Pergamon

PII: S0028–3932(97)00165–6

Neuropsychologia, Vol. 36, No. 7, pp. 581–589, 1998

Printed in Great Britain
0028–3932/98 $19.00+0.00

Tool use and mechanical problem solving in apraxia

GEORG GOLDENBERG* and SONJA HAGMANN

Neuropsychological Department, Hospital München-Bogenhausen, Englschalkingerstrasse 77, D 81925 München, Germany

(*Received* 11 *August* 1997; *accepted* 20 *November* 1997)

Abstract—Moorlaas (1928) proposed that apraxic patients can identify objects and can remember the purpose they have been made for but do not know the way in which they must be used to achieve that purpose. Knowledge about the use of objects and tools can have two sources: It can be based on retrieval of instructions of use from semantic memory or on a direct inference of function from structure. The ability to infer function from structure enables subjects to use unfamiliar tools and to detect alternative uses of familiar tools. It is the basis of mechanical problem solving. The purpose of the present study was to analyze retrieval of instruction of use, mechanical problem solving, and actual tool use in patients with apraxia due to circumscribed lesions of the left hemisphere. For assessing mechanical problem solving we developed a test of selection and application of novel tools. Access to instruction of use was tested by pantomime of tool use. Actual tool use was examined for the same familiar tools. Forty two patients with left brain damage (LBD) and aphasia, 22 patients with right brain damage (RBD) and 22 controls were examined. Only LBD patients differed from controls on all tests. RBD patients had difficulties with the use but not with the selection of novel tools. In LBD patients there was a significant correlation between pantomime of tool use and novel tool selection but there were single cases who scored in the defective range on one of these tests and normally on the other. Analysis of LBD patients' lesions suggested that frontal lobe damage does not disturb novel tool selection. Only LBD patients who failed on pantomime of object use and on novel tool selection committed errors in actual use of familiar tools. The finding that mechanical problem solving is invariably defective in apraxic patients who commit errors with familiar tools is in good accord with clinical observations, as the gravity of their errors goes beyond what one would expect as a mere sequel of loss of access to instruction of use.

Key Words: apraxia; aphasia; tool use; dysexecutive syndrome; parietal lobe; frontal lobe.

Introduction

Apraxia is a symptom of left-brain damage which affects imitation of gestures, performance of meaningful gestures to command, and the actual use of tools and objects. Out of these manifestations, defective use of tools and objects appears to be ecologically most relevant as it deprives patients from independence in daily living [1–4].

In a seminal thesis Moorlaas [5] proposed the term "agnosia of utilization" to account for difficulties which apraxic patients encounter when trying to use tools and objects. He submitted that these patients can identify objects and can remember the purpose they have been made for but do not know the way in which they should be used to achieve that purpose. Moorlaas considered agnosia of utilization to be equivalent to Liepmann's [6] "ideational apraxia".

* Corresponding author. Tel.: +49 89 9270 2106; fax: +49 89 9270 2089; e-mail: Goldenberg@lrz.tum.de

Moorlaas' idea was revived by De Renzi and Lucchelli [1], but these authors proposed to speak of "amnesia" rather than of "agnosia" of utilization. They argued that the inability to recognize the way in which an object can be used stems from insufficient retrieval of knowledge from semantic memory. They wrote: "The cognitive deficit ... concerns the ability to gain access to the semantic repository where the multiple features defining an object are stored, among which there is the way it must be used". One might conceive of semantic knowledge of object use as a kind of "instruction of use" which is addressed as soon as the object has been identified.

Alternatively to retrieval of instruction of use from semantic memory knowledge of tool use can be based on a comparison of the structural properties of tools and objects with the requirements posed by actions, that is, on a direct inference of function from structure [2, 7–10]. Like instructions of use, the direct inference of function from structure can identify both the possible motor actions associated with a tool and the kinds of objects it can be combined with[1]. These two aspects of the functional significance of structure are intimately related. The observation that a screwdriver can be used for driving in screws depends on recognizing that the screw has a slot into which the tip of the screwdriver fits. The slot is necessary to transmit the turning movement from the screwdriver to the screw. The head of a nail should be flat and the head of a hammer should be flat and rigid. Flatness and rigidity are necessary to transmit the power of a rapid stroke to the nail. Thus the motor actions of turning the screwdriver and of striking with the hammer depend on the relationship between the structures of screwdriver and screw and of hammer and nail. Recognizing the action of a screwdriver and of a hammer implies recognition of the screw and of the nail as the appropriate objects to act upon. Conversely, recognition of the function of a screw or of a nail implies recognition of screwdriver and hammer as being the appropriate tools to act upon them.

