32	36
LPFC	.36 (.73)	2.48 (3.61)	3.26 (6.53)	1.22 (2.43)	0 (0)	.21 (.42)	0 (0)	0 (0)	1.54 (3.09)	0 (0)	.16 (.32)	.16 (.32)
RPFC	.22 (.31)	1.28 (2.44)	.83 (1.65)	.10 (.23)	4.41 (8.82)	.11 (.27)	0 (0)	0 (0)	1.54 (3.09)	1.21 (2.70)	0 (0)	0 (0)
Post	2.95 (3.74)	0 (0)	1.07 (2.15)	0 (0)	0 (0)	0 (0)	4.74 (9.48)	10.83 (14.83)	15.71 (13.63)	0 (0)	0 (0)	.03 (.07)

	37	38	39	40	41	44	45	46	47
LPFC	.16 (.32)	.16 (.32)	.16 (.32)	.16 (.32)	.16 (.32)	13.38 (26.47)	17.12 (25.99)	7.72 (15.44)	4.28 (8.57)
RPFC	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	7.18 (14.37)
Post	.32 (.64)	8.91 (17.82)	1.76 (3.52)	4.35 (8.71)	23.89 (18.22)	.04 (.08)	2.74 (5.47)	0 (0)	7.85 (17.56)

Note: LPFC=left prefrontal cortex lesion, RPFC=right prefrontal cortex lesion, Post=Posterior lesions.

Table 3
Cognitive baseline scores for the four groups.

Measure	LPFC	RPFC	Posterior	NC	*p*
Memory					
Paired associate task	10.49 (4.51)	9.60 (1.78)	8.40 (3.15)	13.00 (2.78)	.179
Digit span	5.20 (.91)	5.10 (.45)	5.20 (1.09)	5.75 (.73)	.605
Word span	4.55 (1.40)	3.70 (.41)	3.10 (1.32)	4.85 (.68)	.065
Corsi span	4.85 (.74)	4.80 (.27)	4.55 (.65)	4.65 (.65)	.854
Intelligence					
Pre-morbid: TIB total	106.40 (6.11)	100.40 (11.72)	111.80 (5.45)	113.40 (3.65)	.052
TIB verbal	103.80 (8.58)	98.00 (12.14)	110.20 (7.66)	110.20 (5.07)	.220
TIB performance	110.20 (4.97)	103.60 (13.09)	113.00 (7.14)	111.80 (5.81)	.146
Executive functions					
Cognitive estimation test: total score	39.40 (6.11)	43.60 (4.93)	44.40 (5.98)	47.80 (6.91)	.219
Cognitive estimation test: weight	20.60 (4.51)	21.80 (4.32)	22.60 (2.88)	23.40 (3.29)	.693
Cognitive estimation test: time	18.80 (3.03)	21.80 (1.79)	22.00 (3.54)	24.40 (4.04)	.092
WCST: number of criteria	4.00 (1.22)	3.80 (1.64)	2.80 (2.17)	5.40 (1.34)	.135
WCST: number of Cards	119.60 (18.78)	123.80 (9.39)	115.75 (24.50)	89.80 (22.74)	.243
WCST: preservative errors	29.00 (13.11)	22.00 (14.23)	15.00 (7.81)	12.00 (9.27)	.118
WCST: conceptual responses	43.80 (17.29)	45.80 (16.71)	60.25 (22.01)	69.80 (17.63)	.260
WCST: set	.60 (.55)	1.20 (.45)	2.80 (2.17)	.40 (.55)	.062
Verbal abilities					
Token test	33.30 (.96)	32.00 (1.27)	29.45 (6.16)	33.20 (1.32)	.247
Analogy	11.60 (1.82)	11.80 (1.64)	11.00 (1.22)	12.20 (.84)	.129
Vocabulary	10.20 (2.39)	9.60 (2.19)	12.20 (2.17)	14.20 (3.70)	.222
Attention					
Attention matrices	44.51 (11.28)	45.30 (3.87)	44.00 (8.41)	48.65 (6.89)	.797
Mood					
BDI	9.20 (4.60)	9.20 (9.44)	15.20 (5.01)	4.20 (6.22)	.114

Note: There were no significant differences between the four groups on any of the measures (see text). Exact *p*-values for each test are indicated.

stage of the task, the experimenter helped participants and pointed out information if they were not able to find it, as well as corrected participants if they provided incorrect answers. The purpose of this stage was to ensure that all participants had the same level of understanding about the provided information (i.e., responded correctly) before starting the second part (planning phase) of the task. *All* subjects answered *all* questions correctly.

In the planning phase of the task, participants were provided with blank paper, and a diary divided into seven days (i.e., the length of the trip). They were requested to develop a daily schedule of activities taking into consideration the constraints of time, interests, and money. The task was videotaped and all notes made by participants collected. Importantly, participants were asked to speak aloud and to verbalize their thoughts as they worked on the problem (Goel & Grafman, 2000; Goel et al., 1997). They were explicitly asked not to explain what they were thinking, but rather, simply verbalize the items they were attending to at any given time. The experimenter was present in the room and answered any questions, but did not initiate questions or discussion. The experimenter offered to help participants with mathematical calculations.

