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Is it bigger than a breadbox? Performance of patients with prefrontal lesions on a new executive function test

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Abstract

Executive deficits of problem solving and concept formation have been associated with frontal lobe dysfunction. Here we describe a new clinical test of concept formation based on the parlor game, Twenty Questions. The Twenty Questions Test requires examinees to ask the fewest number of yes/no questions possible in order to identify a target item from an array of 30 line drawings. The items belong to a number of categories and subcategories that exist in a hierarchical, semantic structure. Patients with focal prefrontal lesions asked significantly more questions than controls in their attempt to guess the target items and sometimes exhausted the 20-question limit. Qualitative analyses revealed that patients tended to use ineffective categorization strategies, for example, relying exclusively on questions that referred to single items. Taken together with previous findings, we conclude that prefrontal cortex supports the on-line organization and conceptualization of category exemplars in concept-formation tasks.

Keywords: Executive functioning; Prefrontal lesions; Frontal lobe; Reasoning; Problem solving

A variety of executive function tests have been designed to study problem solving and concept formation in neurologic patients (Battersby, Teuber, & Bender, 1953; Burgess & Shallice, 1996; Channon & Crawford, 1999; Dimitrov, Grafman, & Hollnagel, 1996; Goldstein

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& Scheerer, 1941; Miotto & Morris, 1998). Such tasks typically involve a number of steps, including comprehension and analysis of a problem, generating different potential solutions, identifying/abstracting principles, generating strategies to arrive at solutions, shifting between strategies as needed, and implementing a solution in a coherent fashion. Other, more basic, cognitive processes no doubt are recruited as well, including self-monitoring, working memory, and retrieval (Barcelo, Sanz, Molina, & Rubia, 1997; Shallice & Burgess, 1998; Xu & Corkin, 2001).

While a large system of neural networks is most likely recruited to perform complex problem-solving tasks (Baker et al., 1996; Berman et al., 1995; Burgess, 2000), the group of patients most often associated with deficits in this area are patients with frontal lobe lesions (Burgess & Shallice, 1996; Carlin et al., 2000; Janowsky, Shimamura, Kritchevsky, & Squire, 1989; Klouda & Cooper, 1990; Miller & Tippett, 1996; for an excellent review, see Stuss & Alexander, 2000). Specifically, concept formation and problem solving have been associated with lateral and dorsal portions of prefrontal cortex (Milner & Petrides, 1984; Morris, Ahmed, Syed, & Toone, 1993).

Despite the importance of concept formation and problem solving in everyday life, there are relatively few clinical tests designed specifically to test these abilities (Channon & Crawford, 1999). The most widely used and best known example of this genre of tests is the Wisconsin Card Sorting Task (WCST; Heaton, Chelune, Talley, Kay, & Curtis, 1993). This test requires patients to sort cards according to three high-frequency concepts: color, shape, and number. The sorting rule changes across trials and must be inferred by the patient based on the examiner's right–wrong feedback. An extensive literature has documented an association between performance on this task and lateral prefrontal functioning, based on studies in neurologic patients as well as neuroimaging studies with normal controls (Janowsky et al., 1989; Milner, 1963; Vilkki, 1988; Weinberger & Berman, 1998; but see Anderson, Damasio, Jones, & Tranel, 1991). On the WCST, impairments in concept formation and flexibility of thinking are inferred from perseverative sorting. To this end, the WCST is perhaps the premier instrument for documenting such perseverative responding.

Recently, a new clinical test of concept formation and problem solving was developed to complement tests such as the WCST. The D-KEFS Twenty Questions Test (Delis, Kaplan, & Kramer, 2001) is based on the parlor game in which a player asks yes/no questions to guess which famous person or object the other player is thinking of (see also Goldstein & Levin, 1991; Laine & Butters, 1982; Mosher & Hornsby, 1966). The test assesses concept-formation skills directly from patients' verbalizations rather than inferring such deficits from card sorting responses. The name of the test reflects the rule that a player has only 20 questions in order to arrive at the correct answer. The most efficient way to approach the game is to start with more abstract, high-level categories (e.g., "Is it mineral?") and then move to progressively more specific questions (e.g., "Does it use gasoline?").