Instructions of use can exist only for familiar tools. Presumably they specify the prototypical action associated with the tool as, for example, screwing for a screwdriver, hammering for a hammer, and pinching and pulling for pincers. By contrast, direct inference of function from structure permits the detection of possible uses of unfamiliar tools and the recognition of other ways of using familiar tools than those for which they were specifically designed. These abilities are fundamental to mechanical problem solving. They enable subjects to find solutions to novel mechanical problems and to achieve the goal of familiar mechanical actions when lack of appropriate tools or other contextual constraints prohibit the routine way of performance. For example, normal subjects will easily recognize that pincers but not a screwdriver are apt for hammering a nail, because pincers are rigid and have flat surfaces.

From a review of the literature it seems probable that retrieval of instruction of use from semantic memory is frequently affected by apraxia. Deficient pantomime of tool use is among the most common manifestations of apraxia (e.g., [11–13]). When pantomime of tool use is tested, patients are presented the name of the tool and possibly a short sight of it, but they are usually not allowed to explore its structure sufficiently for inferring its function. They are asked to pantomime its prototypical use. Retrieval of the instruction of use from semantic memory thus appears to be a necessary prerequisite for pantomime of tool use and lack of access to semantic memory a likely source of failure on this test. However, De Renzi *et al.* [11] found that 14 out of 51 patients who scored in the pathological range on pantomime of tool use made distinctly fewer errors when asked to handle the actual tools. This dissociation could signify that errors on pantomime of tool use can have other sources than insufficient retrieval of instructions of use needed for the use of actual tools. Alternatively, the dissociation could indicate that visual and tactile exploration of the actual tools enabled patients to directly infer function from structure.

Evidence that apraxia affects the ability to infer function from structure is scarce. Roy [8] briefly mentioned that apraxic patients had more problems in selecting tools according to possible alternative uses (e.g., a dime for screwing) than according to their prototypical use (e.g., a hammer for pounding). Ochipa *et al.* [14] tested the routine use of familiar tools, the detection of alternative uses of familiar tools and the solution of mechanical puzzles in patients with Alzheimer's disease. Patients did poorer than controls on all of these tests, but the impairment was milder for routine use of familiar tools than for the two tests of mechanical problem solving. We are not aware of studies which systematically assessed the ability to infer function from structure in a representative sample of patients with apraxia from focal left brain damage.

The purpose of the present study was to analyze the relationship between retrieval of instruction of use from semantic memory, the ability to infer function from structure, and actual use of familiar tools in patients with apraxia due to circumscribed lesions of the left hemisphere. Pantomime of tool use was selected for testing access to instructions of tool use. For assessing the ability to infer function from structure we developed a test of selection and application of novel tools. This test was intended to measure mechanical problem solving without calling for planning of multi-step action sequences or for shifting attention between alternative uses of tools. We expected that both, instruction of use and the ability to infer function from structure can support use of familiar tools and that consequently only patients in whom both sources of knowledge about tool use are defective have problems with the use of familiar tools.

Method

Patients with left brain damage (LBD), right brain damage (RBD) and normal controls were tested for pantomime of tool-use, use of familiar tools, and selection and application of novel tools.

Pantomime of tool-use

Subjects were asked to perform ten pantomimes of tool use (fanning air to the face with a fan, looking through binoculars, combing with a comb, cutting with scissors, writing with a pencil, erasing with a gum, pounding with a hammer, turning in an electric bulb, turning a key, pouring liquid from a bottle). As a practice item, tooth-brushing was tested. If this pantomime was not perfect, it was demonstrated. To patients with aphasia

[1] We follow the suggestion [14] to use the term "tool" for the implement which performs an action (e.g., a hammer or a bulb) and "object" for the recipient of the action (e.g., a nail or a socket). In the literature the tests which we used for assessing the use of familiar tools are usually referred to as testing "pantomime of object use" or "use of objects" respectively.

each tool was briefly shown but was hidden from view before the patient started pantomiming. In aphasic patients it was sometimes difficult to ensure that they had understood the instruction to pantomime the tool's use. We decided to assume comprehension of the instruction when the patient reacted to the demonstration of the tool with a distinct movement of the hand different from pointing to the tool or trying to take the tool and different from batonic or sweeping gestures accompanying attempts of verbal expression. If comprehension of the instruction remained dubious, the patient was excluded from the study.