2.2.2. Data analysis

Data analysis was based on data generated in the second (planning) phase of the task. The videotapes for each participant were transcribed. We utilized the "verbal protocol" methodology developed by Ericsson and Simon (1993) and adopted to frontal lobe patients by Goel et al. (1997, 2000). Data were coded both qualitatively and quantitatively by two researchers, blind to the identity of participants.

2.2.3. Coding scheme

Coding the data for analysis involved first rating each plan for quality and completeness. The second step involved articulating the underlying cognitive processes/strategies employed by the participants. Each step is briefly described below.

2.2.4. Analysis of quality of plan

We determined a "*quality of plan*" measure associated with each plan, based on assessments of *reasonableness* and *completeness* of the plan. A plan was considered fully complete if all days were accounted for, and all requirements satisfied (meals, sights, etc.). A plan was considered reasonable if a certain number of cities with a manageable number of sites were visited, coupled with maximum allotment of the budget. Scores for completeness and reasonableness ranged from 1 to 5. Each plan was scored on completeness and reasonableness by two independent raters blind to the condition of the participant. Final score for each measure was the arithmetic mean of the two independent scorers' ratings. A description of each score for each category is provided in Appendix B. Scores for completeness and reasonableness were highly correlated, Kendall's tau=.70, p=.000, we computed a new variable called *quality of plan* (completeness+complexity/2). Inter-rater reliability (alpha) was computed for quality of plan, and found to be .80.

2.2.5. Analysis of planning process

The theoretical framework briefly introduced above (Fig. 1) contains the following six features of real world problem-solving processes: (i) a state space consisting of the series of states (a, b, c etc.); (ii) a set of operators permitting transformations between states (e.g., a→a1); (iii) a series of states connected by common goal or subgoal; (vi) phases of problems scoping and problem-solving (preliminary solutions, refinement, and detailing); and (v) differences in the structure of representations used in the problem space; and (vi) categorization of cognitive processes in terms of lateral and vertical transformations. We adopted a coding scheme from Goel and colleagues (Goel, 1994, 1995; Goel & Pirolli, 1992; Goel et al., 1997; Goel & Grafman, 2000) which enabled us to explicitly code for the first five of these components.

The first step in the coding process involves breaking the verbal protocols into individual statements representing single 'thoughts' or ideas. Content cues, syntactic cues and pauses are used to implement this individuation. We take each statement as constituting a state in the participant's problem space. The segmentation is indicated in Table 4 by each row.

The second step is to infer which operator was applied to get from one state to another. Examples of operators are *add* information, *evaluate* information, *justify* information, etc. This level of analysis gives a picture of cognitive processes at the granularity of a few seconds. The operators applied to each statement are indicated in the fourth column in Table 4. For example, the first statement is a *modification* of a previous statement, the second is a *repetition*, the third and *add*, etc.

The third step involves aggregating these statements into episodes, which are connected sequences of statements in the service of a common subgoal. Episodes are organized around goals/subgoals and strategies. Five goals are given in the problem scenario: reaching destinations, traveling, accommodation, eating, and sightseeing. Participants generate a number of subgoals as they traverse the problem space, and utilize various strategies to achieve the goals/subgoals. An important requirement involves considering the constraints placed on achieving various goals. Episodes typically have a duration of 1–2 min. The vocabulary at this level is one of goals, subgoals and strategies. The example in Table 4 illustrates a single episode focused on the subgoal of destination (see column 3).

The fourth step is to identify the problem solving phases participants engage in. These consist of problem scoping and problem solving phases. Problem scoping is a necessary prerequisite for the solution of ill-structured problems. It involves generating information that is explicitly missing from the problem scenario and incorporating it into the problem space. Problem solving is differentiated into preliminary planning, refinement and detailing phases. Preliminary plan statements result in the initial generation and exploration of ideas. Refinement statements serve to elaborate and develop an idea. Detailing statements specify the final form of an idea. These phases typically have durations of 1–10 min, and are generally engaged sequentially, starting with preliminary planning, passing through refinement, and ending with detailing. However, it is common for participants to return to an earlier phase as previously unnoticed aspects emerge. In the example protocol segment in Table 4, all the statements belong to a preliminary planning problem-solving phase (see column 2).

The fifth step categorized each statement generated during the planning phase in terms of an abstractness rating along one of three levels: abstract, concrete, or intermediate (see Appendix D). We defined *abstract* as a style of thought that is characterized by a more general, vague, and imprecise organization of the holiday (e.g., "they will visit as many cities as they can"), a *concrete* style as one that is characterized by a detailed and precise plan (e.g., "they will visit Galleria Borghese and spend 12 euro"), and *intermediate* as one that that was intermediate between abstract and concrete (e.g., "They should also visit Milan"). The example statements in Table 4 belong to *intermediate* and *concrete* categories (see column 3).

A detailed description of the coding scheme is provided in Appendix C. The counts of the various coding categories resulting from the application of the aforementioned coding scheme to the verbal data provide quantified measures that can in turn be subjected to standard statistical analyses. We computed inter-rater reliability for the episode and statement level codes. In both cases coefficient alpha exceeded .80, which was considered a priori to be the acceptability threshold.