Like the WCST, the Twenty Questions Test requires participants to abstract categories, modify their responses based on feedback, and keep track of previous responses. However, on the Twenty Questions Test, the nature of an examinee's concept-formation skills is reflected directly in his/her verbalizations. In addition, the Twenty Questions Test differs from other concept-formation tasks by offering a much greater number of potential concepts within a hierarchical category structure, affording a broader assessment of categorization skills.

The Twenty Questions Test is also administered in an enjoyable, game-like format where right–wrong feedback is disguised in the yes/no format of the game. Previous versions of this type of test have been used to test problem solving in children and other participant groups (e.g., Laine & Butters, 1982; Levin et al., 1997; Mosher & Hornsby, 1966). The new version of the Twenty Questions Test was constructed to have a systematic hierarchical category structure so that strategic use of super- and subordinate categories could be assessed.

In the current study, we used the Twenty Questions Test to assess problem solving and concept formation in patients with focal, prefrontal cortex lesions. The test version of this procedure is more constrained than the parlor game. Whereas the parlor game is open-ended, the current version is limited as patients attempt to identify the target item from a set of 30 pictured items displayed in a 5 × 6 array. The selection of items was constructed so that there is a hierarchical category structure with items falling into broad categories (e.g., living vs. non-living) and progressively more narrow categories (e.g., land vs. sea animals). The test was designed as a measure of concept formation and problem solving that could be viewed as complementary to other established tests, such as the WCST.

Previous studies in our laboratory have shown that patients with focal prefrontal lesions have intact semantic knowledge about categories but have difficulty retrieving and organizing that information under certain task conditions (Baldo, Delis, Kramer, & Shimamura, 2002; Baldo & Shimamura, 1998; Sylvester & Shimamura, 2002). For example, patients with frontal lesions fail to make use of semantic categories to support learning and retrieval on verbal learning tasks (Baldo et al., 2002). Thus, it was predicted that patients would show a reduced ability to formulate effective questions based on the inherent categorical structure of the task in order to narrow their search. We were also interested in determining whether performance on the Twenty Questions Test depended on other, more basic cognitive processes such as memory retrieval and linguistic competence, and whether performance on this task would be predictive of performance on other measures of problem solving. To this end, we also administered a series of other tasks including verbal fluency, verbal learning, and problem-solving tasks.

1. Methods

1.1. Participants

Participants were 12 patients with prefrontal cortex lesions (4 females and 8 males) and 12 age- and education-matched controls from the same community (4 females and 8 males; see Table 1 for participant characterization). Six of the patients had left hemisphere lesions, five had right hemisphere lesions, and one had a bilateral lesion (see Fig. 1 for lesion reconstructions). Ten of the patients had lesions in lateral prefrontal cortex, and two of the patients (WP and CL) had ventral lesions. In one patient (MK), the lesion may have included a very small region of the anterior temporal pole, but this was difficult to discern from his films. Patients with lesions that extended significantly into non-frontal regions were excluded. Lesion etiologies included stroke ($n = 6$) and surgery for meningioma ($n = 3$), aneurysm ($n = 1$), cyst

Table 1
Participant characterization

Patients	Gender	Lesion site	Volume (cc)	Age at test	Years (post)	Lesion etiology	Educ. (years)	WAIS-R PIQ	Total questions	Percent concrete
OA	M	L	17.5	65	13	Stroke	14	134	46	84.8
WA	F	L	26.2	75	11	Stroke	14	132	27	63.0
LS	F	L	27.9	68	16	Meningioma	16	–	74	100.0
WE	M	L	41.1	69	2	Stroke	15	104	53	100.0
JM	M	L	18.8	54	1	Stroke	11	91	23	56.5
CL	M	L	–	63	10	Meningioma	16	–	27	74.1
EB	F	R	17.3	79	14	Stroke	12	114	53	35.8
SR	F	R	12.9	77	2	Stroke	12	93	67	97.0
WT	M	R	25.9	53	9	Cyst	18	–	28	35.7
MG	M	R	24.5	34	13	AVM	12	–	28	39.3
MK	M	R	200.4	66	17	Aneurysm	17	–	63	96.8
WP	M	BIL	–	54	.08	Meningioma	12	–	29	27.6
Means										
Frontal	8 M, 4 F	6 L, 5 R		63.1	9.0	–	14.1	111.3	43.2	67.6
Control	8 M, 4 F	–	–	64.1	–	–	14.7	–	27.4	31.0

Note. Dashes indicate data that are not available or not applicable. L: left hemisphere; R: right hemisphere; BIL: bilateral; AVM: arterio-venous malformation; Educ.: education; WAIS-R PIQ: Wechsler Adult Intelligence Scale—Revised Performance IQ; total questions: total number of questions asked on the Twenty Questions Test; percent concrete: percentage of questions asked that focused on a single item.