Two points were credited for each correct pantomime. If the subject performed a correct action at a wrong position or with a wrong direction (e.g., placing the hand which holds the handle of the pretended toothbrush before the mouth instead of beside it, or moving the pretended fan parallel to the head rather than towards it), or if the shaping of the hand was inaccurate (e.g., not adapting the width of the grip to the pretended bulb or closing the ring between thumb and index for holding the pretended binoculars), one point was given. One point was given for body part as object errors in otherwise correct pantomimes [12] (e.g., opening and closing a V from index and middle-finger for pretending scissors, or brushing teeth with the index finger). If the subject's movement did not depict any specific features of the specific action (e.g., pointing to the table for using a pen or to the mouth for brushing teeth) no point was given. Likewise, no points were given for movements without any relationship to the specific action associated with the tool (e.g., opening and closing the fist or sweeping the hand above the table) or for perseverations of movements appropriate to previously tested objects.

Use of familiar tools

The tools whose use had been pantomimed were given to the subjects and they were asked to use them. The corresponding objects (sheet of paper for pencil, eraser or scissors, nail for hammer, padlock for key, socket for bulb, glass for bottle) were adapted as to enable a one-handed performance. For example, the nail to hammer upon was fixed in a piece of wood and the back of the padlock was covered by slide-preventing tissue.

Two points were given if the subject used the tool correctly. One point was given if the correct use was found after unsuccessful trials (e.g., if the subject first turned the key of the padlock in the wrong direction and changed the direction of turning only after several attempts to open the padlock or to turn the key farther on in the same direction, or if the subject first looked at the wrong side of the binoculars but then turned them into the correct position) or if the action was in principle correct but clumsy (e.g., if the flat side of the india-rubber was perpendicular rather than parallel to the direction of rubbing, or if the fan was mover correctly but without being widely opened).

Selection and application of novel tools

A set of six cylinders and six tools was constructed for this test (see Fig. 1). Each cylinder had a part to which one of the tools fitted. One cylinder at a time was put in a socket. A collection of three tools was placed beside the socket (for brain lesioned patients on the side ipsilateral to the lesion). The patient was asked to select the one tool that was best suited for taking up the cylinder, to attach it to the cylinder and to lift the cylinder out of the socket. This was demonstrated with the last cylinder of the test and with distractor tools different from those used in the test of the same item.

Two scores were derived from this test:

Novel tool selection A tool was considered as being selected only if the patient tried to apply it to the object. Two points were given when the correct tool was selected at first choice. If the patient first tried a wrong tool but selected the correct one on second choice, one point was given.

Novel tool application Only the application of the correct tool was evaluated. In case a subject had not selected the correct tool it was handed to her or him. Two points were given if insertion of the tool and lifting of the cylinder were performed without error or hesitation. If the subject found the correct application after trial and error, one point was given.

Errors observed on any of the four tests were described verbally or by sketches on the record sheet. The maximum scores obtainable were 20 for pantomime of object use and for use of objects, and 12 each for novel tool selection and novel tool application.

Subjects

Forty-two patients with left brain damage (LBD), 22 patients with right brain damage (RBD) and 22 controls were examined. LBD and RBD patients had suffered a first, unilateral stroke within the middle cerebral artery territory. CT or MRI scans were available from all but one brain damaged patients. All LBD patients had aphasia, and all RBD patients had indications of visuospatial dysfunction or hemi-neglect on neuropsychological testing. Aphasia was classified as global in 17, Broca in 4, Wernicke in 11, amnesic in 6 and transcortical, conduction or non-classifiable in 4 of the LBD patients [15]. Controls were recruited from neurological in-patients without any history or evidence of cerebral disease and from healthy relatives of patients.

Demographic and clinical data of the three groups are displayed in Table 1. There were no significant differences with respect to age, gender distribution, nature of CVA, presence of hemiplegia, and distribution of lesions. The duration since CVA was significantly longer in LBD than in RBD patients ($t = 3.3$; df $= 45.4$; $P < 0.01$). However, there were no significant correlations between duration since CVA and test performance in any of the two groups (all $r < 0.2$).

Results

Comparisons between groups

Table 2 displays the results of the four experimental tests. Because of ceiling effects in RBD patients and controls and for avoiding distortion of significance values by outliers, non-parametric tests (Mann–Whitney test and Spearman rank correlation) were used for statistical evaluation of test results.