3. Results

In accordance with previous studies (Goel & Grafman, 2000; Goel et al., 1997), we found that both patients and normal controls were able to generate a verbal protocol while doing the task. However, the results demonstrated a significant difference in time spent on the task, $F(3, 16)=4.31$, $p=.024$, $\eta^2=.48$. Specifically, patients with posterior lesions ($M=28.20$ min, $SD=6.53$) and RPFC patients ($M=28.75$ min, $SD=12.58$) spent less time on the task than did NC ($M=58.80$ min, $SD=26.01$). LPFC patients fell somewhere in the middle ($M=48.00$ min, $SD=6.06$), but their time on the task did not differ from RPFC patients ($p=.345$), patients with posterior lesions ($p=.281$), or NC ($p=.739$).

3.1. Quality of solution

While there are no right or wrong answers to real world planning tasks, there are better and worse solutions. We quantified the "goodness" of each plan by computing *quality of plan* (see Section 2). The average quality of plan for the sample was 2.81 ($SD=1.06$). The results of an ANOVA demonstrated that there was a significant difference in quality of plan as a function of group, $F(3, 16)=4.76$, $p=.015$, partial $\eta^2=.47$ (Fig. 3). Specifically, RPFC patients produced plans of significantly poorer quality compared to NC ($p=.007$, Dunnett planned posthoc).[1] The difference between LPFC and NC ($p=.715$) and posterior patients and NC ($p=.091$) did not reach significance.

3.2. Cognitive strategies

To explain the differences in the quality of plan across the four groups, we examined participants' cognitive processes in terms of the five measures provided by the coding scheme: states/statements, operators, episodes, problem solving phases, and abstractness of representations.

3.3. State space

To examine quantitative differences in terms of the state space, we examined the total number of states/statements generated in the course of planning by each group ($M=185$, $SD=114$). The results demonstrated that there was no difference between the groups in total statements generated in the course of planning, $F(3, 16)=2.60$, $p=.090$, partial $\eta^2=.34$. We further tested for differences between the four groups in the number of statements/states generated *per minute* in the course of planning ($M=4.76$, $SD=2.16$). The results demonstrated that there was no difference between the four groups in this variable either, $F(3, 16)=.82$, $p=.503$, partial $\eta^2=.15$.

3.4. Operators

Thirteen operators accounting for the transformation of one state to another were coded for (see Table 5). Separate one-way ANOVAs (followed by posthocs) showed that per minute of planning, NC produced significantly more *qualify* statements than all other groups, $F(3, 16)=5.09$, $p=.013$, partial $\eta^2=.50$. Furthermore, although the omnibus test was significant for *propose* statements, $F(3, 15)=4.61$, $p=.018$, partial $\eta^2=.48$, posthoc tests did not reveal any significant difference between the four groups on this measure. Exact p-values for each measure are indicated in Table 5.

3.5. Episodes

At the *episode* level we coded for five goals/subgoals, as well as four types of constraints and miscellaneous items. Separate one-way ANOVAs showed that apart from *sightseeing*, there was no significant difference between the groups on any episode (generated per minute of planning) (see Table 5). Furthermore, although the omnibus test was significant for *sightseeing*, $F(3, 15)=3.92$, $p=.030$, partial $\eta^2=.44$, posthoc tests did not reveal any significant difference between the four groups on this measure. Exact p-values for each measure are indicated in Table 5.

3.6. Problem solving phases

In terms of *problem solving phases* we coded for Experimental task, Monitor, Problem scoping, Preliminary planning, Plan refinement, and Plan detailing (see Table 5). Separate one-way ANOVAs showed that there was no significant difference between the groups on any phase (per minute of planning) (see Table 5). Exact p-values for each measure are indicated in Table 5.

3.7. Abstraction level of statements

We also examined differences in the number of concrete and abstract statements generated by participants as they traversed the problem space. Specifically, for each participant, we computed the ratio of concrete to abstract statements generated during the problem-solving phase of the task (i.e., preliminary, refined, and detailed). The average concrete-to-abstract ratio for the sample was 3.04 ($SD=4.12$). We then compared differences between the four groups. The results of the ANOVA demonstrated that plans produced by patients with lesions to right PFC had a significantly higher ratio of concrete-to-abstract problem-solving statements than normal controls, $F(3, 16)=3.90$, $p=.029$, partial $\eta^2=.42$ ($p=.016$, Dunnett planned posthoc) (Fig. 4). The difference

[1] Planned Dunnett post-hoc tests are pair-wise, testing a specific reference group against all remaining groups. The reference group against which all other groups are compared is NC.

Table 4
Small extract of a patient transcript from the beginning of the problem solving session. Each row corresponds to a state in the problem space. The statements belong to the preliminary phase of problem-solving. They are centered around the subgoal/episode of "destination". The statements belong to either the intermediate or concrete categories as indicated in column 3. The operators apply to the statements are indicated in column 4, along with the source of knowledge (self, experimenter, problem statement), and whether the statement was written or simply verbalized.