Fig. 1. Reconstructions of patients' lesions from CT and MRI scans. Lesions were drawn on a standard MRI template using MRIcro software (Rorden & Brett, 2001). The far right image in each patient series shows the lesion projected onto the lateral surface of the brain.

($n = 1$), and arterio-venous malformation ($n = 1$). The average number of years post-onset of injury was 9.0 years (range: 1 month to 17 years). Patients were screened with the Western Aphasia Battery and were excluded if they scored below the normal cutoff (Aphasia Quotient of 93.8; Kertesz, 1982).

Patients and controls did not differ in terms of age, $F(1, 22) = 0.04$, $P = .84$ (63.08 and 64.08 years, respectively), or education, $F(1, 22) = 0.41$, $P = .52$ (14.08 and 14.67 years, respectively). The participants were over 50 (range 53–79 years for patients and 53–78 years for controls), except for one younger patient and an age-matched control (34 and 33 years, respectively). Participants were screened for drug and alcohol abuse history, dementia, and psychiatric disorders, and controls were additionally screened for prior neurologic history. Participants were right-handed, except for one left-handed patient (CL) and a left-handed matched control.

Testing was completed at the VA Northern California Health Care System in Martinez, CA. All participants read and signed consent forms prior to participating in the study. All participants, except for one of the controls, had participated in studies at the VA previously.

1.2. Materials

The stimuli in the Twenty Questions Test consisted of 30 colored drawings on a single page in a stimulus booklet (Delis et al., 2001). The stimuli were arranged in five rows of six drawings each and consisted of drawings of both animate and inanimate objects (e.g., dog, fork). The items were chosen so that there was a hierarchical structure of higher level categories consisting of 15 items each (living vs. non-living things), mid-level categories consisting of 7–8 items each (plants, animals, kitchen items, and transportation), and lower level categories of 2–3 items each (e.g., fruits, vegetables, silverware).

1.3. Procedure

Participants were instructed to ask the examiner questions in order to determine which picture the examiner had chosen. The participants were told that they could only ask questions to which the examiner could respond "yes" or "no." Participants were told that they should try to guess the correct picture with the fewest number of questions possible. If a participant's first question referred only to one item (e.g., "Is it the submarine?"), she/he was prompted once with a reminder to ask the fewest number of questions possible. The examiner recorded the participant's questions on paper. Participants were allowed a maximum of 20 questions to guess the correct target item. Optimal performance on this test results in correct target identification within four to six questions. After guessing the correct item, or after 20 questions were exhausted, the examiner proceeded to the next trial. There were four target items and thus four trials in all.

All patients and controls were also administered a number of other standardized, neuropsychological measures in the same session. These included a verbal fluency task (FAS task), the California Verbal Learning Test-II (Delis, Kaplan, Kramer, & Ober, 2000), and the D-KEFS Sorting Test.

2. Results

Data from the Twenty Questions Test were first analyzed with a mixed analysis of variance (ANOVA), with Group (control vs. frontal) as a between-subjects variable, Trial (1–4) as a within-subjects variable, and the number of questions asked as the dependent variable. There was a main effect of Group, as patients asked significantly more questions than controls in their attempt to identify the target items across the four trials (mean = 43.2 vs. 27.4, respectively), $F(1, 22) = 7.76$, $P < .05$. This difference between patients and controls would have been even larger had there not been a discontinue rule. That is, a number of patients ($n = 5$) exhausted the 20-question limit on one or more of the four trials without identifying the target item, whereas no controls reached this limit. The effect of Trial was not significant, but the Group × Trial interaction approached significance, $F(1, 3) = 2.57$, $P = .06$. As can be seen in Figure 2, while control participants caught on and improved their performance across the four trials, patients' performance actually decreased across the trials.