LBD patients scored significantly lower than controls on all of the experimental tests (pantomime of tool use: $z = -4.5$, $P < 0.0001$; use of familiar tools: $z = -2.5$, $P < 0.05$; novel tool selection: $z = -4.3$, $P < 0.0001$; novel tool application: $z = -3.8$, $P < 0.001$). The scores of RBD patients were virtually identical to those of controls on pantomime of tool use and use of familiar tools. RBD patients did not significantly differ from controls on novel tool selection ($z = -1.4$, $P > 0.1$), but scored significantly lower on their application ($z = -2.6$,

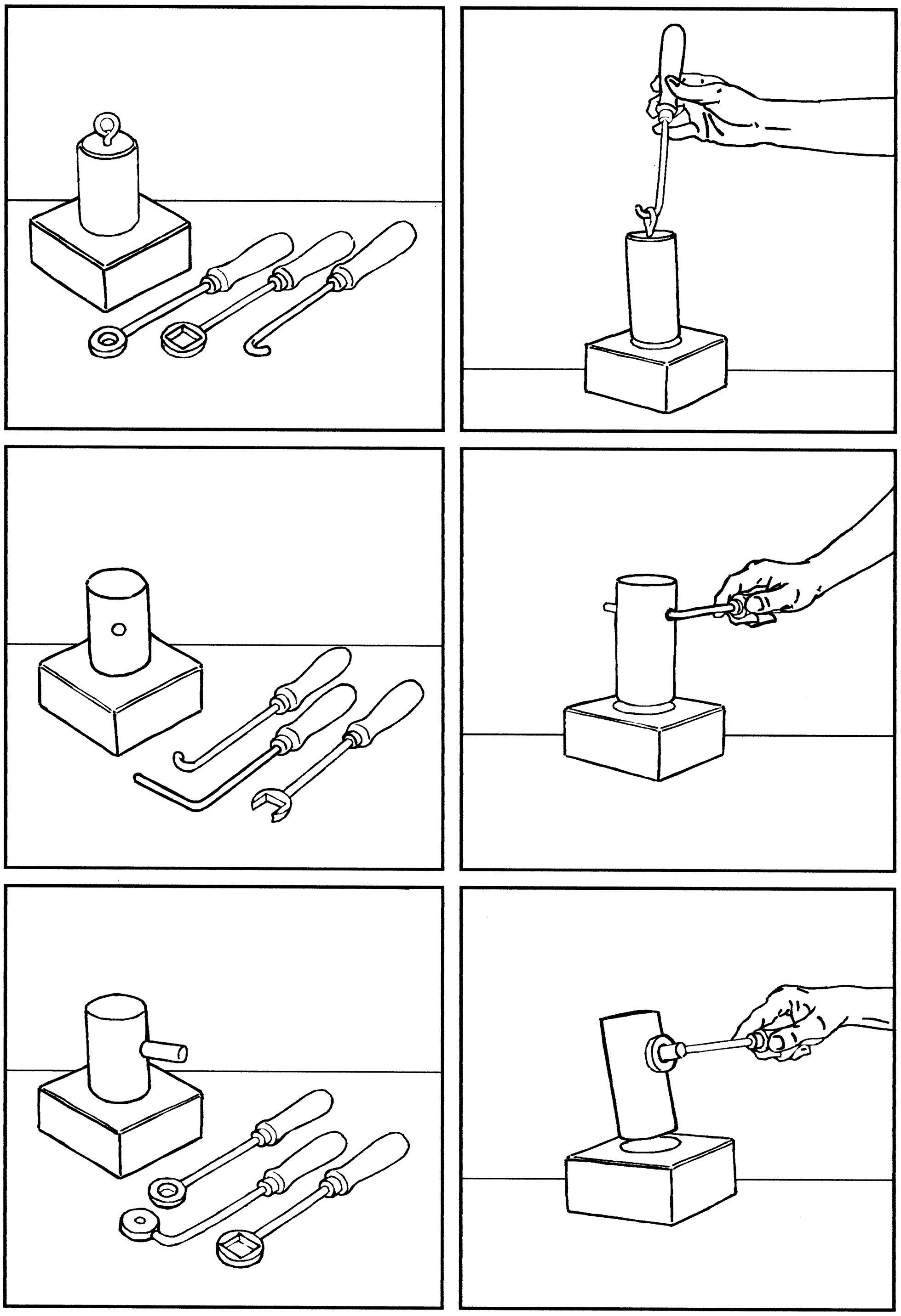

Fig. 1. Three items of the novel tool test. The left side of each row shows the array presented to the patient for tool selection and the right side, the use of the correctly selected tool.