Patient:…let them land in Milan	Problem solving- preliminary plan	Destination[city][intermediate]	Modify.self.verbal
Patient: arrive in Milan…	Problem solving- preliminary plan	Destination [city][intermediate]	Repeat.self. verbal
Patient: this is the diary… …we can make Milan Venice	Problem solving- preliminary plan	Destination [city][intermediate]	Add.self. verbal
Patient: …Milan Venice	Problem solving- preliminary plan	Destination [city][intermediate]	Repeat.self. verbal
Patient: …Venice…then Florence…	Problem solving- preliminary plan	Destination [city][intermediate]	Add.self. verbal
Patient: they stay in Florence…Florence	Problem solving	Destination [city][intermediate]	Repeat.self.written
Patient: Rome…	Problem solving- preliminary plan	Destination [city][intermediate]	Add.self. verbal
Patient: where they stay two days	Problem solving- preliminary plan	Destination [duration][concrete]	Elaborate.self. verbal
Patient: …4…one two three four five and six and 1 day in Naples…Rome…1 2 3 4 it's 5 6 …	Problem solving- preliminary plan	Destination [duration][intermediate]	Add.self. verbal
Patient: I was counting the nights… …	Problem solving- preliminary plan	Destination [duration][intermediate]	Comment.self. verbal
Patient: 1 2 3 5 6 nights … 1 2 3 5 and 7 days	Problem solving- preliminary plan	Destination [duration][concrete]	Elaborate.self. verbal
Patient: two days in Naples…2 days…2 days in Florence…so it' 7 nights…	Problem solving- preliminary plan	Destination [duration][concrete]	Repeat.self. verbal
Patient: 1 2 4 2 6 and 6 2 4 6 2 days in Venice…2 4 6 7…and 8 in Naples…	Problem solving- preliminary plan	Destination [duration][concrete]	Elaborate.self. verbal

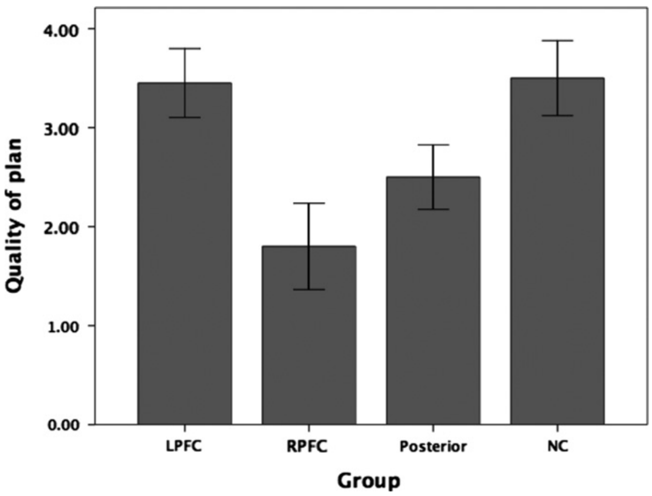

Fig. 3. Average quality of plans generated by the four groups. *Note*: Bars represent standard errors of measurement (SEM).

between LPFC and NC (p=.726) and posterior patients and NC (p=.747) did not reach significance.

Since the distribution of concrete-to-abstract statements is expected to increase as subjects move through the problem space towards a solution (Fig. 1), we divided each participant's total time spent on planning into the initial (early) 25%, middle 50%, and final (late) 25% periods, and recalculated the concrete-to-abstract problem-solving ratio for each time period separately. We conducted a mixed-model ANOVA with time point as a within-subjects variable and group as a between-subjects variable. The interaction between group and time point approached significance, $F(6, 30)=2.35$, $p=.056$, partial $\eta^2=.32$. To explore this interaction further, we investigated the simple main effect of group at each level of time point separately. The results demonstrated that there was no difference in the ratio of concrete-to-abstract problem-solving statements in the early ($F[3, 15]=2.03$, $p=.153$) and late ($F[3, 15]=1.55$, $p=.243$) phases between the four groups. However, in the middle phase, the concrete-to-abstract problem-solving ratio was significantly higher for patients with lesions to right PFC, $F(3, 15)=4.28$, $p=.023$, partial $\eta^2=.46$. In general, the results suggest that rather than being limited to a specific phase, there is a trend toward more concreteness in cognition across all three phases in patients with lesions to right PFC.

4. Discussion

Our results revealed that the plans generated by the right PFC patients were significantly inferior to those generated by the other groups. To account for the differences we examined the underlying cognitive processes of the four groups. We did not find any significant or meaningful differences in the number and types of operators applied, any of the episodes considered, or the number of statements allocated to the different problem-solving phases. We did, however, find interesting differences in terms of the size of the problem space explored, time allocated to solution, and varying ratios of concrete-to-abstract statements utilized by the four groups throughout the problem-solving process. These results go some way in explaining the poor performance of patients with right PFC lesions.

The suboptimal plans generated by patients with right PFC lesions can be linked to their problem-solving strategy. They, as well as patients with posterior lesions, spent less time on the task. However, unlike the other three groups, patients with right PFC lesions also generated a significantly higher ratio of concrete-to-abstract statements in the course of planning (Fig. 4). The finding that patients with right PFC lesions are impaired in abstraction is consistent with the findings reported in Roca et al. (2010). We suggest that the overly concrete traversal of the problem space contributes to real-world planning deficits.

The idea that successful problem solving requires both abstraction and concreteness is very old (see Wallas (1926)). Excessive reliance on either abstract or concrete representations should lead to substandard solutions. In patients with right PFC lesions there was an overrepresentation of concrete problem solving statements in the course of planning. This imbalance would result in premature commitments being made which cannot be revised flexibly in the light of new information as the plan develops. It would also result in selective focus on certain, more concrete aspects of the task. Given that patients with right PFC lesions were the only group to also produce substandard plans, this suggests that excessive concreteness was a contributing factor to impaired planning.