To determine whether perseveration played a role in patients' poor performance, we analyzed the data for repeated questions. There were very few data points, and thus these data were not amenable to analysis. Repeated questions represented only 3% of questions in patients and 1% of questions in controls. These data suggest that patients' poor performance was not due to simply repeating questions. Data were also analyzed for the occurrence of set loss questions, which were defined as questions that were tangential. Only one patient (MK) made such errors, and he asked two set loss questions at the outset of the first trial: "Does that shark

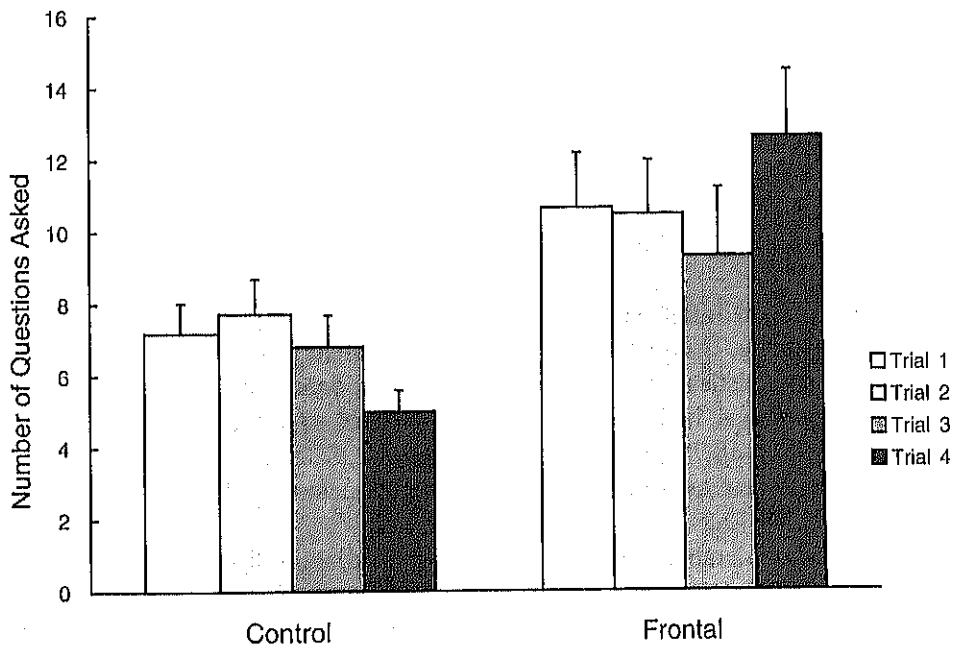

Fig. 2. Control and frontal patients' performance across four trials of the Twenty Questions Test.

bite?" and "Does a red rose smell red?" These questions reflected an initial inability to focus on the set of the task, namely formulating questions to eliminate items.

In the next set of analyses, we were interested in analyzing the quality of participant responses, in order to compare the types of strategies used by patients and controls on the Twenty Questions Test. First, it was apparent that patients tended to focus on low-level categories and specific items, failing to appreciate the superordinate categories (e.g., animals) that could be used to narrow down their search. To quantify this, we calculated an "abstraction score" (AS) for questions 1–4, across the four trials. The AS for each question was based on the minimum number of items eliminated by the participant's question. Comparing controls and patients, there was a significant difference in the total AS for questions 1–5 across the four trials, $F(1, 21) = 13.20$, $P < .01$, with controls having a significantly larger total AS than patients (78.5 vs. 50.3, respectively). These data show that, relative to controls, patients were impaired at asking effective, abstract questions from the outset. Patients' difficulty stemmed both from asking overly concrete questions, as well as asking questions that provided redundant information.

Analysis of individual participants' responses revealed that several frontal patients (EB, WE, MK, LS, and SR) tended to focus on single items from the outset of each trial, despite the fact that they were prompted on every trial to ask as few questions as possible. Data were analyzed for the occurrence of questions that referred only to one item (e.g., "Is it the banana?" or "Is it the fork?"). Frontal patients asked a disproportionately greater percentage of such single-item questions, compared to controls (mean = 67.6% vs. 31.0%, respectively), $F(1, 21) = 16.34$, $P < .001$. This tendency to focus on single items reflects highly concrete thinking that greatly compromised patients' overall performance.