$P < 0.01$). While LBD patients made significantly more errors than RBD patients on novel tool selection ($z = -3.5$, $P < 0.001$), there was no significant difference between both groups of brain damaged patients on novel tool application ($z = -1.5$, $P > 0.1$). Observation of the patients' performance suggested different types of errors underlying poor scores on novel tool application in LBD and RBD patients. The errors of LBD patients mostly concerned the principle of the tool-object interaction. For example, they would press the outer side of a hook against a ring instead of inserting its tip into the opening of the ring. By contrast, the difficulties of the RBD patients

Table 1. Demographic and clinical data

	42 LBD patients	22 RBD patients	22 controls
Women/men	12/30	6/16	8/14
Age	55.5 (10.8)	58.0 (9.3)	53.3 (12.4)
Duration since CVA in months	11.0 (14.6)	3.5 (2.4)	—
Ischemia/bleeding	34/8	17/5	—
Plegic/not plegic	24/18	16/6	—
Number of patients with lesions in			
Frontal lobe	20	8	
Parietal lobe	13	9	
Temporal lobe	19	11	
Basal ganglia	15	8	
White matter	15	10	

Values in parentheses are standard deviations. As lesions can affect more than one location, the number of locations is higher than the number of patients.

affected the exact orientation of the tool relative to the object. For example, they did not succeed in introducing a rod into a close fitting ring because they did not orient the ring exactly perpendicularly to the rod. Some RBD patients had particular difficulties with the lifting of the cylinder. Having fixed the tool to the cylinder they tilted it rather than lifting it vertically.

The correlation between novel tools selection and novel tool application was lower in RBD ($\rho = 0.49$, $P < 0.05$) than in LBD patients ($\rho = 0.60$, $P < 0.001$).

In sum, only LBD patients were impaired on pantomime of tool use, use of familiar tools, and selection of novel tool. Application of novel tools did not distinguish between LBD and RBD patients although the types of errors were qualitatively different.

The topic of this study is defective tool use in apraxia due to lesions of the left hemisphere. Out of the two scores derived from the novel tools we will concentrate on tool selection because it reflects more selectively the specific difficulties which LBD patients experience with unfamiliar tools.

Relationship between novel tool selection, pantomime of tool use, and use of familiar tools

The hypothesis put forward in the introduction predicts that knowledge about prototypical tool use (assessed by pantomime of tool use) and the ability to infer function from structure (assessed by novel tool selection) can both contribute to the use of familiar tools. Indeed results of both tests correlated significantly with the use of familiar tools (pantomime of tool use: $\rho = 0.77$, novel tool selection: $\rho = 0.62$; both $P < 0.001$), but there was also a significant correlation between the two tests ($\rho = 0.64$, $P < 0.001$).

For further analysis of possible dissociations between pantomime of tool use and novel tool selection and of their respective influence on the use of familiar tools, scores of the three tests were classified as defective or

Table 2. Results of experimental tests

	LBD		RBD		Controls	
	Mean	Range	Mean	Range	Mean	Range
Pantomime of tool use	10.0	0–19	16.5	12–20	16.7	12–20
Use of familiar tools	18.3	11–20	19.5*	18–20	19.7	18–20
Novel tool selection	9.5	3–12	11.6	10–12	12.0	12
Novel tool use	10.8	7–12	11.2	5–12	11.95	11–12

* Object use was assessed in only 14 of the RBD patients.

Table 3. Relationship of novel tool selection and pantomime of tool use to use of familiar tools in LBD patients

	Novel tool selection normal Pantomime of tool use normal	Novel tool selection normal Pantomime of tool use defective	Novel tool selection defective Pantomime of tool use normal	Novel tool selection defective Pantomime of tool use defective
Use of familiar tools defective	0	0	0	12
Use of familiar tools normal	19	7	3	1

The values give the number of patients with each combination of test results. Test results were classified as normal or defective according to whether they fell within or below the range of normal controls and RBD patients (see Table 2 and Footnote 2).

Table 4. Dissociations between pantomime of tool use and novel tool selection in LBD patients

Patient	Sex, Age	Novel tool selection	Pantomime of tool use	Aphasia	Lesion
Novel tool selection normal; pantomime of object use defective					
GZ	F; 58	12	5	Broca	F, BG, SC
Novel tool selection defective; pantomime of object use normal					
ML	F; 71	9	17	Broca	SC
WK	M; 57	8	16	Wernicke	T, P

F: Frontal; T: Temporal; P: Parietal; BG: Basal Ganglia; SC: Subcortical.

normal. The lowest scores obtained by RBD patients were taken as cut-off scores[2].

Only patients who scored in the defective range on both, novel tool selection and pantomime of tool use, had a pathological number of errors on the use of familiar tools. Patients who scored normally on at least one of these two tests used familiar tools normally. This relationship would suggest that either knowledge about prototypical tool use (tested by pantomime of tool use) or the ability to infer function from structure (tested by novel tool selection) suffice for supporting use of familiar tools.