However, we did not find the reverse pattern in the case of the patients with left PFC lesions. Our theoretical framework predicts that they should be overly abstract and impaired in the later, more well-structured aspects of the task. One plausible explanation for why we did not find this is that the experimental sessions may not have allowed for sufficient problem structuring and detailing to bring out these difficulties. Another possibility is that the critical regions of left PFC were not lesioned in our patients.

Table 5
Distribution (percentage) of categories at the planning phase, episode, and statement levels.

	LPFC	RPFC	Posterior	NC	*p*
Statement level					
Operators					
Add	48.56 (6.04)	35.36 (11.55)	37.39 (8.09)	42.80 (11.64)	.189
Propose	2.83 (1.69)	7.09 (3.12)	9.92 (4.66)	4.96 (2.11)	.018
Evaluate	5.20 (3.22)	7.05 (3.29)	5.49 (2.43)	10.77 (7.21)	.245
Comment	7.72 (3.37)	10.14 (6.10)	7.33 (3.52)	8.07 (6.03)	.824
Modify	1.88 (.73)	2.96 (2.70)	3.42 (2.16)	2.92 (1.76)	.679
Elaborate	7.85 (4.13)	9.92 (4.19)	8.59 (3.14)	8.76 (3.80)	.865
Justify	2.27 (1.67)	2.59 (2.14)	3.75 (2.12)	3.48 (2.97)	.727
Read	2.00 (3.19)	1.31 (1.79)	1.06 (.84)	.71 (1.59)	.799
Qualify	2.83 (1.29)	2.11 (1.47)	2.67 (1.71)	5.91 (2.17)	.013
Request	7.43 (2.36)	10.11 (6.00)	10.26 (8.49)	7.11 (3.84)	.717
Repeat	7.80 (6.48)	8.27 (7.00)	8.46 (3.39)	3.23 (3.49)	.414
Clarify	.50 (.62)	0 (0)	.30 (.59)	.08 (.17)	.283
Miscellaneous	3.12 (5.13)	3.09 (5.10)	1.37 (.80)	1.19 (.93)	.773
Episode level					
Goals					
Destination	15.57 (3.21)	12.96 (12.51)	13.46 (2.93)	13.46 (8.77)	.959
Travel	19.30 (9.09)	32.35 (12.16)	27.27 (7.35)	22.21 (2.08)	.206
Accommodation	7.87 (5.26)	9.77 (2.70)	7.38 (5.63)	7.05 (3.68)	.772
Sightseeing	15.39 (6.20)	5.67 (7.56)	4.46 (3.48)	16.35 (8.42)	.973
Eating	9.31 (3.16)	8.16 (7.64)	9.47 (9.92)	10.05 (4.16)	.030
Constraints					
Budget	5.74 (3.12)	7.47 (6.74)	7.59 (5.81)	4.79 (3.11)	.778
Interests	1.70 (2.01)	1.34 (1.86)	1.26 (1.76)	2.80 (2.39)	.635
Relaxation	.73 (1.62)	.12 (.27)	.22 (.43)	.46 (.68)	.752
Duration	3.67 (3.75)	2.45 (2.08)	3.35 (2.83)	3.54 (2.11)	.897
Miscellaneous	5.59 (5.68)	5.65 (6.97)	2.60 (1.54)	2.85 (2.28)	.647
Planning phases					
Experimental task	1.76 (1.42)	4.15 (1.79)	1.00 (1.14)	1.82 (1.75)	.597
Monitor	6.40 (1.73)	8.13 (3.44)	5.23 (4.45)	6.60 (6.80)	.149
Problem scoping	19.89 (6.32)	17.79 (4.67)	28.59 (9.51)	21.22 (6.04)	.881
Preliminary plan	26.50 (6.47)	29.96 (5.92)	29.68 (4.49)	25.09 (6.32)	.190
Plan refinement	26.90 (7.05)	29.96 (5.92)	21.84 (2.15)	31.11 (8.81)	.954
Plan detailing	18.55 (10.28)	14.95 (3.16)	13.65 (4.82)	15.15 (3.43)	.763

Note: NC=normal controls; RPFC=patients with lesions to right prefrontal cortex; LPFC=patients with lesions to left prefrontal cortex. Exact *p*-values for each test are indicated.

One alternative explanation that might account for the poor performance of patients with right PFC lesions is the implication of this region in cognitive monitoring and checking. However, we did code for cognitive "monitoring" statements that measure the degree of explicit, top-down, monitoring and checking that participants engaged in. There were no differences in the number and distribution of meta-cognitive monitoring statements across the four groups.

Our results are consistent with classical clinical observations about frontal lobe involvement in abstraction (Goldstein, 1944; Goldstein & Scheerer, 1941). They are also consistent with and expand upon the two previous studies that have administered real-world planning tasks (financial planning and architectural design) to frontal patients and used the verbal protocol analysis methodology (Ericsson & Simon, 1993) to look at underlying cognitive processes (Goel & Grafman, 2000; Goel et al., 1997). In particular, these studies also reported no deficits in frontal patients in the routine control and sequencing of operations at the Statement Level, but did note difficulties at the level of negotiating Episodes and Problem-Solving phases. One of the studies highlighted difficulties in abstraction and problem space development in an architectural design/planning task in a patient with a right PFC lesion (Goel & Grafman, 2000).