Interestingly, we found that some frontal patients asked "pseudo-abstract" questions that referred only to one item (e.g., "Does it give milk? . . . Do you drink from it? . . . Does it travel on tracks?"). We called these questions "pseudo-abstract" because they had the flavor of a higher level question, when in fact the patient was focusing only on a single item (i.e., the cow, the cup, and the train, respectively). Table 2 gives a sample of one patient's haphazard series of questions that include numerous pseudo-abstract questions, as she attempted to guess the target item "spoon." A more effective approach produced by a control participant is shown in Table 3.

2.1. *Hemispheric and lesion size effects*

We were interested in differences between right ($n = 5$) and left ($n = 6$) frontal patients in their performance on the Twenty Questions Test. Due to small group sizes, we conducted descriptive rather than statistical analyses of the results. There was considerable overlap between the two patient subgroups, both in terms of overall number of questions asked (right frontal mean = 47.80, S.D. = 18.78, and left frontal mean = 41.67, S.D. = 19.86) and in terms of the percent of single-item questions asked (right frontal mean = 60.94, S.D. = 32.88, and left frontal mean = 79.72, S.D. = 18.43).

There was also considerable overlap in terms of other variables discussed above. Of the five patients who exhausted twenty questions on at least one trial, three had right frontal lesions (EB, SR, and MK) and two had left frontal lesions (OA and LS). Of the five patients who asked predominantly single-item questions, three had right lesions (EB, SR, and MK), and two had left lesions (WE and LS).

Table 2
Patient EB's questions for target item "spoon"

Patient's questions	Examiner's feedback
1. Do you drink out of it?	No
2. Do you smell it?	No
3. Does it go in water?	No
4. Do you cook in it?	No
5. Do you get milk from it?	No
6. Does it bark?	No
7. Does it keep food cold?	No
8. Do you get juice out of it?	No
9. Is it in the wild?	No
10. Is it yellow?	No
11. Does it bark?	No
12. Does it use gasoline?	No
13. Does it fly?	No
14. Do you eat it?	No
15. Does it grow in the garden?	No
16. Is it purple?	No
17. Does it run on tracks?	No
18. Does it hoot at night?	No
19. Do you eat from it?	Yes
20. Is it a plate?	No

We were also interested in whether lesion size predicted overall performance. We regressed lesion size (in cc, estimated from CT/MRI using in-house software) with the percent of single-item questions asked. There was no relationship between these variables, $r = .35$, $P = .32$. Thus, performance on the Twenty Questions Test was not simply related to the extent or the side of the patient's lesion.

2.2. *Relationship to other neuropsychological measures*

In an effort to determine whether poor patient performance on the Twenty Questions Test related to other cognitive deficits, we ran a series of simple regressions using only the patient

Table 3
Sample control's questions for target item "spoon"

Control's questions	Examiner's feedback
1. Is it animal?	No
2. Is it vegetable?	No
3. Is it a mode of transportation?	No
4. Is it a kitchen implement?	Yes
5. Can it be held?	Yes
6. Is it flatware?	Yes
7. Is it a spoon?	Yes

data. Specifically, we were interested in the degree to which linguistic and mnemonic deficits would predict poor performance on the Twenty Questions Test.

First, we regressed the percent of single-item questions on the Twenty Questions Test with the number of words produced by patients on a verbal fluency task (FAS task). This correlation was not significant, $r = .18$, $P = .59$, suggesting that poor performance was not simply due to reduced fluency. Second, we compared patients' total recall performance on Trials 1–5 of the California Verbal Learning Test-II to the percent of single-item questions on the Twenty Questions Test. Again, there was no relationship, $r = .27$, $P = .43$, suggesting that impaired learning and retrieval could not account for the patients' poor performance on the Twenty Questions Test.