Table 3 lists 7 patients in whom novel tool selection was normal and pantomime of tool use impaired and three patients with the reverse dissociation. This dissociation could have been caused by minor differences of scores close to the cut-off. To exclude this possibility we looked for patients whose scores were at or above the mean of controls on one of the tests and below the cut-off score on the other. There were three of them who are listed in Table 4.

In GZ, novel tool selection was perfect whereas pantomime of tool use was severely defective. ML and WK had definitely pathological scores on novel tool selection and scored like the mean of controls on pantomime of tool use. It thus appears that LBD can affect knowledge about prototypical tool use and the ability to infer function from structure independently from each other.

WK had parietal lobe infarction and ML a white matter lesion lateral to the anterior horn and the cella media of the ventricle. By contrast, GZ had an anterior lesion affecting frontal cortex as well as basal ganglia and subcortical white matter but sparing the parietal lobe. This constellation raises a suspicion that different locations of lesions may underly defective novel tool selection and defective pantomime of tool use.

To further explore the influence of lesion location on novel tool selection and pantomime of tool use we returned to an analysis of the whole group of LBD patients. Table 5 shows the frequency of lesions in each location for patients who scored above or below the cut-off scores for each of the two tests.

The only statistically significant association between a single location and a test concerned the influence of parietal lesions on novel tool selection. Parietal lesions were significantly more frequent in patients with defective tool selection than in those who scored above the cut-off (Fisher's exact test: $P = 0.04$). It must be noted, however, that parietal lesions were also more frequent in patients who failed pantomime of object use than in those who passed this test normally. A further remarkable result is that the frequency of frontal lesions was virtually the same in patients who performed novel tools selection below or above the cut-off. This permits the conclusion that frontal lobe lesions do not contribute to defective selection of novel tools.

Discussion

The design of the study was based on the assumptions that pantomime of tool use probes the retrieval of instruction of use from semantic memory and selection of unfamiliar tools the capability to infer function from structure. Use of familiar tools can be based on either of these components. The main result of the study is that both components of knowledge about tool use can be affected by LBD. There is a high correlation between them, but in single cases only one of these components was defective and the other normal. The assumption that use of familiar tools can be based either on instruction of use or on direct inference of function from structure is confirmed by the finding that only patients who scored

[2] For pantomime of object use and for use of objects the lowest scores of the RBD patients were identical to the lowest score of controls. For novel tools selection all controls scored at the maximum whereas the lowest RBD score was two points below. This lower cut-off was preferred to distinguish a significant impairment on novel tool-selection from a non-specific influence of brain damage on test results. However, Table 3 was retabulated with a classification based exclusively on the controls' scores on selection of unfamiliar tools, that is, with any score below the maximum considered defective. This did not change the main conclusion that all patients who were impaired on the use of object test scored in the pathological range on pantomime of object use as well as on selection of unfamiliar tools, but the number of patients in whom both of these tests were defective and who nonetheless solved the use of objects tests normally (lower cell in rightmost column) increased from 1 to 6.

Table 5. Influence of location on pantomime of tool use and novel tool selection

	Frontal lesion	Temporal lesion	Parietal lesion	White matter lesion	Basal ganglia lesion
Pantomime of tool use normal	42	36	23	60	42
Pantomime of tool use defective	58	58	42	42	32
Novel tool selection normal	46	34	19	50	42
Novel tool selection defective	47	65	53	47	29

To facilitate comparisons, the numbers of patients are given in percentage.

in the defective range on both pantomime of tool use and novel tool selection committed errors when actually using familiar tools.

We will first discuss possible reservations to the interpretation of pantomime of tool use as measuring the integrity of semantic knowledge about tool use, and then the significance of defective selection of unfamiliar tools.

Pantomime of tool use

Pantomime of tool use requires that knowledge about the appropriate use of tools is demonstrated by performing the manual action associated with their prototypical use, but a failure on this traditional apraxia test can have other reasons than the inability to retrieve knowledge about tool use. It may be caused by a failure of visually identify the tool shown to the patient. This possibility seems very unlikely as no patient displayed any evidence to visual agnosia, and as major visual perceptual deficits would be an unlikely sequel of left middle cerebral artery strokes. A more important source of error could be a lack of "abstract behaviour" [16] necessary to retrieve and express knowledge about an action in the absence of the tactual and visual experiences which normally elicit it. The inability to perform actions outside of their appropriate context has been accused as being a crucial factor in the genesis of apractic errors [17, 18]. A patient who is unable to demonstrate knowledge about prototypical use of tools by pantomime may nonetheless be able to access this knowledge when given the actual tools to manipulate, because the tactual and visual experience of the actual tools and objects facilitates retrieval from semantic memory.