It is also natural to try to relate these results to the numerous patient and neuroimaging studies of planning involving the Tower of Hanoi and Tower of London tasks. After all, they are all planning tasks, and a few of these studies do show differential task involvement of left and right prefrontal cortex, as in the Kaller et al. (2011) study, discussed above. Here we urge restraint

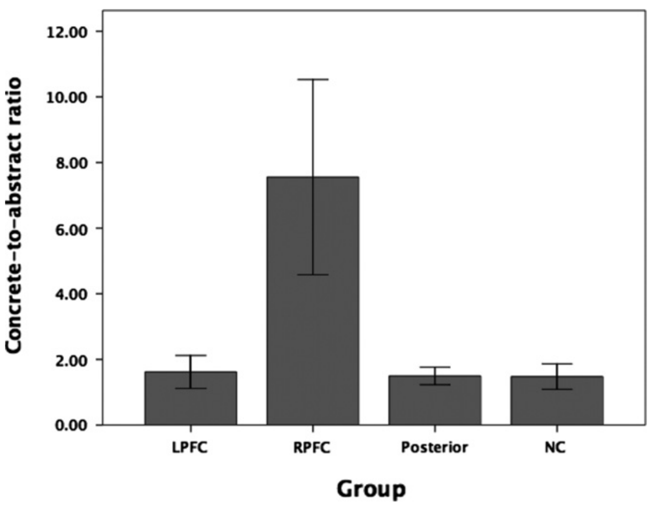

Fig. 4. Average abstractness of statements generated by the four groups. *Note*: Bars represent standard errors of measurement (SEM).

and caution. While it may be tempting to try to map their results regarding right PFC activation in the "search depth" condition onto our results and vocabulary of vertical and lateral transformations, the qualitative differences between real world, ill-structured problems, and well-structured problems overwhelm any similarities in terms of planning/ordering sequences of steps, and make comparisons premature. In particular, well-structured problems come with a pre-specified state space that only needs to be traversed in a particular sequence, whereas in ill-structured problems the state space itself needs to be constructed.

Finally, our results should be understood in the context of three caveats. First, our patient numbers are modest. Second, the lesion locations in our left and right frontal groups do differ. We have accommodated this difference by focusing on the role of the right PFC, rather than the differences between the right and left PFC. Third, while there are no significant differences in the age and education of the four groups, the normal controls do display a trend for being younger and having more years of education than the patients (see Table 1).

In summary, successful functioning in the real world requires a judicious balancing act between systems that support vague, abstract representations and the accompanying lateral transformations, and systems that support more precise, articulate, concrete representations and the accompanying vertical transformations. Our results are consistent with the claim that damage to the right PFC system impairs the encoding and processing of more abstract and vague representations that facilitate lateral transformations. This results in prematurely locking onto precise concrete patterns, and quickly drawing conclusions, albeit substandard ones. Our results go some way toward linking the generation of suboptimal plans in an ill-structured task to the recruitment of a specific cognitive strategy involving overt concreteness in cognition, and localize it to the right prefrontal cortex.

Acknowledgment

This study was funded in part by a Grant from CHIR to VG. A portion of these results was presented at the annual meeting of the Society for Cognitive Neuroscience in San Francisco, CA, March 2009.

Appendix A. Task instructions and the problem scenario

Thank you for agreeing to participate in our study. Very generally, we are interested in people's problem-solving and reasoning processes, particularly those associated with planning tasks. Therefore, during the next little while we are going to ask you to engage in a planning exercise as called for in the accompanying problem scenario.

As you can see, the session will be taped on a video recorder. The tapes provide us with a trace of your problem-solving activity and allow us to engage in in-depth analysis at a later date.

For the recordings to be of maximal benefit to us, we are going to ask you to *talk aloud* as you proceed through the task. By this we do not mean that you should explain what you are thinking. Rather, you should just try to vocalise the fragments of thoughts and ideas that you might be attending to at the time. That is, we all talk to our selves when we solve problems. We would just like you to talk a little louder so we can hear. We would like to get a continuous stream of such vocalizations from you.

It is not easy (or even normal) to attend to a complex task and verbalize at the same time. Therefore, you will undoubtedly lapse into periods of silence. This is to be expected. During such periods we will prompt you to speak. This is a routine part of our experimental methodology.

We have decided to give you no time restriction. We have two hours of tape and will not mind if you choose to go over if necessary. However, it is important that you *address the problem as fully as possible and outline a reasonably detailed plan of action*.

Also, the enclosed problem scenario is rather sparse. It is intended that you converse with the experimenter to iron out any difficulties and shortcomings.

Finally, travel plan sheets, day planner sheets, an expenses worksheet, and scrap paper are provided such that you may be able to detail your plan of action.

Please begin.

Problem scenario

Paolo and Elena, a middle-aged (45 and 42 years respectively), professional couple from New York (America) are planning visit Italy for a week during Easter, leaving their 13-year-old daughter with her grandparents.