Last, we were interested in the relationship of the current task to other tests of problem solving. Participants were also given the D-KEFS Sorting Test (Delis et al., 2001), which involves sorting cards based on a number of characteristics, including both perceptual (e.g., shape) and conceptual (e.g., semantic category) concepts. We compared the patients' total number of sorts on this task to performance on the Twenty Questions Test. In this case, there was a significant relationship, such that poorer performance on the Twenty Questions Test was strongly associated with a fewer number of correct sorts on the Sorting Test, $r = -.75$, $P < .01$.

3. Discussion

In the current study, we used a new clinical test of executive functioning to assess concept formation and problem-solving performance in patients with focal prefrontal lesions. The Twenty Questions Test was designed to serve as a complementary tool to tests such as the Wisconsin Card Sorting Test (WCST) and to assess concept-formation skills directly from patients' verbalizations rather than inferring such deficits from a sorting response. The Twenty Questions Test requires examinees to identify a target item from a pictured array of 30 common items by asking the examiner the fewest number of yes/no questions possible. An earlier version of this procedure had been used in the past to study normal development of concept formation in children (Mosher & Hornsby, 1966) and deficits in concept formation following closed head injury (Goldstein & Levin, 1991) and chronic alcohol abuse (Laine & Butters, 1982). The new clinical version of the test incorporated a number of changes, including the addition of a systematic hierarchical organization of the categories and subcategories represented in the stimulus array. We found that focal frontal patients were impaired on the Twenty Questions Test, requiring significantly more questions than controls in their attempt to identify the target items. These findings are in keeping with a long literature associating poor concept formation and problem-solving ability with frontal dysfunction (Goldstein, 1949; Milner, 1963; Stuss & Alexander, 2000; Weinberger & Berman, 1998). Our results are also consistent with earlier studies that tested more heterogeneous patient groups with earlier versions of this type of task (Goldstein & Levin, 1991; Klouda & Cooper, 1990).

We found that frontal patients' poor performance on the Twenty Questions Test was due to the use of ineffective and highly concrete approaches to the task. A number of frontal patients asked predominantly single-item questions (e.g., "Is it the owl?") or focused on concrete attributes (e.g., "Does it have feathers?") from the outset rather than narrowing down their

search more gradually. Similarly, some frontal patients asked "pseudo-abstract" questions that referred only to one item (e.g., "Does it hoot at night?"). Such questions revealed that patients understood that they should not simply name off different items, but the capacity to construct meaningful, multi-object conceptual categories appeared to be lacking (see also Klouda & Cooper, 1990). Quantifying this effect, we found that frontal patients' questions had a much lower "abstraction score" than controls' across trials, that is, the questions they asked eliminated many fewer items. This effect was due both to frontal patients' tendency to ask overly concrete questions, as well as to ask questions that provided information that was already provided by prior questions. These findings suggest that frontal cortex is crucial for the ability to abstract conceptual categories on-line. Other work from our laboratory has demonstrated, however, that frontal cortex is not crucial for the storage of those conceptual representations (Baldo, Chen, & Shimamura, 1997; Sylvester & Shimamura, 2002).

The present study did not include a neurologic control group to test the specificity of this test as a measure of frontal dysfunction, but such work is currently under way. A related limitation of the current study was that it tested a relatively small number of patients, due to strict inclusionary criteria (e.g., focal frontal lesion, normal language, etc.). We chose to err on the side of population consistency, at the sacrifice of a larger group, in order to better characterize executive dysfunction in the absence of other complicating factors (e.g., memory or language dysfunction).

In terms of clinical application, the Twenty Questions Test proved to be an easy and useful test to administer. Unlike some tests of concept formation and problem solving that can sometimes elicit frustration or outright refusal from patients, the Twenty Questions Test was well tolerated and enjoyed by both patient and control groups. This may be due to the fact that the test resembles a well-known parlor game and disguises the right–wrong feedback in the yes/no format of the game. Also, in terms of clinical use, the test takes a considerably shorter time to administer than many other tests of problem solving, with test time ranging from approximately 5–10 min. Another advantage of the Twenty Questions Test is that it elicits verbal responses from patients that directly reflect concrete or stimulus-bound thinking, rather than having to infer such deficits. In contrast, tests such as the WCST are superior for documenting perseverative tendencies, because repetitive yes/no questions were relatively rare in the current study. Together, these instruments may offer a more comprehensive assessment of concept-formation and problem-solving skills than each test administered in isolation.

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