We found that only one out of 13 patients who scored defectively on selection of unfamiliar tools as well as on pantomime of tool use manipulated actual tools normally, whereas all of the three patients in whom selection of unfamiliar tools was defective but pantomime of tool use normal were able to do so. Thus, failure or success on pantomime of tool use had predictive power for actual tool use. This suggests that the results on pantomime of tool use were indicative of the integrity of knowledge about tool use and did not merely reflect the ability to evoke this knowledge outside of its appropriate context.

According to theories which distinguish between conceptual and executive variants of apraxia, defective pantomime of tool use could be due to defective motor execution of the correctly conceived movement [19–21]. A deficit of motor execution might also affect the handling of actual tools. However, defective execution would not be ameliorated by additional knowledge about the correct concept of the action. This contrasts with our finding that actual tool use was normal in all of the seven patients in whom pantomime of tool use was defective but selection of unfamiliar tools normal. The influence of selection of unfamiliar tools on actual tool use can be explained by the contribution of an additional source of knowledge about tool use. The observation that additional knowledge can compensate for impaired pantomime of tool makes it likely that pantomime itself is indicative of knowledge about tool use.

Selection of unfamiliar tools and mechanical problem solving

Selection of novel tools put minimal and trivial demands on motor execution. All of the patients were able to carry out the motor act of taking up a tool and approaching it to the object. The errors concerned exclusively the selection of the tool. After exclusion of defective motor execution there remain two possible sources of errors: defective visual discrimination of the tools, or an inability to recognize functional relationships between tools and cylinders. There are two arguments for dismissing defective visual discrimination as a source of errors. First, the perceptual differences between the tools were as conspicuous as to make visual discriminations a rather trivial task (see Fig.1). Second, it would be very unlikely that a task of visual discrimination leads to errors in patients with left brain damage but not in patients with right brain damage. We think that they were able to visually discriminate the shapes of the tools but that they were unable to understand the functional significance of the perceived shapes for the motor actions of attaching the tool to the cylinder and lifting it.

The selection of the tool fitting a given cylinder required a concept of the motor action which attached the tool to the corresponding appendix of the cylinder. The further motor action of lifting the cylinder put additional constraints on the selection of the tool. Fixation of the tool to the cylinder had to be as stable as to prevent the cylinder from falling down when the tool was raised. Only a tool that fit the appendix firmly enough to guarantee stable fixation was apt for being selected. For correct tool selection the appropriateness of its shape to the affordances of the subsequent motor actions had to be considered. Analysis of novel tools selection thus exemplifies the intimate link between planning of motor actions and selection of appropriate tools for the action.

As selection of novel tools is closely related to tool use and motor planning, and as it is affected by LBD we feel justified to include its impairment among the manifestations of apraxia. The observation that selection of novel tools can dissociate from pantomime of tool use is a further demonstration that different manifestations of apraxia can occur independently from each other [1, 5, 22, 23].

Selection of novel tools is a non-routine task testing mechanical problem-solving. Analysis of the lesions suggested that damage to the frontal lobes does not impair performance. Novel tool selection thus differs from other types of non-routine and problem solving tasks which are sensitive to frontal lobe damage [24–26]. Selection of novel tools does not require planning ahead for more than one step, and there is only one possible solution for each item. Typical "frontal lobe tests" require either planning ahead of several steps (e.g., the "Tower of London" puzzle [26]) or a shifting between different solutions which are all equally possible (e.g., sorting and fluency tasks [24]).

Our finding that mechanical problem solving is invariably defective in apraxic patients who commit errors when using simple tools is in good accord with clinical observations of these patients' behaviour. The gravity of their errors cannot satisfactorily be explained by defective knowledge about tool use. For example, patients may try to eat soup with the fork or to press tooth-paste out of a closed tube (see [1, 3, 4] for further illustrative examples). Presumably, a normal person who has never been taught how to use a fork or a tube would recognize that these ways of using them cannot lead to the intended purpose and would quickly find out the feasable way to accomplish the task. The inability of apraxic patients to compensate their lack of knowledge about tool use by mechanical problem solving has led to the hypothesis that their problem solving capacity must have suffered from frontal lobe damage [27]. Our results suggest that loss of the ability to infer function from structure and a consecutive inability to solve mechanical problems does not depend on frontal lobe damage.

Acknowledgements—Construction of the novel tool test was supported by the Austrian Science Foundation project 8910*M*.