Elena is an architect with a strong passion for the **arts and the sculpture**. She has wanted to visit Italy since she was a student of architecture at the University of New York. Paolo is a lawyer with a passion for **archeology** and does not have much patience for the Fine Arts. Neither Paolo nor Elena speak Italian, however they want to organize their holiday by themselves, taking into account their respective interests. They have only one week to spend there, and they want to organize their holiday in the best way. In terms of holiday expenses, Paolo and Elena have a budget for the trip of € 3500.

A. The task consists of two parts:

(1) The first is to answer the attached questions.

(2) The second task is to help Paolo and Elena plan and structure an itinerary giving a list of things they should do, when they should do them, and the financial cost of each item.

Keep the following constraints in mind:

(i) The travel budget is €3500 (including transportation).

(ii) There are different attractions that each wants to visit.

(iii) Both want to eat well, and sleep comfortably every day.

(iv) It is important to leave time for relaxation and enjoyment of surroundings.

Appendix B. Scoring scheme for quality of plan

Completeness

1. Substantially incomplete
   - not all days accounted for
   - no plans for meals, sights, interests, relaxation, accommodation, or travel
2.
   - not all days accounted for
   - few/no plans for meals, sights, interests, relaxation, accommodation, or travel
   - includes at least some budget
3.
   - all/almost all days accounted for
   - few meals, sights, interests, relaxation, accommodation, or travel
   - may be completed by missing one or two requirements (especially relaxation or interests)
4.
   - all days are accounted for
   - one or more requirements may be partially incomplete (especially relaxation or interests)
   - budget is considered on most days.
5. Fully complete
   - all days are accounted for
   - all requirements are complete

Reasonableness

1. Poorly constructed plan

- 1 city or $>5/6$ cities visited
- itinerary is geographically unmanageable
- inconsistent meal planning
- unmanageable or deficient number of sights visited (usually >6/day)
- under/over budget by more than approximately 1000 Euro

2.
- 1 city or >5 cities visited
- itinerary is geographically unmanageable
- inconsistent meal planning on most days
- unmanageable or deficient number of sights visited (<2 or >6/day) on most days
- under/over budget by 500–1000 Euro

3.
- 2 or 5 cities visited
- itinerary is basically efficient (forms a loop or a straight line on a map, with possibly some inefficiencies)
- meal planning generally consistent with the nature of the trip
- reasonably number of sights (between 2 or 6/day) on most days
- under/over budget by 500–1000 Euro

4.
- between 2 and 5 cities visited
- efficient itinerary (forms a loop or a straight line on a map)
- meal planning generally consistent with the nature of the trip
- consistently manageable number of sights
- budget is within 500 Euro of maximum allotment

5. Very desirable plan
- 3 or 4 cities visited
- efficient itinerary (forms a loop or a straight line on a map)
- meal planning generally consistent with the nature of the trip
- consistently manageable number of sights, with consideration of interests
- budget is very close to maximum allotment

Note. In forming a rating, the number of cities, the layout of the itinerary, and the budget planning are given the greatest weight.

Appendix C. Coding scheme

The verbal protocols are first transcribed and cross-referenced with the written and drawn documents. The transcribed protocols are then divided into utterances or statements meant to capture single "thoughts" or ideas. Both content cues (e.g. shift in topic) and noncontent cues (e.g. a pause) are used to effect this individuation. This results in a fine-grained individuation of statements with a mean duration of five to ten seconds. A complex tri-level coding scheme is applied to each statement (see Fig. A.1).

The *plan phase level* codes (see Fig. A.2), identify the statement as either an experimental task (*exp-task*), monitoring (*monitor*), plan development (*plan-development*), or *misc* statement type, where each is defined as follows:

Exp-task: any statement having to do with the experimental design and setup.
Monitor: any statement used to take stock, further, review, or comment on the problem solving *process* itself. Most of these correspond to what in the literature have been called meta-cognitive statements.
Plan-development: statements that advance the state of the plan/design.
Misc: any statement that does not fall into one of the above categories.

The plan development statements are further categorized into the following four subcategories:

Problem-structuring: statements that serve to solicit or generate information to structure the problem.
Preliminary-plan: statements that result in the initial generation and exploration of some aspect of the plan.
Refine: statements that serve to elaborate and further the commitment to an already generated plan idea or element.
Detail: Statements that serve to detail and give the final form to some aspect of the plan.

The second or *module* level code (see Fig. A.3) serves to aggregate statements into what are generally called episodes, which are connected sequences of statements in the service of a common subgoal. For example, in a travel planning task, the episodes might be components like destinations, travel, accommodations, sights, etc. These episodes may contain sub-episodes like, trains, planes, specific cities, specific sites, etc.