References

1. De Renzi, E. and Luchelli, F., Ideational apraxia. *Brain*, 1988, **111**, 1173–1185.
2. Goldenberg, G. and Hagmann, S., Therapy of activities of daily living in patients with apraxia. Neuropsychological Rehabilitation, 1998, **8**, 123–141.
3. Mayer, N. H., Reed, E., Schwartz, M. F., Montgomery, M. and Palmer, C., Buttering a hot cup of coffee: An approach to the study of errors of action in patients with brain damage. In *The Neuropsychology of Everyday Life*: *Assessment and Basic Competencies*, ed. D. E. Tupper and K. D. Cicerone. Kluwer Academic Publishers, Boston Dordrecht London, 1990, pp. 259–284.
4. Poeck, K., Ideatorische Apraxie. *Journal of Neurology*, 1983, **230**, 1–5.
5. Moorlaas, J. *Contribution à l'étude de l'apraxie*. Amédée Legrand, Paris, 1928.
6. Liepmann, H., *Drei Aufsätze aus dem Apraxiegebiet*. Karger, Berlin, 1908.
7. Jeannerod, M., Decety, J. and Michel, F., Impairment of grasping movements following a bilateral posterior parietal lesion. *Neuropsychologia*, 1994, **32**, 369–380.
8. Roy, E. A. and Square, P. A., Common considerations in the study of limb, verbal and oral apraxia. In *Neuropsychological studies of apraxia and related disorders*, ed. E. A. Roy. North-Holland, Amsterdam, New York, Oxford, 1985, pp. 111–162.
9. Sirigu, A., Duhamel, J. R. and Poncet, M., The role of sensorimotor experience in object recognition—a case of multimodal agnosia. *Brain*, 1991, **114**, 2555–2573.
10. Vaina, L. M. and Jaulent, M. C., Object structure and action requirements: A compatibility model for functional recognition. *International Journal of Intelligent Systems*, 1991, **6**, 313–336.
11. De Renzi, E. Faglioni, P. and Sorgato, P., Modality-specific and supramodal mechanisms of apraxia. *Brain*, 1982, **105**, 301–312.
12. Goodglass, H. and Kaplan, E., Disturbance of gesture and pantomime in aphasia. *Brain*, 1963, **86**, 703–720.
13. Heilman, K. M. and Rothi, L. J. G., Apraxia. In *Clinical Neuropsychology*, ed. K. M. Heilman and E. Valenstein. Oxford University Press, New York Oxford, 1993, pp. 141–164.
14. Ochipa, C., Rothi, L. F. G. and Heilman, K. M., Conceptual apraxia in Alzheimer's disease. *Brain*, 1992, **115**, 1061–1071.
15. Huber, W., Poeck, K., Weniger, D. and Willmes, K. *Aachener Aphasie Test*. Hogreve, Goettingen, 1983.
16. Goldstein, K., *Language and Language Disturbances* Grune and Stratton, New York, 1948.
17. De Renzi, E., Apraxia. In *Handbook of clinical neuropsychology* Vol 2, ed. F. Boller and J. Grafman. Elsevier, Amsterdam New York Oxford, 1990, pp. 245–263.
18. Poeck, K., The two types of motor apraxia. *Archives Italiennes de Biologie*, 1982, **120**, 361–369.
19. Barbieri, C. and De Renzi, E., The executive and ideational components of apraxia. *Cortex*, 1988, **24**, 535–544.
20. Heilman, K. M., Rothie, L. J., and Valenstein, E.,

Two forms of ideomotor apraxia. *Neurology*, 1982, **32**, 342–346.
21. Rothi, L. J. G., Ochipa, C. and Heilman, K. M., A cognitive neuropsychological model of limb praxis. *Cognitive Neuropsychology*, 1991, **8**, 443–458.
22. Goldenberg, G. and Hagmann, S., The meaning of meaningless gestures: A study of visuo-imitative apraxia. *Neuropsychologia*, 1997, **35**, 333–341.
23. Poeck, K. and Lehmkuhl, G., Ideatory apraxia in a left-handed patient with right-sided brain lesion. *Cortex*, 1980, **16**, 273–284.
24. Lezak, M. D., *Neuropsychological assessment*. Oxford University Press, New York Oxford, 1983.
25. Luria, A. R., *Higher Cortical Functions in Man*, Trans. Basil Haigh. 2nd edn revised and expanded Basic Books, New York, 1980.
26. Shallice, T., Specific impairments of planning. *Philosophical Transactions of the Royal Society of London*, 1982, B**298**, 199–209.
27. Schwartz, M. F., Re-examining the role of executive functions in routine action production. *Annals of the New York Academy of Sciences*, 1995, **769**, 321–335.