The third or *statement level* code (see Fig. A.4) has four independent fields; the *operator* applied, the *content* to which it is applied, the *mode* of the output, and the *source* of knowledge used. *Operators* are a labeling of statements by the function they serve in the problem space. While no theoretical commitment is made to any specific set, the eleven noted below are adequate for current purposes:

Add: the basic operation of putting something into the problem space with some degree of commitment.
Propose: indicates that an idea is being entertained but is not yet committed to the problem space.
Evaluate: means that the statement is an explicit evaluation of a previous statement or plan component in the problem space.
Comment: it is by large the report of an activity rather than the execution of it. They generally occur with monitoring statements. Often it involves the subject explaining what he has just done, or just making some remarks which may or may not be task relevant.
Modify: a statement which deletes or alters an existing idea or element which is already a part of the problem space. It is sometimes difficult to distinguish between *add* and *modify*; between an old idea being modified and a new idea begin added.
Elaborate: expands an existent idea or element.
Justify: offers a rationale for the addition, modification, elaboration, of ideas or elements in the problem space.
Read: any time the subject reads from the experimental task instructions, problem scenario, or any other documents supplied with the task.
Qualify: a statement used to hedge or further qualify the previous statement.
Request: statements used to ask questions of or make suggestions to the experimenter.
Repeat: the application of the same operator to the same content again. While any operator can be repeated, it is usually only *add, modify,* and *elaborate* operations which actually are repeated.
Misc: any statement which can't be coded with one of the above operators.

The *content* to which the operator is applied is also noted. The *mode of output* of a statement is encoded as either *verbal* or *written*: Hand and facial gestures are not encoded.

Verbal: statements which are only uttered verbally, with no accompanying mark-on-paper.

Written: statements accompanied by marks-on-paper. These statements may or may not have an associated verbalization.

Each statement is also encoded for the *source of knowledge* for the statement. The four categories used are the *experimenter*, the *design brief, self* (retrieved from long-term memory), and *inferred* (deductively) from the information existent in the problem space.

Experimenter: this is information which is either given to the subject by the experimenter, or actively solicited by the subject from the experimenter.
Design-brief: this is information which the subject has gotten directly from the problem scenario and any accompanying documents.
Self: this is information which the subject either generates or retrieves from his long-term memory.
Infer: this is information which the subject infers (in the strong deductive sense) from the information existent in the problem space.

Appendix D. Level of abstractness

Abstract

Statements coded as 'abstract' are those that suggest a wide-reaching approach to designing the travel plan. They often include a variety of elements within one idea, and reflect a holistic view of the travel plan. Abstract statements could be focused on a single module (i.e., destination, travel, or budgetary constraints), but tend to offer a more general perspective on the module that is not overly bound by specifics or details. An example of abstract statement was "I start from the places they want to go first of all/ so let's see she is interested in art.. he in archeology.. let's do Rome for Paolo.. interests are enough even for Elena … let's see if there are other solutions first."

Concrete

Statements were coded as concrete if they were restricted to details and had a fairly narrow focus. Concrete statements tend to reflect precision in the participant's strategy of planning the task, with a money- or time-focused approach to the travel plan.

Fig. A.1. A three-level coding scheme.

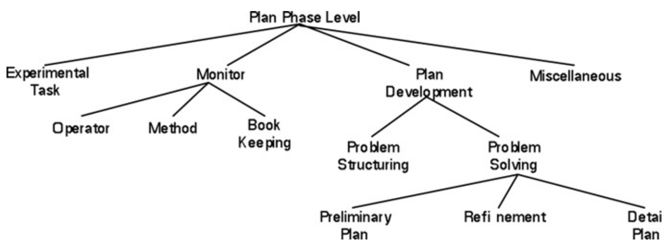

Fig. A.2. Coding scheme: plan phase level.

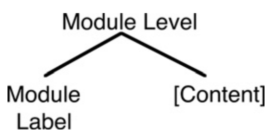

Fig. A.3. Coding scheme: module level.

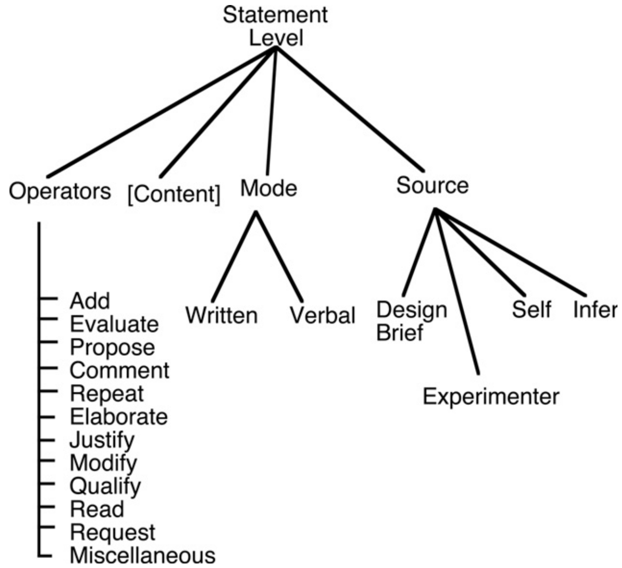

Fig. A.4. Coding scheme: statement level.

An example of concrete statement was "I would consider that the hotel is close, and they do not need to take the bus … yes, we do a close hotel and they can walk …/… they arrive at 11, they bring in their luggage…/… and are hungry so go to lunch at a pizzeria… one hour."

Intermediate

Statements coded as 'intermediate' were not considered to be particularly abstract or concrete, but rather, reflected an intermediary approach to planning the itinerary. Intermediate statements often occurred during transitions between abstract and concrete thinking. An example of intermediate statement was **"**So from New York to Florence … oh… there is no flight to Florence../ … I don't know there is not … we must delete it."

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